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

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 5th, 50th and 95th percentile results for the 100 values of the index were calculated *by sorting only the index being considered*. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution. These statistics provide the expected degree and range of impacts that would occur if spills of the simulated oil type and volume occur somewhere along the location's transportation route. Impacts would be different for spills released at different locations than those included in the modeling matrix, as well as different (and not necessarily proportional) for other spill volumes. The results are discussed in Volume I, Sections 4-6.

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.04	11.5	23.9	11.7	7.3	-	26.3
JF-Bunk-N	36.2	56.3	66.3	54.7	9.1	36.6	72.8
JF-Dies-N	0.93	3.2	12.3	4.2	4.0	-	12.2
JF-Crud-N	6.1	18.6	29.9	18.2	7.3	3.6	32.7
SJ-Crud-N	14.5	26.1	36.2	26.0	6.6	12.7	39.3
CL-Bunk-N	0	63.2	77.0	54.6	23.9	6.7	102.5
CU-Bunk-N	51.3	71.1	80.5	69.1	9.8	49.6	88.7

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.022	4.3	11.4	4.9	3.8	-	12.4
JF-Bunk-N	19.1	33.7	47.1	33.8	9.2	15.4	52.2
JF-Dies-N	-	-	0.0015	0.076	0.57	-	1.2
JF-Crud-N	4.7	13.8	20.0	12.8	5.1	2.5	23.0
SJ-Crud-N	2.3	16.6	23.1	14.9	6.2	2.5	27.2
CL-Bunk-N	0.0001	33.4	61.5	31.2	20.5	0	72.2
CU-Bunk-N	11.0	42.2	56.7	38.7	14.8	9.0	68.4

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2.0	7.0	15.2	7.0	3.6	-	14.2
JF-Bunk-N	0.6	1.2	3.2	1.4	0.9	-	3.2
JF-Dies-N	24.9	43.2	66.3	44.4	12.9	18.5	70.2
JF-Crud-N	0.3	1.0	4.1	1.5	1.2	-	3.8
SJ-Crud-N	0.2	0.6	2.8	1.1	1.6	-	4.3
CL-Bunk-N	0.0	5.1	14.5	5.2	3.9	-	13.1
CU-Bunk-N	0.4	1.4	3.4	1.6	0.9	-	3.5

Table II.2-4. Summary of results for all stochastic scenarios of 100 runs each: Percent of spilled hydrocarbon mass mechanically removed (%). [As no reponse was assumed, no removal occurred.]

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	-	-	-	-	-
JF-Bunk-N	-	-	-	-	-	-	-
JF-Dies-N	-	-	-	-	-	-	-
JF-Crud-N	-	-	-	-	-	-	-
SJ-Crud-N	-	-	-	-	-	-	-
CL-Bunk-N	-	-	-	-	-	-	-
CU-Bunk-N	-	-	-	-	-	-	-

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3,359	26,550	9,255	10,391	-	30,037
JF-Bunk-N	208	473	965	533	238	57	1,010
JF-Dies-N	125	355	797	396	228	-	852
JF-Crud-N	658	1,855	3,763	1,945	897	152	3,739
SJ-Crud-N	122	852	2,904	1,201	954	-	3,110
CL-Bunk-N	33	119	540	199	171	-	541
CU-Bunk-N	1	5	11	6	3	-	12

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	2,399	22,893	7,101	8,167	-	23,436
JF-Bunk-N	207	464	975	530	237	56	1,005
JF-Dies-N	85	272	740	326	204	-	734
JF-Crud-N	543	1,434	2,966	1,529	727	76	2,983
SJ-Crud-N	97	537	2,018	771	649	-	2,070
CL-Bunk-N	33	121	540	196	166	0	527
CU-Bunk-N	1	5	11	6	3	-	11

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	1,027	5,974	2,040	2,020	-	6,079
JF-Bunk-N	160	354	822	428	217	-	863
JF-Dies-N	120	440	1,551	588	481	-	1,550
JF-Crud-N	546	2,435	5,536	2,647	1,576	-	5,799
SJ-Crud-N	1,524	4,552	9,167	4,958	2,340	278	9,638
CL-Bunk-N	-	589	1,573	635	491	-	1,617
CU-Bunk-N	143	279	506	296	115	67	525

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	796	3,703	1,295	1,229	-	3,752
JF-Bunk-N	160	344	813	411	212	-	835
JF-Dies-N	54	201	836	302	277	-	856
JF-Crud-N	473	1,656	3,241	1,783	905	-	3,593
SJ-Crud-N	1,006	2,492	3,805	2,528	883	761	4,294
CL-Bunk-N	-	567	1,472	607	467	-	1,541
CU-Bunk-N	140	260	485	284	108	67	500

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	605,920	4,493,300	1,369,300	1,528,100	-	4,425,500
JF-Bunk-N	9,200	82,797	435,010	140,660	149,610	-	439,880
JF-Dies-N	84,487	344,140	1,374,500	465,070	422,970	-	1,311,010
JF-Crud-N	98,193	1,184,900	3,817,500	1,473,700	1,188,300	-	3,850,300
SJ-Crud-N	757,260	2,986,000	7,568,900	3,406,800	2,050,600	-	7,508,000
CL-Bunk-N	-	191,800	1,004,700	335,380	341,220	-	1,017,820
CU-Bunk-N	2,511	70,795	210,880	79,953	68,244	-	216,441

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	584,800	1,651,800	670,540	545,370	-	1,761,280
JF-Bunk-N	154,330	287,070	461,300	287,120	91,302	104,516	469,724
JF-Dies-N	11,077	76,226	440,650	122,760	135,380	-	393,520
JF-Crud-N	350,340	1,155,200	2,026,200	1,173,100	487,560	197,980	2,148,220
SJ-Crud-N	868,180	1,585,700	2,263,700	1,551,200	449,320	652,560	2,449,840
CL-Bunk-N	-	280,160	626,100	300,020	187,700	-	675,420
CU-Bunk-N	123,010	204,850	365,020	216,210	68,534	79,142	353,278

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	36,336,000	211,430,000	68,702,000	69,596,000	-	207,894,000
JF-Bunk-N	17,881,000	34,676,000	95,179,000	42,215,000	22,730,000	-	87,675,000
JF-Dies-N	511,050	4,408,300	24,155,000	7,300,400	7,897,000	-	23,094,400
JF-Crud-N	24,337,000	108,780,000	228,760,000	113,280,000	64,193,000	-	241,666,000
SJ-Crud-N	84,092,000	202,950,000	398,520,000	214,040,000	96,393,000	21,254,000	406,826,000
CL-Bunk-N	0	59311000	167220000	63182000	52573000	0	168328000
CU-Bunk-N	14,550,000	28,445,000	63,761,000	31,519,000	14,773,000	1,973,000	61,065,000

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	7,257	974,128	281,660	401,722	-	1,085,104
JF-Bunk-N	9,092	14,365	24,651	15,746	4,886	5,974	25,518
JF-Dies-N	13,709	20,590	37,575	22,645	7,560	7,524	37,766
JF-Crud-N	19,252	115,943	278,416	126,652	78,868	-	284,388
SJ-Crud-N	44,504	62,771	116,619	72,525	26,956	18,614	126,437
CL-Bunk-N	2,605	28,111	150,560	50,761	48,632	-	148,025
CU-Bunk-N	13	79	191	89	57	-	203

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	22,349	83,938	564,703	205,770	210,912	-	627,593
JF-Bunk-N	1,925	5,152	11,449	5,998	2,991	16	11,980
JF-Dies-N	814	6,343	19,992	7,995	6,075	-	20,145
JF-Crud-N	22,347	31,791	47,661	32,832	7,713	17,407	48,257
SJ-Crud-N	13,068	13,663	15,420	13,982	879	12,223	15,740
CL-Bunk-N	917	2,755	11,582	4,380	3,514	-	11,408
CU-Bunk-N	6	17	35	18	9	-	37

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	527	4,214	1,321	1,493	-	4,308
JF-Bunk-N	556	1,055	3,745	1,375	938	-	3,251
JF-Dies-N	9	208	1,117	370	428	-	1,225
JF-Crud-N	720	3,449	10,144	4,252	2,945	-	10,142
SJ-Crud-N	5,717	6,846	7,979	6,874	676	5,522	8,226
CL-Bunk-N	3	3,288	16,178	5,208	8,306	-	21,820
CU-Bunk-N	173	1,022	2,464	1,156	734	-	2,624

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	22,349	92,883	1,539,016	488,751	611,866	-	1,712,483
JF-Bunk-N	12,485	21,018	39,138	23,120	8,247	6,627	39,613
JF-Dies-N	14,528	27,072	58,541	31,010	13,852	3,306	58,714
JF-Crud-N	45,608	153,806	328,242	163,739	87,505	-	338,749
SJ-Crud-N	63,977	83,475	139,398	93,384	28,122	37,140	149,627
CL-Bunk-N	8,688	39,600	163,133	60,349	50,185	-	160,718
CU-Bunk-N	192	1,118	2,689	1,263	800	-	2,864

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	98.77	144.23	499.16	234.18	155.71	-	545.59
JF-Bunk-N	0.96	1.62	2.92	1.80	0.62	0.57	3.03
JF-Dies-N	0.90	2.09	5.03	2.45	1.31	-	5.07
JF-Crud-N	2.95	14.44	33.74	15.71	9.38	-	34.47
SJ-Crud-N	6.01	7.46	11.74	8.24	2.14	3.95	12.52
CL-Bunk-N	2.16	6.42	26.85	10.18	8.13	-	26.45
CU-Bunk-N	60.04	94.77	141.60	97.09	23.44	50.21	143.97

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	-	18,189	1,585	5,696	-	12,978
JF-Bunk-N	-	-	-	-	-	-	-
JF-Dies-N	256	472	973	517	214	89	944
JF-Crud-N	-	-	-	-	-	-	-
SJ-Crud-N	-	-	-	-	-	-	-
CL-Bunk-N	-	-	-	-	-	-	-
CU-Bunk-N	-	-	-	-	-	-	-

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.3	1,053	4,601	1,376	1,388	-	4,152
JF-Bunk-N	52	59	82	62	10	41	82
JF-Dies-N	44	45,108	103,599	49,500	29,488	-	108,476
JF-Crud-N	5,721	11,444	34,139	14,544	8,834	-	32,212
SJ-Crud-N	1,693	3,829	17,383	6,807	9,599	-	26,005
CL-Bunk-N	0.3	4	29	6	9	-	24
CU-Bunk-N	2,948	3,299	4,015	3,382	343	2,695	4,069

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	-	3,243	30,746	9,026	10,561	-	30,149
JF-Bunk-N	-	16,997	108,804	33,955	35,399	-	104,752
JF-Dies-N	-	11,412	118,054	28,928	41,555	-	112,038
JF-Crud-N	12,141	159,528	403,740	174,703	117,105	-	408,913
SJ-Crud-N	117,942	287,366	528,744	305,639	130,644	44,351	566,926
CL-Bunk-N	-	1,001	2,686	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-	-	-	-

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	0.35	4,295	35,347	10,403	11,949	-	34,301
JF-Bunk-N	52	17,056	108,886	34,016	35,409	41	104,834
JF-Dies-N	44	56,521	221,653	78,428	71,042	-	220,513
JF-Crud-N	17,862	170,972	437,878	189,247	125,939	-	441,125
SJ-Crud-N	119,634	291,195	546,127	312,446	140,243	44,351	592,931
CL-Bunk-N	0.26	1,005	2,716	1,092	868	-	2,829
CU-Bunk-N	2,948	3,299	4,015	3,382	343	2,695	4,069

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	193	739	8,011	2,677	3,114	-	8,905
JF-Bunk-N	50	115	266	137	68	13	273
JF-Dies-N	43	379	954	436	273	17	981
JF-Crud-N	431	888	1,729	953	396	284	1,744
SJ-Crud-N	371	483	760	527	156	283	838
CL-Bunk-N	18	127	643	221	212	0	645
CU-Bunk-N	3	6	12	7	3	2	13

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	36	139	1,501	502	584	-	1,669
JF-Bunk-N	9.3	22	50	26	13	2.4	51
JF-Dies-N	8.1	71	179	82	51	3.3	184
JF-Crud-N	81	166	324	179	74	53	327
SJ-Crud-N	70	90	142	99	29	53	157
CL-Bunk-N	3.3	24	121	41	40	0	121
CU-Bunk-N	0.6	1.2	2.3	1.3	0.6	0.4	2.4

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	120	462	5,006	1,673	1,946	-	5,565
JF-Bunk-N	31	72	166	85	43	8	171
JF-Dies-N	27	237	596	272	170	11	613
JF-Crud-N	269	555	1,080	595	247	177	1,090
SJ-Crud-N	232	302	475	329	97	177	524
CL-Bunk-N	11	79	402	138	132	0	403
CU-Bunk-N	1.9	4.0	7.8	4.4	1.9	1.3	8.2

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	14	55	598	200	232	-	664
JF-Bunk-N	3.7	9	20	10	5	1.0	20
JF-Dies-N	3.2	28	71	33	20	1.3	73
JF-Crud-N	32	66	129	71	30	21	130
SJ-Crud-N	28	36	57	39	12	21	63
CL-Bunk-N	1.3	9.5	48.0	16.5	15.8	0	48.1
CU-Bunk-N	0.2	0.5	0.9	0.5	0.2	0.2	1.0

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

Scenario	5th Percentile	50th Percentile	95th Percentile	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	238	248	248	246	8	230	261
JF-Bunk-N	27.0	28.3	32.2	29.1	1.5	26.1	32.0
JF-Dies-N	45.0	45.0	49.1	45.8	1.9	42.1	49.5
JF-Crud-N	218	238	268	238	15	208	267
SJ-Crud-N	228	249	269	249	17	214	284
CL-Bunk-N	0.0**	27.1	29.5	19.9	12.3	0.0	44.6
CU-Bunk-N	*	*	*	*	*	*	*

* WA Compensation Schedule damages were not calculated for the Upper Columbia River
** For some runs, the oiling was entirely outside WA jurisdiction where the Compensation Schedule does not apply.

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

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume V, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts at Tatoosh Island.

Table II.3-1. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island
OC-C250K-N	13.9	11.1	22.4
OC-C250K-Fed	15.8	11.3	21.8
OC-C250K-WA	15.8	6.4	21.8
OC-C250K-3	15.9	8.1	21.4

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	7.8	6.2	7.1
OC-C250K-Fed	7.7	6.1	7.0
OC-C250K-WA	7.7	3.2	6.4
OC-C250K-3	7.9	4.5	6.6

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.3-3. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island
OC-C250K-N	5.9	12.6	9.0
OC-C250K-Fed	11.4	16.8	8.9
OC-C250K-WA	11.4	19.6	8.7
OC-C250K-3	12.1	17.4	8.3

** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-4. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	0.04	0.72	0.95
OC-C250K-WA	0.04	3.30	3.54
OC-C250K-3	0.48	3.95	4.31

* The Federal and Washington State responses involved the same removal amounts and timing.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	3,251	46,034	21,583
OC-C250K-Fed	4,032	40,633	21,524
OC-C250K-WA	4,032	34,931	22,100
OC-C250K-3	4,140	36,685	20,242

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	2,127	33,931	16,508
OC-C250K-Fed	2,967	27,434	16,603
OC-C250K-WA	2,967	23,518	16,711
OC-C250K-3	2,854	25,896	16,757

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island**
OC-C250K-N	6,939	931	3,418
OC-C250K-Fed	7,482	900	3,446
OC-C250K-WA	7,482	558	4,085
OC-C250K-3	6,850	900	3,209

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.3-8. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	3,869	726	2,510
OC-C250K-Fed	3,050	746	2,361
OC-C250K-WA	3,050	394	2,476
OC-C250K-3	3,148	686	2,394

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island**
OC-C250K-N	5,318,700	463,390	2,189,100
OC-C250K-Fed	6,389,900	429,080	2,280,800
OC-C250K-WA	6,389,900	360,840	2,831,600
OC-C250K-3	5,701,700	545,590	1,964,400

** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	1,620,600	467,160	1,228,800
OC-C250K-Fed	1,092,300	471,310	1,165,500
OC-C250K-WA	1,092,300	197,200	1,253,300
OC-C250K-3	1,148,100	354,050	1,244,600

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	256.2	26.0	86.9
OC-C250K-Fed	238.1	26.3	85.7
OC-C250K-WA	238.1	12.1	103.7
OC-C250K-3	211.1	21.4	87.2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-12. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	-	1,645,669	740,850
OC-C250K-Fed	37,655	1,308,244	745,836
OC-C250K-WA	37,655	1,104,813	751,445
OC-C250K-3	31,775	1,228,368	753,782

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-13. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	77,378	898,618	448,708
OC-C250K-Fed	99,053	730,838	451,187
OC-C250K-WA	99,053	629,684	453,976
OC-C250K-3	96,129	691,120	455,138

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.3-14. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island
OC-C250K-N	4,887	468	2,004
OC-C250K-Fed	3,693	485	1,998
OC-C250K-WA	3,693	182	1,974
OC-C250K-3	4,022	433	1,904

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.3-15. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	82,265	2,544,755	1,191,561
OC-C250K-Fed	140,400	2,039,567	1,199,021
OC-C250K-WA	140,400	1,734,679	1,207,395
OC-C250K-3	131,926	1,919,921	1,210,824

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.3-16. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island*
OC-C250K-N	139.38	745.68	413.53
OC-C250K-Fed	155.39	621.81	415.36
OC-C250K-WA	155.39	547.14	417.41
OC-C250K-3	153.23	592.49	418.27

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-17. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.14 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	-	-	-
OC-C250K-WA	-	-	-
OC-C250K-3	-	-	-

Table II.3-18. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island
OC-C250K-N	559	3,492	1,929
OC-C250K-Fed	2,979	5,339	1,877
OC-C250K-WA	2,979	6,524	1,776
OC-C250K-3	3,277	5,586	1,616

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-19. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	33,652	2,454	21,968
OC-C250K-Fed	25,006	2,980	21,091
OC-C250K-WA	25,006	1,753	22,727
OC-C250K-3	25,473	2,395	21,266

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for Tatoosh Island*
OC-C250K-N	34,211	5,945	23,897
OC-C250K-Fed	27,985	8,318	22,968
OC-C250K-WA	27,985	8,276	24,503
OC-C250K-3	28,750	7,982	22,882

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.3-21. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	675	13,021	6,246
OC-C250K-Fed	987	10,502	6,283
OC-C250K-WA	987	8,983	6,325
OC-C250K-3	945	9,905	6,341

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-22. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	126	2,440	1,170
OC-C250K-Fed	185	1,968	1,177
OC-C250K-WA	185	1,683	1,185
OC-C250K-3	177	1,856	1,188

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-23. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	422	8,137	3,903
OC-C250K-Fed	617	6,563	3,926
OC-C250K-WA	617	5,613	3,952
OC-C250K-3	591	6,189	3,963

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for Tatoosh Island*
OC-C250K-N	50.3	971	466
OC-C250K-Fed	73.7	784	469
OC-C250K-WA	73.7	670	472
OC-C250K-3	70.5	739	473

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.3-25. Summary of results for alternate response scenarios for Outer Coast spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	248	248	248
OC-C250K-Fed	248	248	248
OC-C250K-WA	248	246	246
OC-C250K-3	247	245	245

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

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume VIII. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.4-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	62.6	68.9	60.9
JF-B25K-Fed	58.9	70.5	54.0
JF-B25K-WA	57.4	60.4	45.5
JF-B25K-3	55.9	53.7	36.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	19	22	50
JF-B25K-Fed	17	18	43
JF-B25K-WA	16	20	36
JF-B25K-3	16	19	29

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	0.6	3.5	1.4
JF-B25K-Fed	0.5	2.0	1.2
JF-B25K-WA	0.5	2.7	1.1
JF-B25K-3	0.5	2.3	0.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	5.8	5.8	12.7
JF-B25K-WA	8.5	14.6	28.4
JF-B25K-3	11.6	24.1	42.1

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	790	321	183
JF-B25K-Fed	740	250	181
JF-B25K-WA	771	281	150
JF-B25K-3	707	250	146

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	789	321	183
JF-B25K-Fed	740	250	181
JF-B25K-WA	761	275	149
JF-B25K-3	701	246	146

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	904	752	342
JF-B25K-Fed	846	711	296
JF-B25K-WA	919	742	264
JF-B25K-3	816	674	270

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-B25K-N	901	751	301
JF-B25K-Fed	846	711	296
JF-B25K-WA	918	695	264
JF-B25K-3	816	634	269

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	330,060	290,630	81,483
JF-B25K-Fed	292,700	288,380	56,700
JF-B25K-WA	329,870	298,710	86,740
JF-B25K-3	295,890	208,960	134,050

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	573,760	461,300	260,220
JF-B25K-Fed	553,670	422,430	238,820
JF-B25K-WA	589,150	443,460	177,230
JF-B25K-3	519,690	464,870	135,930

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	107.8	95.3	42.8
JF-B25K-Fed	102.2	89.8	37.3
JF-B25K-WA	110.7	93.0	30.2
JF-B25K-3	96.4	90.0	28.3

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	21,075	11,436	8,586
JF-B25K-Fed	20,074	9,976	8,541
JF-B25K-WA	20,499	10,486	7,884
JF-B25K-3	19,262	9,887	7,817

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	9,260	3,360	1,615
JF-B25K-Fed	8,647	2,466	1,587
JF-B25K-WA	8,907	2,778	1,185
JF-B25K-3	8,150	2,411	1,144

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-B25K-N	2,437	2,056	915
JF-B25K-Fed	2,299	1,955	901
JF-B25K-WA	2,480	1,914	821
JF-B25K-3	2,221	1,761	833

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	32,772	16,852	11,119
JF-B25K-Fed	31,020	14,397	11,033
JF-B25K-WA	31,886	15,179	9,892
JF-B25K-3	29,633	14,059	9,796

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	2.47	1.25	0.89
JF-B25K-Fed	2.34	1.07	0.89
JF-B25K-WA	2.40	1.13	0.81
JF-B25K-3	2.24	1.06	0.80

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	-	-	-
JF-B25K-WA	-	-	-
JF-B25K-3	-	-	-

Table II.4-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-B25K-N	52	86	61
JF-B25K-Fed	51	69	59
JF-B25K-WA	51	76	58
JF-B25K-3	51	72	55

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	122,377	106,837	16,997
JF-B25K-Fed	115,578	108,294	16,511
JF-B25K-WA	129,176	100,524	16,511
JF-B25K-3	110,722	94,211	21,853

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	122,429	106,923	17,058
JF-B25K-Fed	115,629	108,363	16,570
JF-B25K-WA	129,227	100,600	16,569
JF-B25K-3	110,773	94,283	21,908

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	225.7	112.5	50.3
JF-B25K-Fed	212.1	96.3	49.6
JF-B25K-WA	221.5	99.6	42.0
JF-B25K-3	201.4	90.5	42.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	42.3	21.1	9.4
JF-B25K-Fed	39.7	18.0	9.3
JF-B25K-WA	41.5	18.7	7.9
JF-B25K-3	37.7	17.0	8.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	141.1	70.3	31.4
JF-B25K-Fed	132.5	60.2	31.0
JF-B25K-WA	138.4	62.2	26.2
JF-B25K-3	125.8	56.5	26.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-B25K-N	16.8	8.4	3.8
JF-B25K-Fed	15.8	7.2	3.7
JF-B25K-WA	16.5	7.4	3.1
JF-B25K-3	15.0	6.8	3.2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.4-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	29.6	28.3	28.4
JF-B25K-Fed	29.2	28.0	27.5
JF-B25K-WA	28.7	27.1	25.8
JF-B25K-3	28.1	25.8	24.1

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

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXI. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.5-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit**	Worst run for Protection Island*
JF-D65K-N	13.8	17.5	6.0
JF-D65K-Fed	6.7	18.1	6.4
JF-D65K-WA	7.7	18.9	5.1
JF-D65K-3	9.1	16.9	5.2

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.5-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	-	-	-
JF-D65K-WA	-	-	-
JF-D65K-3	-	-	-

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	25.5	22.3	40.7
JF-D65K-Fed	34.3	18.8	37.2
JF-D65K-WA	32.3	14.6	36.1
JF-D65K-3	31.7	14.6	33.5

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	2.8	4.1	3.8
JF-D65K-WA	3.9	9.2	8.4
JF-D65K-3	4.8	13.3	12.2

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	587	325	170
JF-D65K-Fed	541	303	174
JF-D65K-WA	535	267	166
JF-D65K-3	544	263	155

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	552	288	166
JF-D65K-Fed	506	273	172
JF-D65K-WA	469	238	164
JF-D65K-3	494	230	154

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,451	1,564	685
JF-D65K-Fed	1,057	1,521	746
JF-D65K-WA	1,051	1,638	583
JF-D65K-3	1,276	1,204	569

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	1,767	1,054	322
JF-D65K-Fed	674	941	336
JF-D65K-WA	701	1,011	286
JF-D65K-3	949	896	339

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,034,600	1,016,100	481,760
JF-D65K-Fed	884,670	1,046,700	551,420
JF-D65K-WA	808,820	1,142,300	428,250
JF-D65K-3	1,027,900	749,120	430,320

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-D65K-N	416,800	548,040	203,140
JF-D65K-Fed	172,350	474,440	194,130
JF-D65K-WA	242,010	495,470	154,700
JF-D65K-3	248,580	454,730	138,750

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	36.5	24.9	8.9
JF-D65K-Fed	14.8	24.8	9.7
JF-D65K-WA	14.6	27.0	6.8
JF-D65K-3	17.7	17.7	7.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	31,065	21,260	16,735
JF-D65K-Fed	29,341	20,706	16,937
JF-D65K-WA	27,970	19,398	16,639
JF-D65K-3	28,902	19,117	16,271

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	14,760	6,882	3,246
JF-D65K-Fed	13,376	6,437	3,409
JF-D65K-WA	12,274	5,386	3,169
JF-D65K-3	13,023	5,160	2,873

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	2,301	1,314	346
JF-D65K-Fed	835	1,171	365
JF-D65K-WA	869	1,259	302
JF-D65K-3	1,182	1,070	412

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	48,126	29,455	20,327
JF-D65K-Fed	43,552	28,314	20,711
JF-D65K-WA	41,113	26,043	20,111
JF-D65K-3	43,107	25,347	19,556

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-D65K-N	3.90	2.21	1.42
JF-D65K-Fed	3.61	2.11	1.46
JF-D65K-WA	3.37	1.88	1.41
JF-D65K-3	3.53	1.84	1.34

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit**	Worst run for Protection Island*
JF-D65K-N	509	330	256
JF-D65K-Fed	521	386	243
JF-D65K-WA	525	359	239
JF-D65K-3	562	353	248

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	319	29	38,643
JF-D65K-Fed	22,510	24	29,860
JF-D65K-WA	17,466	24	26,922
JF-D65K-3	15,907	24	20,567

**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.5-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	257,862	163,169	22,824
JF-D65K-Fed	81,099	142,773	22,824
JF-D65K-WA	87,412	156,369	16,511
JF-D65K-3	129,661	137,917	29,138

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-D65K-N	258,182	163,197	61,467
JF-D65K-Fed	103,608	142,797	52,684
JF-D65K-WA	104,878	156,393	43,433
JF-D65K-3	145,568	137,941	49,704

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.5-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	361.6	197.8	296.0
JF-D65K-Fed	399.5	183.8	252.0
JF-D65K-WA	356.1	170.4	230.3
JF-D65K-3	373.9	160.5	195.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	67.8	37.1	55.5
JF-D65K-Fed	74.9	34.4	47.2
JF-D65K-WA	66.7	31.9	43.2
JF-D65K-3	70.1	30.1	36.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	226.0	123.6	184.9
JF-D65K-Fed	249.6	114.8	157.5
JF-D65K-WA	222.5	106.5	143.9
JF-D65K-3	233.7	100.3	122.2

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	27.0	14.8	22.1
JF-D65K-Fed	29.8	13.7	18.8
JF-D65K-WA	26.6	12.7	17.2
JF-D65K-3	27.9	12.0	14.6

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.5-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	45.0	47.1	47.2
JF-D65K-Fed	48.9	46.5	46.8
JF-D65K-WA	48.7	45.4	44.0
JF-D65K-3	48.4	42.7	43.3

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

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XIV. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Table II.6-1. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island
JF-C250K-N	25.8	32.4	23.8
JF-C250K-Fed	24.3	32.2	22.8
JF-C250K-WA	25.1	33.0	22.6
JF-C250K-3	23.0	31.9	21.7

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-2. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	19.5	7.6	14.5
JF-C250K-Fed	19.2	7.5	13.6
JF-C250K-WA	18.6	6.2	13.9
JF-C250K-3	18.1	6.5	14.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-3. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	0.6	0.2	0.9
JF-C250K-Fed	1.0	0.2	0.9
JF-C250K-WA	0.7	0.2	0.8
JF-C250K-3	0.8	0.2	1.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-4. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	2.0	0.9	1.9
JF-C250K-WA	4.5	2.3	4.2
JF-C250K-3	6.7	3.6	6.3

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	1,236	1,117	593
JF-C250K-Fed	1,299	1,065	576
JF-C250K-WA	1,255	864	584
JF-C250K-3	1,200	878	561

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-6. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	817	556	543
JF-C250K-Fed	954	578	522
JF-C250K-WA	916	493	527
JF-C250K-3	839	527	496

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-7. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	7,661	1,789	2,407
JF-C250K-Fed	6,731	1,949	2,620
JF-C250K-WA	5,930	1,364	2,526
JF-C250K-3	5,991	1,440	2,521

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-8. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	3,109	1,382	1,901
JF-C250K-Fed	3,378	1,366	2,062
JF-C250K-WA	2,944	1,158	1,928
JF-C250K-3	2,846	1,265	1,926

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-9. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island**
JF-C250K-N	5,936,100	575,260	975,730
JF-C250K-Fed	5,296,600	839,800	1,308,200
JF-C250K-WA	4,194,700	289,320	1,126,300
JF-C250K-3	4,458,700	326,870	1,312,200

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.6-10. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	1,725,200	1,213,600	1,431,600
JF-C250K-Fed	1,434,600	1,109,600	1,312,200
JF-C250K-WA	1,735,000	1,074,700	1,399,700
JF-C250K-3	1,532,600	1,113,000	1,208,500

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-11. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	309.1	103.6	141.4
JF-C250K-Fed	254.7	102.5	143.5
JF-C250K-WA	239.6	90.3	142.0
JF-C250K-3	234.4	92.1	134.6

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-12. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	49,403	20,855	19,452
JF-C250K-Fed	64,256	23,156	17,188
JF-C250K-WA	60,053	13,921	17,678
JF-C250K-3	51,681	17,622	14,372

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-13. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	25,292	22,503	22,366
JF-C250K-Fed	26,743	22,728	22,145
JF-C250K-WA	26,332	21,826	22,193
JF-C250K-3	25,514	22,188	21,870

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-14. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	6,613	2,752	3,990
JF-C250K-Fed	7,214	2,717	4,352
JF-C250K-WA	6,243	2,251	4,051
JF-C250K-3	6,024	2,490	3,968

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-15. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	81,310	46,112	45,837
JF-C250K-Fed	98,214	48,602	43,711
JF-C250K-WA	92,630	37,999	43,950
JF-C250K-3	83,221	42,301	40,238

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-16. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	6.54	3.15	2.98
JF-C250K-Fed	8.30	3.42	2.71
JF-C250K-WA	7.80	2.32	2.76
JF-C250K-3	6.81	2.76	2.37

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-17. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	-	-	-
JF-C250K-WA	-	-	-
JF-C250K-3	-	-	-

Table II.6-18. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Protection Island*
JF-C250K-N	7,947	5,119	10,547
JF-C250K-Fed	10,814	5,050	10,481
JF-C250K-WA	8,738	4,939	9,543
JF-C250K-3	9,774	4,896	11,687

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.6-19. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	362,273	178,216	213,674
JF-C250K-Fed	396,760	165,597	247,182
JF-C250K-WA	319,546	147,144	214,160
JF-C250K-3	309,835	161,711	223,385

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-20. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	370,220	183,336	224,221
JF-C250K-Fed	407,574	170,648	257,663
JF-C250K-WA	328,284	152,083	223,703
JF-C250K-3	319,609	166,607	235,072

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.6-21. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	684.1	490.9	528.1
JF-C250K-Fed	768.5	495.6	530.2
JF-C250K-WA	715.3	452.1	516.5
JF-C250K-3	684.4	471.4	516.9

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-22. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	128.2	92.0	98.9
JF-C250K-Fed	144.0	92.9	99.3
JF-C250K-WA	134.0	84.7	96.8
JF-C250K-3	128.2	88.3	96.9

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-23. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	427.5	306.8	330.0
JF-C250K-Fed	480.2	309.7	331.3
JF-C250K-WA	447.0	282.5	322.8
JF-C250K-3	427.7	294.6	323.0

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-24. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit*	Worst run for Protection Island*
JF-C250K-N	51.0	36.6	39.4
JF-C250K-Fed	57.3	37.0	39.6
JF-C250K-WA	53.4	33.7	38.5
JF-C250K-3	51.1	35.2	38.6

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.6-25. Summary of results for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	268	248	222
JF-C250K-Fed	261	245	217
JF-C250K-WA	264	247	219
JF-C250K-3	261	245	217

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

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XVII. For the alternate response scenarios, the following 6 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Lopez Island;
3. the worst case run for impacts at Orcas Island;
4. the worst case run for impacts at Lummi Island;
5. the worst case run for impacts at Padilla Bay; and
6. the 50th percentile run based on shoreline oiling and area-based costs for cleanup.

Table II.7-1. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	34.1	24.9	31.4	26.1	27.6	29.8
SJ-C250K-Fed	33.0	23.5	31.7	27.8	24.4	29.2
SJ-C250K-WA	31.8	23.1	30.5	24.6	26.9	29.2
SJ-C250K-3	30.5	24.0	29.1	23.9	24.2	29.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-2. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	13.8	15.1	16.5	14.4	20.5	17.0
SJ-C250K-Fed	13.1	14.6	14.7	13.4	21.4	17.2
SJ-C250K-WA	11.6	14.5	15.0	14.5	17.6	15.0
SJ-C250K-3	11.7	12.7	15.0	12.1	20.1	15.9

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island**	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	2.8	1.4	0.5	0.6	1.6	0.4
SJ-C250K-Fed	2.7	1.4	0.4	0.7	1.7	0.5
SJ-C250K-WA	2.7	1.4	0.5	1.1	1.7	0.4
SJ-C250K-3	2.7	1.4	0.4	1.1	1.7	0.5

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-4. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	1.8	2.0	2.0	1.6	1.8	1.3
SJ-C250K-WA	4.2	4.6	4.4	3.7	3.6	3.4
SJ-C250K-3	5.9	6.8	6.5	5.5	5.2	5.0

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	1,777	4,025	786	409	606	372
SJ-C250K-Fed	1,760	4,323	577	375	604	250
SJ-C250K-WA	1,530	2,969	606	508	796	258
SJ-C250K-3	2,272	3,981	658	316	600	231

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	1,255	3,626	577	293	535	267
SJ-C250K-Fed	1,132	3,927	445	259	528	189
SJ-C250K-WA	1,025	2,658	423	353	597	185
SJ-C250K-3	1,475	3,451	459	228	515	171

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-7. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	11,810.5	4,145.4	5,782.8	4,416.0	7,161.6	4,105.5
SJ-C250K-Fed	8,803.4	5,067.1	5,543.8	5,633.4	5,816.4	4,774.7
SJ-C250K-WA	9,596.9	4,351.1	4,375.0	3,728.1	9,385.9	6,806.8
SJ-C250K-3	9,305.3	4,107.5	4,798.4	3,964.0	5,669.2	5,438.6

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-8. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	4,542.45	2,802.85	3,324.41	2,543.73	3,276.26	2,763.21
SJ-C250K-Fed	5,131.01	2,701.24	3,625.27	3,176.84	2,851.36	2,635.86
SJ-C250K-WA	5,038.34	2,857.75	2,959.48	2,138.42	3,861.82	3,058.27
SJ-C250K-3	4,560.75	2,491.68	2,830.54	2,627.51	2,747.38	2,409.13

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

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

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island**	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	9,604,900	2,435,100	3,348,300	2,706,300	5,035,800	2,105,900
SJ-C250K-Fed	6,581,100	3,439,500	3,094,000	3,916,000	4,168,300	2,934,200
SJ-C250K-WA	7,501,500	2,854,800	2,367,400	2,397,100	6,951,400	5,038,500
SJ-C250K-3	7,149,000	2,615,800	2,748,600	2,463,700	3,732,700	3,638,000

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-10. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	2,205,600	1,710,300	2,434,500	1,709,700	2,125,800	1,999,600
SJ-C250K-Fed	2,222,300	1,627,600	2,449,800	1,717,400	1,648,100	1,840,500
SJ-C250K-WA	2,095,400	1,496,300	2,007,600	1,331,000	2,434,500	1,768,300
SJ-C250K-3	2,156,300	1,491,700	2,049,800	1,500,300	1,936,500	1,800,600

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-11. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)**
SJ-C250K-N	514	159	285	203	344	206
SJ-C250K-Fed	396	193	285	253	264	228
SJ-C250K-WA	430	165	227	162	419	299
SJ-C250K-3	415	154	236	184	274	254

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.7-12. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	92,659	190,946	64,502	52,685	62,750	51,609
SJ-C250K-Fed	87,615	203,445	59,035	51,295	62,436	48,380
SJ-C250K-WA	83,180	150,815	58,108	55,174	65,356	48,251
SJ-C250K-3	101,802	183,674	59,605	49,996	61,896	47,614

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-13. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	14,638	17,844	13,720	13,334	13,663	13,299
SJ-C250K-Fed	14,474	18,252	13,542	13,289	13,653	13,194
SJ-C250K-WA	14,329	16,535	13,511	13,416	13,748	13,190
SJ-C250K-3	14,937	17,607	13,560	13,247	13,635	13,169

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-14. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	8,348	7,128	7,442	6,861	7,406	7,024
SJ-C250K-Fed	8,786	7,152	7,666	7,332	7,090	6,930
SJ-C250K-WA	8,717	7,095	7,171	6,560	7,842	7,244
SJ-C250K-3	8,362	7,491	7,075	6,924	7,013	6,761

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-15. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	115,649	215,921	85,666	72,883	83,821	71,936
SJ-C250K-Fed	110,878	228,852	80,245	71,919	83,181	68,507
SJ-C250K-WA	106,229	174,448	78,793	75,152	86,948	68,688
SJ-C250K-3	125,103	208,775	80,243	70,169	82,546	67,547

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-16. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)
SJ-C250K-N	9.84	17.65	7.60	6.66	7.46	6.57
SJ-C250K-Fed	9.44	18.64	7.16	6.55	7.43	6.32
SJ-C250K-WA	9.08	14.46	7.09	6.86	7.67	6.31
SJ-C250K-3	10.56	17.07	7.21	6.45	7.39	6.26

* Differences between runs are less than the randomized variability in the model and are not significant.

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

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	-	-	-	-	-	-
SJ-C250K-WA	-	-	-	-	-	-
SJ-C250K-3	-	-	-	-	-	-

Table II.7-18. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island**	Worst run for Padilla Bay**	50th Percentile Run (based on shore cost)*
SJ-C250K-N	17,347	8,576	2,942	3,557	9,976	2,815
SJ-C250K-Fed	16,317	8,811	2,777	4,547	10,264	3,257
SJ-C250K-WA	16,317	8,576	2,920	7,080	10,264	2,563
SJ-C250K-3	16,317	8,576	2,755	6,674	10,264	3,055

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-19. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	623,325	242,536	424,678	328,406	489,324	364,744
SJ-C250K-Fed	724,311	229,324	495,463	463,373	411,935	357,189
SJ-C250K-WA	718,648	268,956	399,657	260,938	575,198	444,972
SJ-C250K-3	620,032	214,233	359,083	366,636	400,140	340,207

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-20. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	640,672	251,112	427,620	331,963	499,300	367,559
SJ-C250K-Fed	740,627	238,135	498,240	467,920	422,199	360,446
SJ-C250K-WA	734,965	277,533	402,577	268,018	585,463	447,535
SJ-C250K-3	636,349	222,809	361,838	373,310	410,404	343,262

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.7-21. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	728.6	818.1	526.0	468.2	574.2	473.4
SJ-C250K-Fed	742.6	847.1	533.3	511.3	550.6	464.7
SJ-C250K-WA	729.4	724.1	501.3	470.1	609.4	488.4
SJ-C250K-3	746.0	792.6	491.8	487.8	545.4	456.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-22. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	136.5	153.3	98.6	87.7	107.6	88.7
SJ-C250K-Fed	139.2	158.7	99.9	95.8	103.2	87.1
SJ-C250K-WA	136.7	135.7	93.9	88.1	114.2	91.5
SJ-C250K-3	139.8	148.5	92.2	91.4	102.2	85.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-23. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	455.3	511.2	328.7	292.6	358.8	295.8
SJ-C250K-Fed	464.1	529.3	333.3	319.5	344.1	290.4
SJ-C250K-WA	455.8	452.5	313.2	293.7	380.8	305.2
SJ-C250K-3	466.2	495.3	307.3	304.8	340.8	285.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-24. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Lopez Island*	Worst run for Orcas Island*	Worst run for Lummi Island*	Worst run for Padilla Bay*	50th Percentile Run (based on shore cost)*
SJ-C250K-N	54.4	61.0	39.2	34.9	42.8	35.3
SJ-C250K-Fed	55.4	63.2	39.8	38.1	41.1	34.7
SJ-C250K-WA	54.4	54.0	37.4	35.1	45.5	36.4
SJ-C250K-3	55.7	59.1	36.7	36.4	40.7	34.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.7-25. Summary of results for alternate response scenarios for San Juan Island spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	228	238	228	228	249	268
SJ-C250K-Fed	227	237	267	227	248	267
SJ-C250K-WA	225	264	263	265	226	246
SJ-C250K-3	224	232	261	233	224	244

II.8. COMPARISON OF ALTERNATIVE RESPONSES: LOWER COLUMBIA RIVER – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XX. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Baker Bay; and
3. the worst case run for impacts at the Columbia National Wildlife Refuge.

Table II.8-1. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	73.4	68.1	72.4
CL-B25K-Fed	72.1	66.8	72.4
CL-B25K-WA	73.0	65.5	71.2
CL-B25K-3	69.2	64.1	70.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-2. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	7.3	41.7	23.4
CL-B25K-Fed	7.5	40.3	19.4
CL-B25K-WA	7.2	40.3	18.5
CL-B25K-3	7.7	41.2	17.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-3. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	1.0	5.4	3.0
CL-B25K-Fed	1.1	5.3	2.6
CL-B25K-WA	1.1	5.3	2.4
CL-B25K-3	1.1	5.5	2.3

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-4. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	1.6	2.2	1.6
CL-B25K-WA	3.4	4.4	3.4
CL-B25K-3	6.7	8.1	6.7

Table II.8-5. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	74	96	105
CL-B25K-Fed	79	90	95
CL-B25K-WA	69	83	90
CL-B25K-3	71	76	86

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-6. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	74	95	101
CL-B25K-Fed	79	89	95
CL-B25K-WA	69	83	90
CL-B25K-3	71	76	85

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-7. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	1,506	1,284	1,738
CL-B25K-Fed	1,469	1,200	1,498
CL-B25K-WA	1,640	1,231	1,840
CL-B25K-3	1,502	1,037	1,607

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-8. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	1,470	1,176	1,665
CL-B25K-Fed	1,469	1,162	1,463
CL-B25K-WA	1,640	1,052	1,770
CL-B25K-3	1,466	967	1,607

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-9. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	671,790	929,360	1,211,500
CL-B25K-Fed	812,380	892,210	889,700
CL-B25K-WA	1,023,300	888,690	1,202,500
CL-B25K-3	787,270	751,620	1,066,400

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.8-10. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge**
CL-B25K-N	833,970	354,980	526,190
CL-B25K-Fed	656,230	307,280	608,530
CL-B25K-WA	616,560	341,920	637,650
CL-B25K-3	714,470	285,190	540,750

* Differences between runs are less than the randomized variability in the model and are not significant.
**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.8-11. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	187.9	111.1	167.2
CL-B25K-Fed	168.8	101.2	159.6
CL-B25K-WA	179.3	107.1	188.7
CL-B25K-3	177.4	88.2	164.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-12. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	15,000	21,183	23,094
CL-B25K-Fed	16,394	19,405	21,144
CL-B25K-WA	13,433	17,599	19,816
CL-B25K-3	14,140	15,388	18,241

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-13. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	1,810	2,256	2,393
CL-B25K-Fed	1,910	2,128	2,253
CL-B25K-WA	1,697	1,997	2,157
CL-B25K-3	1,748	1,838	2,044

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-14. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit*	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	7,420	12,810	60,916
CL-B25K-Fed	7,819	8,645	64,708
CL-B25K-WA	8,790	9,474	60,609
CL-B25K-3	7,671	8,648	63,636

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-15. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	24,229	36,249	86,404
CL-B25K-Fed	26,123	30,178	88,105
CL-B25K-WA	23,920	29,070	82,582
CL-B25K-3	23,559	25,874	83,921

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-16. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	4.2	5.3	5.6
CL-B25K-Fed	4.5	5.0	5.3
CL-B25K-WA	4.0	4.7	5.0
CL-B25K-3	4.1	4.3	4.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-17. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	-	-	-
CL-B25K-WA	-	-	-
CL-B25K-3	-	-	-

Table II.8-18. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	0	5	0
CL-B25K-Fed	0	5	0
CL-B25K-WA	0	5	0
CL-B25K-3	0	5	0

Table II.8-19. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	2,681	2,074	3,057
CL-B25K-Fed	2,691	2,050	2,681
CL-B25K-WA	3,024	1,852	3,270
CL-B25K-3	2,696	1,726	2,975

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-20. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge*
CL-B25K-N	2,682	2,079	3,058
CL-B25K-Fed	2,691	2,054	2,682
CL-B25K-WA	3,024	1,856	3,270
CL-B25K-3	2,696	1,732	2,976

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-21. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	83.4	119.0	225.3
CL-B25K-Fed	89.8	103.3	225.1
CL-B25K-WA	80.0	97.7	211.6
CL-B25K-3	80.5	87.2	211.4

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-22. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	15.6	22.3	42.2
CL-B25K-Fed	16.8	19.4	42.2
CL-B25K-WA	15.0	18.3	39.6
CL-B25K-3	15.1	16.3	39.6

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-23. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	52.1	74.3	140.8
CL-B25K-Fed	56.1	64.6	140.7
CL-B25K-WA	50.0	61.1	132.2
CL-B25K-3	50.3	54.5	132.1

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-24. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	6.2	8.9	16.8
CL-B25K-Fed	6.7	7.7	16.8
CL-B25K-WA	6.0	7.3	15.8
CL-B25K-3	6.0	6.5	15.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.8-25. Summary of results for alternate response scenarios for Lower Columbia River spills of Bunker C fuel: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	30.3	28.2	27.7
CL-B25K-Fed	27.0	28.2	27.7
CL-B25K-WA	28.1	27.9	27.5
CL-B25K-3	29.0	26.9	27.3

II.9. COMPARISON OF ALTERNATIVE RESPONSES: UPPER COLUMBIA RIVER – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXIII. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Ridgefield National Wildlife Refuge (referred to as run#1); and
3. the (second) worst case run for impacts at Ridgefield National Wildlife Refuge (referred to as run#2).

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

Table II.9-1. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	76.8	75.7	69.2
CU-B25K-Fed	75.3	75.1	67.8
CU-B25K-WA	74.0	73.6	68.1
CU-B25K-3	72.5	71.6	68.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-2. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	44.5	41.8	58.3
CU-B25K-Fed	45.0	39.2	56.7
CU-B25K-WA	44.6	40.1	56.1
CU-B25K-3	44.3	37.5	53.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-3. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	2.6	2.5	1.6
CU-B25K-Fed	2.6	2.3	2.1
CU-B25K-WA	2.6	2.4	2.1
CU-B25K-3	2.6	2.2	2.1

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-4. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	1.8	2.2	2.2
CU-B25K-WA	3.3	3.3	3.8
CU-B25K-3	5.3	6.6	7.4

Table II.9-5. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	12.8	6.9	8.0
CU-B25K-Fed	12.5	6.4	8.2
CU-B25K-WA	12.7	7.1	8.1
CU-B25K-3	12.5	6.6	7.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-6. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	12.6	6.9	7.9
CU-B25K-Fed	12.4	6.3	7.9
CU-B25K-WA	12.5	7.1	7.4
CU-B25K-3	12.4	6.6	7.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-7. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	743	309	196
CU-B25K-Fed	668	289	183
CU-B25K-WA	595	294	149
CU-B25K-3	617	299	178

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-8. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	705	274	196
CU-B25K-Fed	665	254	183
CU-B25K-WA	593	257	149
CU-B25K-3	579	262	178

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-9. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	294,230	80,335	42,678
CU-B25K-Fed	261,090	50,209	40,168
CU-B25K-WA	153,640	85,356	23,096
CU-B25K-3	289,210	52,720	35,147

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-10. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	448,370	228,950	153,140
CU-B25K-Fed	406,700	239,000	143,100
CU-B25K-WA	441,840	208,870	148,120
CU-B25K-3	327,870	246,530	143,100

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-11. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	80.9	30.3	14.9
CU-B25K-Fed	71.6	31.7	14.1
CU-B25K-WA	69.1	28.9	11.6
CU-B25K-3	61.5	32.4	14.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-12. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Ridgefield National Wildlife Refuge (#1)**	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	56	54	54
CU-B25K-Fed	92	73	77
CU-B25K-WA	92	75	76
CU-B25K-3	92	74	76

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.9-13. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Ridgefield National Wildlife Refuge (#1)**	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	10	10	9
CU-B25K-Fed	31	20	23
CU-B25K-WA	31	21	22
CU-B25K-3	31	20	22

**The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area.

Table II.9-14. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	3,462	882	284
CU-B25K-Fed	3,239	769	213
CU-B25K-WA	2,832	783	18
CU-B25K-3	2,756	811	185

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-15. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	3,529	946	347
CU-B25K-Fed	3,363	862	313
CU-B25K-WA	2,956	880	116
CU-B25K-3	2,879	905	283

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-16. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	156	107	115
CU-B25K-Fed	154	103	115
CU-B25K-WA	154	109	110
CU-B25K-3	153	105	112

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-17. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Area (km^2) where dissolved aromatic concentration exceeds 1ppb at some depth and at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	-	-	-
CU-B25K-WA	-	-	-
CU-B25K-3	-	-	-

Table II.9-18. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	3,728	3,689	3,357
CU-B25K-Fed	3,740	3,629	3,537
CU-B25K-WA	3,728	3,652	3,544
CU-B25K-3	3,721	3,595	3,537

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-19. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	-	-	-
CU-B25K-WA	-	-	-
CU-B25K-3	-	-	-

Table II.9-20. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)**
CU-B25K-N	3,728	3,689	3,357
CU-B25K-Fed	3,740	3,629	3,537
CU-B25K-WA	3,728	3,652	3,544
CU-B25K-3	3,721	3,595	3,537

* Differences between runs are less than the randomized variability in the model and are not significant.
** Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.9-21. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	15.1	6.2	4.0
CU-B25K-Fed	14.8	6.0	4.1
CU-B25K-WA	13.4	6.1	3.4
CU-B25K-3	13.1	6.1	4.0

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-22. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	2.8	1.2	0.7
CU-B25K-Fed	2.8	1.1	0.8
CU-B25K-WA	2.5	1.1	0.6
CU-B25K-3	2.5	1.1	0.8

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-23. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	9.5	3.9	2.5
CU-B25K-Fed	9.2	3.7	2.6
CU-B25K-WA	8.4	3.8	2.1
CU-B25K-3	8.2	3.8	2.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.9-24. Summary of results for alternate response scenarios for Upper Columbia River spills of Bunker C fuel: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)*	Worst run for Ridgefield National Wildlife Refuge (#2)*
CU-B25K-N	1.1	0.5	0.3
CU-B25K-Fed	1.1	0.4	0.3
CU-B25K-WA	1.0	0.5	0.3
CU-B25K-3	1.0	0.5	0.3

* Differences between runs are less than the randomized variability in the model and are not significant.

II.10. COMPARISON OF ALTERNATIVE RESPONSES: OUTER COAST-SEA LANES – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXVI, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts for sensitive locations identified in Geographic Response Plans (GRPs).

Table II.10-1. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	54.0	28.6	62.6
OL-B150K-Fed	54.5	28.7	60.5
OL-B150K-WA	51.0	27.0	56.3
OL-B150K-3	55.2	28.5	58.0

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-2. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	39.0	34.9	31.7
OL-B150K-Fed	36.6	34.6	31.8
OL-B150K-WA	34.2	31.5	31.9
OL-B150K-3	33.5	32.3	30.9

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.10-3. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	8.7	7.2	15.6
OL-B150K-Fed	8.5	7.2	11.4
OL-B150K-WA	7.7	7.0	11.4
OL-B150K-3	8.1	6.8	11.1

Table II.10-4. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K-Fed	1.9	1.7	1.8
OL-B150K-WA	6.6	5.6	5.6
OL-B150K-3	6.8	6.1	5.7

Table II.10-5. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	917	5,563	392
OL-B150K-Fed	902	5,222	369
OL-B150K-WA	876	5,654	376
OL-B150K-3	818	5,315	355

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-6. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	916	5,563	390
OL-B150K-Fed	887	5,091	368
OL-B150K-WA	863	5,615	376
OL-B150K-3	808	5,222	354

* Differences between runs are less than the randomized variability in the model and are not significant.
** Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.10-7. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	3,134	1,312	2,355
OL-B150K-Fed	3,071	1,432	1,932
OL-B150K-WA	2,457	1,484	2,270
OL-B150K-3	3,112	1,434	2,311

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-8. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	3,014	1,293	2,295
OL-B150K-Fed	2,882	1,425	1,872
OL-B150K-WA	2,390	1,480	2,270
OL-B150K-3	3,084	1,414	2,252

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-9. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*,**
OL-B150K-N	727,270	172,790	371,730
OL-B150K-Fed	659,060	207,180	270,270
OL-B150K-WA	456,140	241,290	213,150
OL-B150K-3	721,300	324,560	507,300

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-10. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	2,406,600	1,138,800	1,983,100
OL-B150K-Fed	2,411,700	1,224,900	1,661,700
OL-B150K-WA	2,000,800	1,242,500	2,057,300
OL-B150K-3	2,391,000	1,109,800	1,804,100

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-11. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	363.6	104.6	273.2
OL-B150K-Fed	361.1	113.8	216.9
OL-B150K-WA	288.4	116.9	271.6
OL-B150K-3	370.1	107.0	259.3

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore.

Table II.10-12. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs**
OL-B150K-N	12,645	205,840	-
OL-B150K-Fed	11,457	186,197	-
OL-B150K-WA	10,429	208,011	-
OL-B150K-3	8,147	191,671	-

* Differences between runs are less than the randomized variability in the model and are not significant.
** Injuries to waterfowl were not significant for this run.

Table II.10-13. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*,**	Worst run for GRPs
OL-B150K-N	25,448	99,125	17,102
OL-B150K-Fed	24,994	91,634	16,740
OL-B150K-WA	24,602	99,953	16,868
OL-B150K-3	23,732	93,721	16,516

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-14. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	34,478	5,287	23,892
OL-B150K-Fed	29,524	7,040	17,229
OL-B150K-WA	23,015	7,769	21,428
OL-B150K-3	31,125	6,893	20,112

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-15. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)**	Worst run for the Olympia Coast National Marine Sanctuary*,**	Worst run for GRPs*
OL-B150K-N	72,571	310,252	40,994
OL-B150K-Fed	65,976	284,872	33,969
OL-B150K-WA	58,046	315,733	38,297
OL-B150K-3	63,004	292,285	36,628

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area and so more birds.

Table II.10-16. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	34	108	26
OL-B150K-Fed	34	101	25
OL-B150K-WA	33	109	26
OL-B150K-3	32	103	25

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-17. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.08 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K-Fed	-	-	-
OL-B150K-WA	-	-	-
OL-B150K-3	-	-	-

Table II.10-18. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	95	84	143
OL-B150K-Fed	93	84	114
OL-B150K-WA	88	83	113
OL-B150K-3	90	81	112

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.10-19. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	30,341	9,556	23,296
OL-B150K-Fed	28,844	10,481	18,936
OL-B150K-WA	23,868	11,538	23,119
OL-B150K-3	31,046	10,833	22,988

* Differences between runs are less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact more shoreline and so more intertidal invertebrates.

Table II.10-20. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary**	Worst run for GRPs*
OL-B150K-N	30,435	9,640	23,438
OL-B150K-Fed	28,938	10,565	19,050
OL-B150K-WA	23,955	11,620	23,233
OL-B150K-3	31,136	10,914	23,099

* Differences between runs are less than the randomized variability in the model and are not significant.
**Booms deflecting oil away from sensitive shorelines cause oil to remain at sea for a longer time period, resulting in greater entrainment in the water column.

Table II.10-21. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	302	1,448	178
OL-B150K-Fed	287	1,330	163
OL-B150K-WA	268	1,466	172
OL-B150K-3	269	1,363	167

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-22. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	56.6	271.4	33.4
OL-B150K-Fed	53.7	249.1	30.6
OL-B150K-WA	50.3	274.8	32.3
OL-B150K-3	50.4	255.5	31.4

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-23. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	189	905	111
OL-B150K-Fed	179	831	102
OL-B150K-WA	168	916	108
OL-B150K-3	168	852	105

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-24. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary*	Worst run for GRPs*
OL-B150K-N	22.5	108.1	13.3
OL-B150K-Fed	21.4	99.2	12.2
OL-B150K-WA	20.0	109.4	12.8
OL-B150K-3	20.1	101.7	12.5

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.10-25. Summary of results for alternate response scenarios for Outer Coast-Sea Lanes spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	196.3	176.8	191.8
OL-B150K-Fed	194.5	176.0	191.1
OL-B150K-WA	191.8	173.3	189.6
OL-B150K-3	190.3	172.4	189.3

II.11. COMPARISON OF ALTERNATIVE RESPONSES: GRAYS HARBOR – BUNKER C

The results of the alternate response scenarios for this location and oil are summarized in this section. More detailed results are in Volume XXIX, and discussion of the results is in Volume I. For the alternate response scenarios, the following 3 representative runs were selected from the 100 stochastic runs assuming no response and rerun with each set of response assumptions. The individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Willapa Bay; and
3. the worst case run for impacts for sensitive locations identified in Geographic Response Plans (GRPs).

Table II.11-1. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass coming ashore (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	77.2	73.7	75.6
GH-B25K-Fed	69.2	71.8	74.1
GH-B25K-WA	56.4	67.6	71.8
GH-B25K-3	44.8	63.2	68.9

Table II.11-2. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass settling to sediments (in subtidal and extensive intertidal habitats, %).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	14.9	28.0	27.9
GH-B25K-Fed	14.5	30.3	24.7
GH-B25K-WA	10.5	23.8	23.2
GH-B25K-3	10.4	23.5	20.3

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.

Table II.11-3. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	0.8	1.3	2.9
GH-B25K-Fed	0.7	1.3	2.7
GH-B25K-WA	0.5	1.1	2.6
GH-B25K-3	0.5	1.1	2.3

Table II.11-4. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Percent of spilled hydrocarbon mass mechanically removed (%).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K-Fed	9.8	3.8	6.4
GH-B25K-WA	25.8	8.4	11.1
GH-B25K-3	42.5	14.2	15.5

Table II.11-5. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	59	121	46
GH-B25K-Fed	57	120	32
GH-B25K-WA	55	117	27
GH-B25K-3	51	112	27

Table II.11-6. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	59	121	46
GH-B25K-Fed	57	120	32
GH-B25K-WA	55	117	27
GH-B25K-3	51	111	27

Table II.11-7. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	2,027	1,198	1,394
GH-B25K-Fed	1,948	942	1,201
GH-B25K-WA	1,588	1,026	878
GH-B25K-3	1,070	979	868

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.11-8. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline length (km) oiled by > 100 g/m2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	1,988	1,156	1,276
GH-B25K-Fed	1,948	903	1,122
GH-B25K-WA	1,548	948	878
GH-B25K-3	1,070	898	868

* Differences between alternative response runs are less than the randomized variability in the model and are not significant.

Table II.11-9. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)**	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	1,101,200	712,040	795,000
GH-B25K-Fed	1,140,500	317,440	592,740
GH-B25K-WA	867,850	519,700	238,780
GH-B25K-3	511,270	483,180	278,110

*Differences between runs are, for some comparisons, less than the randomized variability in the model and are not significant.
** The booms may deflect oil away from sensitive areas. This oil then becomes more dispersed, allowing it to impact a larger area when it does come ashore (unless additional cleanup removes it).

Table II.11-10. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	925,720	486,180	598,550
GH-B25K-Fed	807,930	624,770	608,100
GH-B25K-WA	719,900	506,590	639,370
GH-B25K-3	559,030	496,100	589,930

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-11. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Cost (in millions of 2003$) for shoreline cleanup (per area costs only).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	217.9	115.5	138.8
GH-B25K-Fed	202.4	107.9	128.8
GH-B25K-WA	169.7	106.3	109.4
GH-B25K-3	120.5	102.7	105.2

Table II.11-12. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of waterfowl oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay	Worst run for GRPs*
GH-B25K-N	-	4,658	-
GH-B25K-Fed	-	4,543	-
GH-B25K-WA	-	4,230	-
GH-B25K-3	-	3,648	-

* Injuries to waterfowl were not significant for this run.

Table II.11-13. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of seabirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	1,835	3,071	1,561
GH-B25K-Fed	1,789	3,047	1,271
GH-B25K-WA	1,745	2,981	1,169
GH-B25K-3	1,664	2,859	1,163

Table II.11-14. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of wading birds and shorebirds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	14,363	8,152	9,045
GH-B25K-Fed	14,071	6,261	7,899
GH-B25K-WA	11,082	6,595	6,076
GH-B25K-3	7,511	6,223	6,001

* Differences between alternate response runs are less than the randomized variability in the model and are not significant.

Table II.11-15. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of birds oiled.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	16,197	15,881	10,606
GH-B25K-Fed	15,859	13,851	9,170
GH-B25K-WA	12,827	13,806	7,246
GH-B25K-3	9,176	12,730	7,164

Table II.11-16. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total number of mammals oiled.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay	Worst run for GRPs*
GH-B25K-N	2	4	2
GH-B25K-Fed	2	4	2
GH-B25K-WA	2	3	2
GH-B25K-3	2	3	2

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-17. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Area (km^2) where dissolved aromatic concentration exceeds 1ppb (averaged over each grid cell and within some depth interval) at some time after the spill (An entry "-" indicates the area is less than a grid cell size of 0.04 km^2.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K-Fed	-	-	-
GH-B25K-WA	-	-	-
GH-B25K-3	-	-	-

Table II.11-18. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to subtidal fish and invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)*	Worst run for Willapa Bay*	Worst run for GRPs*
GH-B25K-N	12	13	16
GH-B25K-Fed	12	13	15
GH-B25K-WA	11	12	15
GH-B25K-3	11	12	15

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-19. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to intertidal invertebrates (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	20,168	11,811	13,030
GH-B25K-Fed	19,762	9,228	11,462
GH-B25K-WA	15,671	9,692	8,967
GH-B25K-3	10,737	9,228	8,880

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-20. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total impact (kg) to fish and invertebrates in subtidal and intertidal habitats (direct loss of biomass and future production foregone).

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay*	Worst run for GRPs
GH-B25K-N	20,180	11,824	13,045
GH-B25K-Fed	19,774	9,241	11,478
GH-B25K-WA	15,682	9,705	8,982
GH-B25K-3	10,748	9,240	8,894

* Differences between runs are less than the randomized variability in the model and are not significant.

Table II.11-21. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Compensatory restoration area (acres) assuming wetland (saltmarsh) creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	45.7	58.2	32.3
GH-B25K-Fed	44.7	53.6	27.5
GH-B25K-WA	38.0	52.7	22.8
GH-B25K-3	29.7	49.0	22.5

Table II.11-22. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	8.6	10.9	6.0
GH-B25K-Fed	8.4	10.0	5.1
GH-B25K-WA	7.1	9.9	4.3
GH-B25K-3	5.6	9.2	4.2

Table II.11-23. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Compensatory restoration area (acres) assuming eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	28.6	36.3	20.2
GH-B25K-Fed	27.9	33.5	17.2
GH-B25K-WA	23.7	32.9	14.2
GH-B25K-3	18.6	30.6	14.1

Table II.11-24. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (in millions of 2004$), assuming compensatory restoration is eelgrass bed creation.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	3.4	4.3	2.4
GH-B25K-Fed	3.3	4.0	2.0
GH-B25K-WA	2.8	3.9	1.7
GH-B25K-3	2.2	3.7	1.7

Table II.11-25. Summary of results for alternate response scenarios for Grays Harbor spills of crude oil: Total NRDA costs (millions of $), using WA Compensation Schedule.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for GRPs
GH-B25K-N	33.7	32.8	32.5
GH-B25K-Fed	32.6	32.7	31.1
GH-B25K-WA	31.5	32.6	30.2
GH-B25K-3	26.7	32.0	27.1

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 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D. S. Etkin (Environmental Research Consulting). The results are being evaluated by the WA Department of Ecology as part of their rulemaking process and cost-benefit analyses.

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

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

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

Nine spill scenarios were run in stochastic mode using combinations of seven spill locations (along transportation routes), 3 oil types (crude, bunker C fuel, and diesel) and response combinations including protective booming and mechanical removal. For each scenario, the model was run numerous times, randomly sampling environmental conditions during and after the spill. For each stochastic scenario, selected worst-case runs (of 100 randomly-selected events), in terms of environmental consequences, were examined in detail for NRDA, socioeconomic, and response costs. The runs with the most impact on selected sensitive sites or that oiled the most shoreline were selected. These 3 events were run with alternate response plans to evaluate the change in consequences resulting from different response implementations.

Specifications for the scenarios (amount, duration of release, etc.) were provided by the Department of Ecology based on Washington state planning standards, federal planning standards, and input from Stakeholders. The spill locations were along shipping routes in Washington state waters. Spill sites for each individual run were randomized along the designated route for that scenario. The oil types selected were those typically shipped (Alaska North slope crude and diesel fuel) or used to power vessels (Bunker C). The spill volumes were selected to be a relatively large spill, but of a size that would be handled primarily by the state rather than the federal government. The crude oil spills are all 250,000 bbl, the diesel spills are 65,000 bbl, and the Bunker C spills are 150,000 bbl or 25,000 bbl.

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

Because all impact indices are not necessarily correlated with shore cost, the 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. These are listed in the tables in the report, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard

deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Note that the response alters the resulting shoreline oiling and so different runs may become higher in shoreline impact if mechanical removal and booming are added to the scenario. In the results where alternative response options are examined, the individual run dates and times are held constant across alternate response scenarios so inter-comparisons may be made.

Table E-1 lists the scenarios examined. All the results are summarized in tables in Volume II, organized by location and oil type. The key results and discussion are described in Sections 4-6 of Volume I. Volume I also contains a description of the model used (Section 2), input data sources and assumptions (Section 3), and conclusions (Section 7).

Oil Recovery Rates

The Phase I modeling results, assuming recovery operations at the Effective Daily Recovery Capability (EDRC) rate, indicated that the mechanical removal capacities examined would be sufficient for cleaning up much of the spill volumes evaluated and could reduce impacts to biota and shorelines. However, the Phase I simulations assumed that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities. In addition, dispersant use, if performed with mechanical recovery, would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by the Phase I results.

In Phase II modeling, the mechanical recovery rates were adjusted to take into account inefficiencies in applying mechanical recovery methods as observed in many actual spill responses and as indicated by research done by experts in the field (Etkin, 2005b). The modeled removal rate decreased over time due to the spreading of the oil on the water surface and decreasing opportunities to effectively corral and remove oil. As a result, most of the removal would occur in the first 72 hours, and the percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations. However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in the Strait of Juan de Fuca and Grays Harbor. The capacity standards input to the model were larger relative to the spill volume for the 25,000 bbl bunker fuel scenarios than for those using the other two oil types or for the Outer Coast-Sea Lanes 150,000 bbl bunker fuel spill scenario. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Strait of Juan de Fuca or near/in Grays Harbor. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal

standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

Differences in Impacts with Alternative Response Scenarios

Because the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to “hold” oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

Because the differences in amounts of oil removed are small in the Phase II simulations, the differences between runs are in many cases less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. There are also figures in Section 4 of this volume (Figures 4-1 to 4-9) that summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

Potential Impacts of Spills for the Scenarios Examined

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

Table E-2 summarizes the shoreline oiling, listing the length of shore where cleanup would occur. The scenario run for the Straits of Juan de Fuca using diesel fuel resulted in the lowest percentage of spilled hydrocarbons eventually coming ashore. This reflects the fact that diesel is more volatile and soluble than the other types of oil that were modeled. While a high percentage of Bunker fuel typically hit the shore, the overall area affected by shoreline oiling was largest in spills of crude oil due to the greater volume of spilled crude that was modeled. Furthermore, locations where shipping routes are closer to land (i.e., San Juan Islands, the Lower and Upper Columbia River, and Grays Harbor) usually had a higher percentage of oil coming ashore.

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). Table E-3 summarizes the bird impacts. The highest level of bird mortality was seen in the outer coast region, because the oil remained at sea longer and there were higher abundance of birds there compared to other areas, such as in the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas.

Table E-4 shows that the mammal impacts are projected to be minor, with the exception of the outer coast and upper Columbia River scenarios. The mammals primarily impacted in the outer coast scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the upper Columbia River, the mammals impacted would be mostly muskrat and mink.

Table E-5 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations). Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for a larger volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water. The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

Impacts to intertidal invertebrates (Table E-6) were evaluated for geoducks, soft-shell clams, razor clams, and hard clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The impacts to clams are proportional to the shoreline area heavily oiled. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca, and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

The natural resource damages (Table E-7) were based on estimated costs to restore equivalent resources and/or ecological services. This is the preferred method used by natural resource trustees, based on guidance in the OPA regulations. The Washington Compensation Schedule is designed for small spills, much less than the volumes considered here. Habitat Equivalency Analysis (HEA) was used to estimate the required amount of habitat (saltmarsh) restoration for NRD compensation of injuries to wildlife, fish and invertebrate species. Production by the restored habitat ultimately benefits wildlife, fish and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results. According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds.

The changes in natural resource damages with different response alternatives were estimated by examining individual runs, holding spill conditions constant so comparisons can be made. In most scenarios, the difference between no mechanical removal and any of the mechanical removal capacity assumptions (state, federal or 3rd alternative) was less than the variability in the model. In some scenarios, the state mechanical response capacities were higher than the federal, and the 3rd alternative capacities were higher than the state's, so that the damages typically were higher for the federal and lower for the 3rd alternative than for the state standards. Variability in some of the results involving mechanical response was insignificant and due to the randomization routine employed to simulate natural dispersion.

Table E-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
OC-C250K-N	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	No Removal
OC-C250K-Fed	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	Federal Caps
OC-C250K-WA	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	WA Caps
OC-C250K-3	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	3rd Caps
JF-B25K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	No Removal
JF-B25K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	Federal Caps
JF-B25K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	WA Caps
JF-B25K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	3rd Caps
JF-D65K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	No Removal
JF-D65K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	Federal Caps
JF-D65K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	WA Caps
JF-D65K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	3rd Caps
JF-C250K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	No Removal
JF-C250K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	Federal Caps
JF-C250K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	WA Caps
JF-C250K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	3rd Caps

Table E-1 (cont.) Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
SJ-C250K-N	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	No Removal
SJ-C250K-Fed	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	Federal Caps
SJ-C250K-WA	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	WA Caps
SJ-C250K-3	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	3rd Caps
CL-B25K-N	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal
CL-B25K-Fed	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Federal Caps
CL-B25K-WA	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	WA Caps
CL-B25K-3	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	3rd Caps
CU-B25K-N	Upper Columbia River	Portland to Longview	Bunker C	25,000	No Removal
CU- B25K -Fed	Upper Columbia River	Portland to Longview	Bunker C	25,000	Federal Caps
CU- B25K -WA	Upper Columbia River	Portland to Longview	Bunker C	25,000	WA Caps
CU- B25K -3	Upper Columbia River	Portland to Longview	Bunker C	25,000	3rd Caps
OL-B150K-DESW1-N	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	No Removal
OL-B150K-DESW1-R-Fed	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait	Bunker C	150,000	Federal Caps

Scenario Name	Site	Location	Oil	bbls	Response
		of Juan de Fuca			
OL-B150K-DESW1-R-WA	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	WA Caps
OL-B150K-DESW1-R-3	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	3rd Caps
GH-B25K-N2	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	No Removal
GH-B25K-R-Fed	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	Federal Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	WA Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	3rd Caps

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

Table E-2. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,040	2,020	-	6,079
JF-Bunk-N	428	217	-	863
JF-Dies-N	588	481	-	1,550
JF-Crud-N	2,647	1,576	-	5,799
SJ-Crud-N	4,958	2,340	278	9,638
CL-Bunk-N	635	491	-	1,617
CU-Bunk-N	296	115	67	525
OL-Bunk-N	1,034	729	-	2,491
GH-Bunk-N	539	383	-	1,305

Table E-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	488,751	611,866	-	1,712,483
JF-Bunk-N	23,120	8,247	6,627	39,613
JF-Dies-N	31,010	13,852	3,306	58,714
JF-Crud-N	163,739	87,505	-	338,749
SJ-Crud-N	93,384	28,122	37,140	149,627
CL-Bunk-N	60,349	50,185	-	160,718
CU-Bunk-N	1,263	800	-	2,864
OL-Bunk-N	121,305	97,079	-	315,464
GH-Bunk-N	31,669	38,202	-	108,073

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	234.0	156.0	-	545.0
JF-Bunk-N	1.8	0.6	0.6	3.0
JF-Dies-N	2.4	1.3	-	5.1
JF-Crud-N	15.7	9.4	-	34.5
SJ-Crud-N	8.2	2.1	4.0	12.5
CL-Bunk-N	10.2	8.1	-	26.5
CU-Bunk-N	97.1	23.0	50.0	144.0
OL-Bunk-N	55.6	27.4	0.9	110.4
GH-Bunk-N	7.42	7.42	-	22.26

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,376	1,388	-	4,152
JF-Bunk-N	62	10	41	82
JF-Dies-N	49,500	29,488	-	108,476
JF-Crud-N	14,544	8,834	-	32,212
SJ-Crud-N	6,807	9,599	-	26,005
CL-Bunk-N	6	9	-	24
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	82	31	20	145
GH-Bunk-N	17	4	8	25

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,026	10,561	-	30,149
JF-Bunk-N	33,955	35,399	-	104,752
JF-Dies-N	28,928	41,555	-	112,038
JF-Crud-N	174,703	117,105	-	408,913
SJ-Crud-N	305,639	130,644	44,351	566,926
CL-Bunk-N	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-
OL-Bunk-N	7,986	6,753	-	21,492
GH-Bunk-N	5,181	3,769	-	12,718

Table E-7. Summary of results for all stochastic scenarios of 100 runs each: Total NRDA restoration costs (in millions of 2004$), assuming compensatory restoration is wetland creation.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	502	584	-	1,669
JF-Bunk-N	26	13	2.4	51
JF-Dies-N	82	51	3.3	184
JF-Crud-N	179	74	53	327
SJ-Crud-N	99	29	53	157
CL-Bunk-N	41	40	0	121
CU-Bunk-N	1.3	0.6	0.4	2.4
OL-Bunk-N	112	85	0.1	282
GH-Bunk-N	25	32	0.01	88

1. INTRODUCTION

As part of their rulemaking related to oil spill preparedness (Washington State Contingency Plan Rule), the Washington State Department of Ecology (WDOE) needs to evaluate the implications of various spill response options being considered. Oil spill fate and effects modeling and analysis was performed to estimate the impacts of potential spills in Washington's outer coast, sound and river environments, assuming various response options and operational timing and using conventional mechanical containment and recovery operations. US Coast Guard federal response capability standards, current Washington State standards, and potential theoretical higher response capability standards were simulated for scenarios involving spills of crude oil, bunker fuel and diesel into Washington waters in seven geographic locations: Strait of Georgia (near the San Juan Islands), Strait of Juan de Fuca, Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, Grays Harbor, and lower and upper Columbia River. These locations were selected to be representative of potential spill sites along transportation routes. The upper Columbia River was used to evaluate implications of spills into large rivers of similar dimensions and river flow.

The SIMAP (Spill Impact Model Application Package) model system, comprised of three-dimensional oil fate and biological effects models, was used for this study. The modeling was performed in probabilistic (stochastic) mode, randomly varying location along shipping routes, spill date, and time, and so environmental conditions during and after the release among potential conditions that would occur. The model results from these stochastic scenarios were analyzed to estimate mean, standard deviation, and 5th, 50th and 95th percentile results for surface water and shoreline oiling, water column and sediment contamination, biological impacts (to wildlife, fish, invertebrates, and habitats), and natural resource damages (NRD) for losses of ecological services. NRD costs were based on the Washington Compensation Schedule and the US Oil Pollution Act (OPA) NRD procedures involving compensatory restoration and associated costs. Response costs and socioeconomic damages were evaluated in a companion study by D.S. Etkin (Environmental Research Consulting; Etkin, 2005b,c; Etkin et al., 2006).

This report describes the approach, model, data inputs, and results of the second phase of modeling performed to support WDOE's rule development. The modeling analysis now described as Phase I is described in the draft report of that work (French McCay et al., 2004b), and an updated report available in November 2005 (French McCay et al., 2005b). Summaries of the Phase I model results are in French McCay et al. (2005b). In addition, Etkin (2004a,b) and Etkin et al. (2005, 2006) describe the response modeling assumptions used as inputs to the oil spill modeling, as well as the response and socioeconomic costs estimated to result from the scenarios evaluated as part of Phase I.

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

would be able to locate and reach that oil and recover it at the EDRC rate. With these assumptions, the model results indicated that up to 50-70% of the spilled oil would be recoverable. Moreover, the differences between the three alternative mechanical recovery standards were small because, with the high efficiencies assumed, the capacities were large enough in all three cases to eventually recover much of the oil.

However, in an actual spill response, there are a number of reasons why such high efficiencies and recovery rates would not be realized, including logistical problems, difficulty in tracking oil, breakdowns, etc. Thus, in Phase II of the modeling, reported here, increasing inefficiencies in recovery capability with time were built into the response model assumptions for all three alternative capacity standards. The response model assumptions for Phase II were developed by Dr. D. S. Etkin and WDOE, as described in Etkin (2005b) and Etkin et al. (2006). The inputs to the oil spill model are briefly summarized in Section 3.6 below.

Inputs to the oil spill model SIMAP include habitat and depth mapping, winds, currents, other environmental conditions, chemical composition and properties of the oils most likely to be spilled, specifications of the release (amount, location, etc.), toxicity parameters, and biological abundance. These model inputs were developed as part of Phase I. Descriptions of these data are contained in this Phase II report as well. Model results are displayed by a Windows graphical user interface that animates the trajectory and concentrations over time. The figures included here (Volumes II-XXIX) are snapshots taken from that output, synoptically (over time after the spill) showing the areas and volumes where oil or concentrations in the water would move if there were a spill of the assumed volume and conditions.

In Phase II, SIMAP was first run in stochastic mode for 9 scenarios assuming no response to estimate probabilities and degrees of oil exposure for each location in the vicinity of a spill. The output of the stochastic model includes time histories of a large number of spill trajectories. These distributions are used to (1) estimate the percent of these hypothetical spills where water surface, water column, and shoreline areas will be affected by a release; (2) determine the highest exposure concentration in time and for any possible environmental condition; and (3) identify the worst-case runs out of 100 randomly-selected events that either, had the most impact on selected sensitive sites or oiled the most shoreline.

For each of the 9 stochastic scenarios, 100 simulations were run for a given spill location (shipping route segment), oil and (no) response scenario, varying the spill date and time, and thus the environmental conditions, for each run. The results were sorted by degree of shoreline oiling, weighed by cleanup cost per unit area. The cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (the per area portion of the costs) are related to biological impacts on shorelines. Response and socioeconomic costs are also related to shoreline oiling. Thus, total costs related to a spill are for the most part related to degree of shoreline oiling.

In Phase II, the results for worst-case runs based on shore costs or impacts to selected sensitive sites were evaluated in detail. However, certain impacts, such as to waterfowl and seabirds, were more closely related to water surface oiled. Impacts to fish and invertebrates in the subtidal zone (below the low tide level) were related to water contaminated above a threshold for effects. Intertidal zone impacts to clams were related to degree of soft (sand, mud, or wetland) shoreline oiling. Because other impact indices were not necessarily correlated with shore cost, the results for other indices were not typically in increasing order from 5th to 95th percentile run by shore cost. The actual 5th, 50th and 95th percentile results for the 100 values of the index were calculated by sorting only the index being considered. The mean and standard deviation of the 100 results were also calculated. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

It should also be noted that the response alters the resulting shoreline oiling and so different runs become higher in shoreline impact if mechanical removal and booming are added to the scenario. When alternative response options were examined, the individual run dates and times were held constant across alternate response scenarios so inter-comparisons could be made.

Table 1-1 lists the scenarios examined in Phase II. The 9 stochastic scenarios are those with no response assumed. The other scenarios were run for selected runs by altering the response assumed from the no-response base run. Thus, only the 3 runs were examined in the alternate scenarios. Figures 1-1 to 1-3 show the hypothetical spill locations examined.

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed.

Scenario Name	Site	Location	Oil	bbls	Response
OC-C250K-N	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	No Removal
OC-C250K-Fed	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	Federal Caps
OC-C250K-WA	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	WA Caps
OC-C250K-3	Outer Coast	Duntz Rock NW Cape Flattery	ANS crude	250,000	3rd Caps
JF-B25K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	No Removal
JF-B25K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	Federal Caps
JF-B25K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	WA Caps
JF-B25K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Bunker C	25,000	3rd Caps
JF-D65K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	No Removal
JF-D65K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	Federal Caps
JF-D65K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	WA Caps
JF-D65K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	Diesel	65,000	3rd Caps
JF-C250K-N	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	No Removal
JF-C250K-Fed	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	Federal Caps
JF-C250K-WA	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	WA Caps
JF-C250K-3	Strait of Juan de Fuca	Neah Bay to south end Lopez Island	ANS Crude	250,000	3rd Caps

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed (continued).

Scenario Name	Site	Location	Oil	bbls	Response
SJ-C250K-N	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	No Removal
SJ-C250K-Fed	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	Federal Caps
SJ-C250K-WA	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	WA Caps
SJ-C250K-3	San Juan Islands	Rosario Str/Georgia Str south Lopez Island to off Cherry Point	ANS crude	250,000	3rd Caps
CL-B25K-N	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	No Removal
CL-B25K-Fed	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	Federal Caps
CL-B25K-WA	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	WA Caps
CL-B25K-3	Lower Columbia River	3 miles off mouth Columbia River to Astoria	Bunker C	25,000	3rd Caps
CU-B25K-N	Upper Columbia River	Portland to Longview	Bunker C	25,000	No Removal
CU- B25K -Fed	Upper Columbia River	Portland to Longview	Bunker C	25,000	Federal Caps
CU- B25K -WA	Upper Columbia River	Portland to Longview	Bunker C	25,000	WA Caps
CU- B25K -3	Upper Columbia River	Portland to Longview	Bunker C	25,000	3rd Caps
OL-B150K-DESW1-N	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	No Removal
OL-B150K-DESW1-R-Fed	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	Federal Caps

Table 1-1 Oil spill modeling scenarios: Scenario names by location, oil type, volume, and response assumed (continued).

Scenario Name	Site	Location	Oil	bbls	Response
OL-B150K-DESW1-R-WA	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	WA Caps
OL-B150K-DESW1-R-3	Outer Coast-Sea Lanes	3 miles from shore from entrance of Grays Harbor to entrance of Strait of Juan de Fuca	Bunker C	150,000	3rd Caps
GH-B25K-N2	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	No Removal
GH-B25K-R-Fed	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	Federal Caps
GH-B25K-R-WA	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	WA Caps
GH-B25K-R-3	Grays Harbor	3miles off Grays Harbor entrance to entrance of harbor	Bunker C	25,000	3rd Caps

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

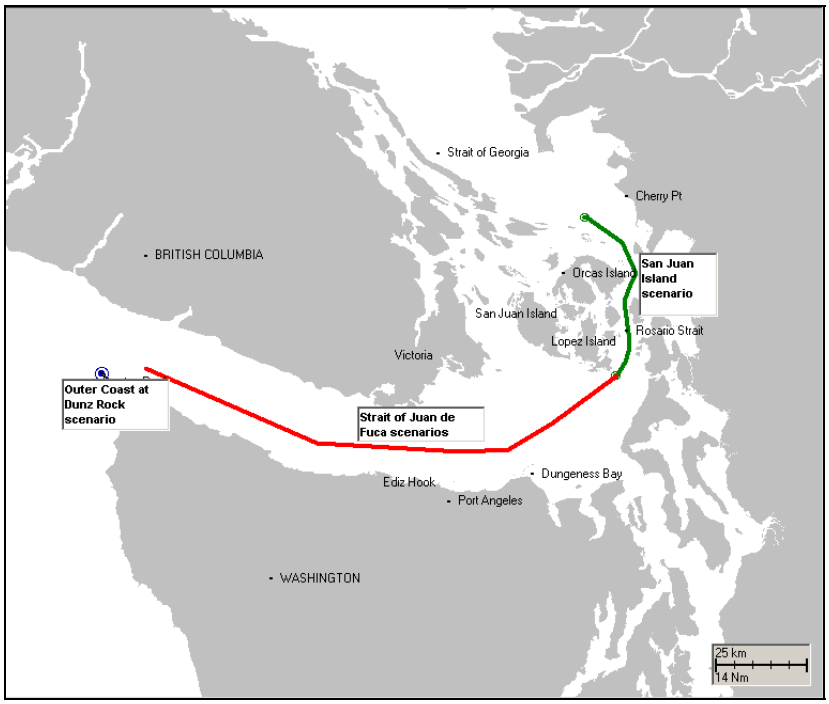


Figure 1-1. Shipping route segments where the hypothetical spills are assumed to occur: Straits and Outer Coast at Duntz Rock scenarios.

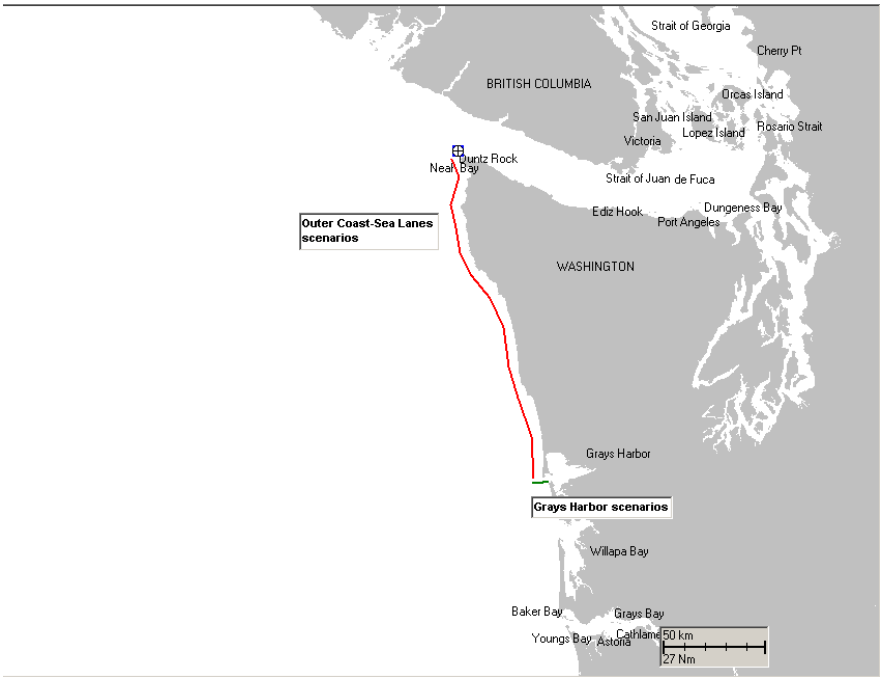


Figure 1-2. Shipping route segments where the hypothetical spills are assumed to occur: Outer Coast-Sea Lanes and Grays Harbor scenarios.

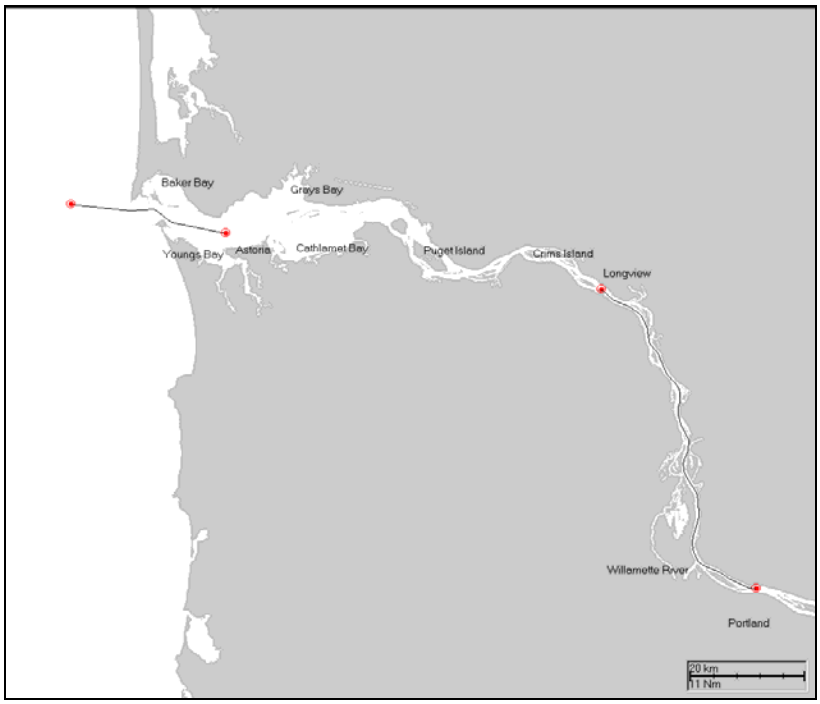


Figure 1-3. Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

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

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

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

Section 2 describes the model used for both the Phase I and the Phase II analyses. Section 3 describes the model input data sources and assumptions (again, the same in both Phase I and II, with the exception of the response scenario assumptions and some of the spill volumes and locations). Thus, Sections 2 and 3 are very similar to the description in the Phase I report (Volume I of French McCay et al, 2004b, 2005b), with the exception of Section 3.6, which describes the scenarios simulated.

The Phase II results are described in Sections 4-7. Results of the physical fates model are in Section 4. Section 5 describes the biological impact results. Estimates of economic damages (NRDA costs) based on restoration of resources and their services are in Section 6. Discussion and conclusions are in Section 7, including a comparison of the Phase I and II results. Section 8 contains the references cited.

Details of the model input data and results for Phase II are in appended volumes to this main report, organized as follows. Volume II contains summary tables for all 28 scenarios. Volumes III to XXIX contain specific results for each location and oil type combination, in sets of 3 volumes: (1) model inputs, (2) results for stochastic model scenarios, and (3) results for alternate response scenarios.

2. SIMAP MODEL DESCRIPTION

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

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

While the NRDAM/CME was developed for simplified natural resource damage assessments of small spills in the United States, SIMAP is designed to evaluate fates and effects of both real and hypothetical spills in marine, estuarine and freshwater environments worldwide. SIMAP may be run in stochastic mode to evaluate a distribution of spill results, rather than just a single result for a specific hind-cast. Additions and modifications to prepare SIMAP were made to increase model resolution, allow modification and site-specificity of input data, allow incorporation of temporally varying current data, evaluate subsurface releases and movements of subsurface oil, track multiple chemical components of the oil, enable stochastic modeling, and facilitate analysis of results.

The consideration of the impacts of subsurface oil is important, particularly in the evaluation of impacts on aquatic organisms. Surface floating oil primarily impacts wildlife and intertidal biota, and not aquatic biota in subtidal habitats. At higher wind speeds than about 12 knots (or at lower wind speeds if dispersant is applied), oil will entrain into the water column, unless it has become too viscous to do so after weathering and the formation of mousse. Once oil is entrained in the water in the form of small droplets, monoaromatics (MAHs) and polynuclear aromatic hydrocarbons (PAHs) dissolve into the water column. The dissolved MAHs and PAHs are the most bioavailable and toxic portion of the oil. The dissolution rate is very sensitive to the droplet size (because it involves mass transfer across the surface area of the droplet), and the amount of hydrocarbon mass dissolved is a function of the mass entrained and droplet size distribution. These are in turn a function of soluble hydrocarbon content of the oil, the amount of evaporation of these components before entrainment, oil viscosity (which

increases as the oil weathers and emulsifies), oil surface tension (which may be reduced by surfactant dispersants), and the energy in the system (the higher the energy the smaller the droplets). Large droplets (greater than a few hundred microns in diameter) resurface rapidly, and so dissolution from those is also inconsequential. Dispersant application facilitates the entrainment of oil into the water in a smaller size distribution than would occur naturally, with the median droplet size about 20 μm (Lunel, 1993a,b).

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

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

2.1 Physical Fates Model

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

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

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

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

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

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

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

This number of components provides sufficient accuracy for the evaporation and dissolution calculations, particularly given the time frame (minutes) over which dissolution occurs from small droplets and the rapid resurfacing of large droplets (see discussion above). The alternative of treating oil as a single compound with empirically-derived rates (e.g., Mackay et al, 1980; Stiver and Mackay, 1984) does not provide sufficient accuracy for impact analyses because the impacts to water column organisms are caused by MAHs and PAHs, which have specific properties that differ from the other

volatile and soluble compounds. Use of more pseudo components does not improve accuracy, as the major constituents of concern are well characterized (sufficiently similar in properties within the pseudo-component group of chemicals) by the modeled component properties used in SIMAP. The model has been validated both in predicting dissolved concentrations and resulting toxic effects, supporting the adequacy of the use of this number of pseudo-components (French McCay, 2003).

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

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

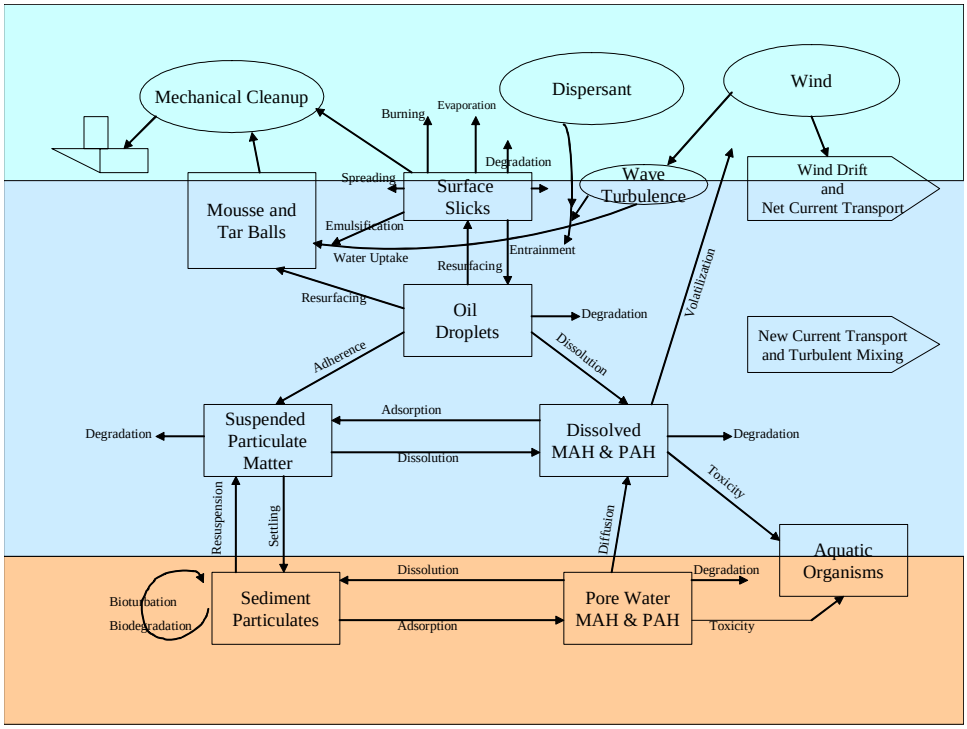


Figure 2-1. Simulated oil fates processes in open water

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

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

The dissolved aromatic hydrocarbon concentration in the water column is calculated from the mass in the Lagrangian elements, as follows. Concentration is contoured on a three-dimensional Lagrangian grid system. This grid (of 200 X 200 cells in the horizontal and 5 vertical layers) is scaled each time step to just cover the volume occupied by aromatic particles, including the dispersion around each particle center. This maximizes the resolution of the contour map at each time step and reduces error caused by averaging mass over large cell volumes. Distribution of mass around the particle center is described as Gaussian in three dimensions, with one standard deviation equal to twice the diffusive distance ($2D_xt$ in the horizontal, $2D_zt$ in the vertical, where D_x is the horizontal and D_z is the vertical diffusion coefficient, and t is particle age). The plume grid edges are set at one standard deviation out from the outer-most particle. These data are used by the biological effects model to evaluate exposure, toxicity and impacts.

2.2 Biological Effects Model

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

The area potentially affected by the spill is represented by a rectangular grid with each grid cell coded as to habitat type. The habitat grid is also used by the physical fates

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

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

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

2.2.1 Wildlife

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

A portion of the wildlife in the area swept by the slick over a threshold thickness is assumed to die, based on probability of encounter with the slick multiplied by the probability of mortality once oiled. The probability of encounter with the slick is related to the percentage of the time an animal spends on the water or shoreline surface. The

probability of mortality once oiled is nearly 100% for birds and fur-covered mammals (assuming they are not successfully treated) and much lower for other wildlife. The products of the two probabilities for various wildlife behavior groups are in Table 2-2. Estimates for the probabilities are derived from information on behavior and field observations of mortality after spills (reviewed in French et al., 1996a). The threshold thickness of oil for inducing mortality at a given probability is 10 micron (~10g/m^2), based on data and calculations in French et al. (1996a). The wildlife mortality model has been validated with more than 20 case histories, including the *Exxon Valdez* and other large spills, verifying that these values are reasonable (French and Rines, 1997; French McCay 2003, 2004; French McCay and Rowe, 2004).

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

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

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

2.2.2 Fish and Invertebrates

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

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

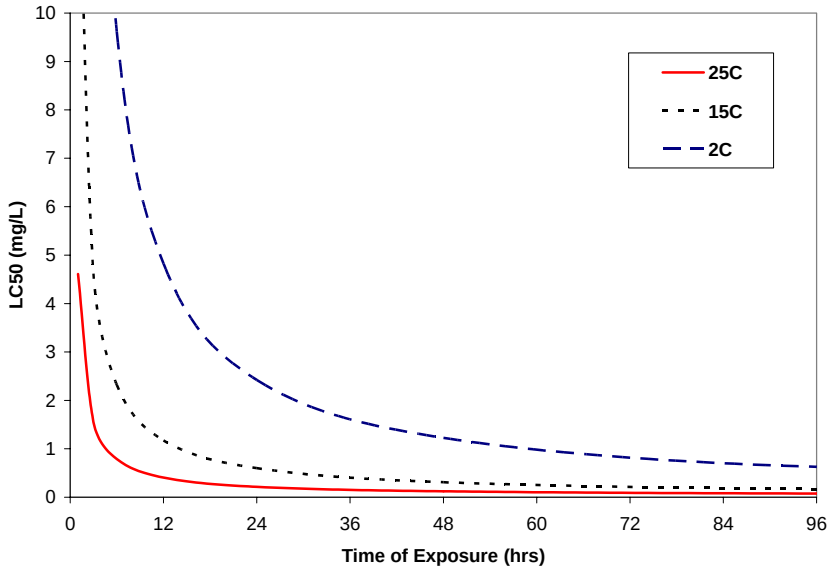


Figure 2-2. LC50 of dissolved PAH mixtures from oil, as a function of exposure duration and temperature.

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

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

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

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

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

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

2.2.3 Validation of the Biological Effects Model

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

2.2.4 Quantification of Fish and Invertebrate Impacts as Lost Production

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

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

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

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

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

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

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

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

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

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

addition to the prey animals directly killed. This may be accomplished by providing additional prey production to compensate for the direct predator loss.

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

2.3 Stochastic Modeling

2.3.1 Approach

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

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

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

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

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

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

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

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

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

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

Table 2-3 lists biological resource categories and the exposure measures used to develop linear regressions for each group. Impacts to wildlife (birds and marine or aquatic mammals) and subtidal fish and invertebrates were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions for all scenarios except the Outer Coast – Sea Lanes and Grays Harbor;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions for the Outer Coast – Sea Lanes and Grays Harbor scenarios only;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines for all scenarios except the Outer Coast – Sea Lanes and Grays Harbor (nearly all shoreline impacts were in Washington for these scenarios);
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by >10g/m^2, which is the threshold thickness for oiling wildlife with a lethal dose.

The individual runs were for specific spill dates, using the abundances for the appropriate season. As impacts are proportional to pre-spill abundance, the wildlife results were corrected to be for an annual mean abundance using the ratio of annual mean to seasonal abundance before the regression slope and intercept were calculated. This correction was not made for fish and invertebrates as the results are not directly proportional because of the differences in distribution of young-of-the-year and older age classes.

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

Resource	**Exposure Measure**
Waterfowl	Water surface area swept by > 10 g/m^2 of oil and wetland area oiled by > 100 g/m^2
Seabirds	Water surface area swept by > 10 g/m^2 of oil
Raptors	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Cetaceans	Water surface area swept by > 10 g/m^2 of oil (open waters only)
Pinnipeds (seals)	Water surface area swept by > 10 g/m^2 of oil
Other mammals	Water surface area swept by > 10 g/m^2 of oil (nearshore and wetland)
Wading birds	Wetland and soft shoreline area oiled by > 100 g/m^2
Shorebirds	Wetland and soft shoreline area oiled by > 100 g/m^2
Fish and invertebrates in water or on bottom, plankton	Maximum percentage of oil in the water column at any time after the spill
Benthic biota (in the sediments)	Sediment concentrations (>1 ppb dissolved aromatic concentration in pore water)

The regression slopes and intercepts were used to estimate the impacts for all 100 runs of the stochastic model scenarios. The regressions were also used to estimate the biological impacts for all runs of the alternative response scenarios. Also, the mean and standard deviation of impacts on biological resources were reported along with 95% confidence intervals, which were calculated by adding or subtracting two standard deviations from the mean.

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

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

3. MODEL INPUT DATA

3.1 Geographical and Model Grid

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

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

Model grids were constructed for each spill location (i.e., shipping route segment), sized just large enough to include areas where oil would be transported after a spill. The grids were divided into as many cells as possible (within memory limits of the computer for the model code) to obtain the maximum resolution. The gridded habitat type data are shown in Section B.2 of Volumes III, VI, IX, XII, XV, XVIII, XXI, XXIV, and XXVII. The grid scale resolution and dimensions are indicated in Table E-3 of each volume.

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

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

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

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

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

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

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

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

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

3.2 Environmental Data

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

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

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

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

significant at about 100 mg/L suspended sediment concentration. There is no indication that high suspended sediment concentrations would occur in any of the areas where spills were simulated.

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

3.3 Currents

3.3.1 Tidal and Other Currents

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

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

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

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

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

Existing sources of current data were considered for the oil spill modeling of the Strait of Juan de Fuca, outer coast at Duntz Rock and Columbia River scenarios. However, we need to model spills for sample dates from at least a decade, with the tidal and other forces for those dates, and in high resolution in the area of the spill site. Thus, we applied BFHYDRO, and compared the predictions to existing current data, as well as National Oceanic and Atmospheric Administration tidal predictions, as part of the calibration and verification of the hydrodynamic model results. The ASA model also is compatible with the oil trajectory model SIMAP and does not require a data processing step to input the current data to SIMAP.

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

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

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

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

3.3.1.2 San Juan Islands Scenario

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

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

3.3.1.3 Outer Coast-Sea Lanes and Grays Harbor Scenarios

The barotropic hydrodynamic model, HYDROMAP (Isaji et al., 2002) was used to obtain the depth-averaged tidal currents in this study. HYDROMAP is a globally re-locatable hydrodynamic model, capable of simulating complex circulation patterns due to tidal forcing and wind stress. HYDROMAP operates over a spatially-nested, rectangular, grid that may have up to six step-wise changes in resolution in the horizontal plane. The spatial nesting capability allows the model resolution to step up as land or complex bathymetry is approached. HYDROMAP has been recently applied to study the tidal circulation in South China Sea, northeast coast of US (Isaji et al., 2001) and Moreton Bay, Australia (Zigic et al, 2003). The spatial nesting of the grid provided the hydrodynamic model with a good resolution on the offshore and a fine resolution near the coast, especially in Grays Harbor, Grays Bay, and Willapa Bay. The grid used in this study consisted of 22,200 active water cells, with cell size varying from 5 km x 5 km in the off-shore to about 625 m x 625 m near the coast. The tidal forcing for the 5 major harmonic constituents (M_2, S_2, N_2, K_1, and O_1), derived from the Global Ocean Tidal Model (TPOX5.1) developed at the Oregon State University (Egbert et. al. 1994), was applied along the offshore open boundaries.

Seasonal components (climatic winter and summer) of the offshore currents for the present study were assembled from results of the three-dimensional hydrodynamic simulations from a high-resolution global ocean circulation model, Parallel Ocean

Program (POP). The time-averaged daily outputs of the results from POP, for the global ocean at a horizontal resolution of 1/6 degree, forced by observed temperature and wind stress during 1985-1995 (Maltrud et al., 1998), was used to obtain the seasonally averaged currents used in the present study. The seasonal currents thus assembled from POP compared well with a schematic of the large-scale boundary currents off the US west coast given in Hickey (1998).

3.3.2 Wind-driven Surface Currents

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

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

Youssef and Spaulding (Youssef, 1993; Youssef and Spaulding, 1993, 1994) developed a set of equations to describe the percent of wind speed and angle as functions of wind speed and depth in the water. This algorithm has been incorporated into SIMAP. The wind drift is applied to the upper 5 meters of the water column. The SIMAP algorithm was validated with observations of the drift of floating fuel and bitumen in surface water after an intentional (test) Orimulsion spill (French et al., 1997). This Youssef and Spaulding algorithm was used in model runs for surface wind drift.

3.4 Oil Properties, Toxicity, and Impact Thresholds

The oil types modeled were crude oil, Bunker C (heavy fuel oil), and diesel (light fuel oil). Physical and chemical data on the oils were taken from the NRDAM/CME database (French et al., 1996b) and the Environment Canada catalogue of crude oil and oil product properties (Whiticar et al., 1992; Jokuty et al., 1996, 1999). PAH concentrations were based on data in French McCay (2002) or Lee et al. (1992); MAH concentrations were from Jokuty et al. (1996, 1999) or Wang et al. (1995); and the volatile aliphatic concentrations were calculated from boiling curves (in Jokuty et al. 1996, 1999), subtracting the volatile aromatics. The volatile aliphatics are evaporated and volatilize from the surface water and so their mass is accounted for in the overall mass balance.

However, as they do not dissolve in significant amounts, they have no influence on the biological effects on water column and benthic organisms. Minimum oil slick thickness was assumed 1 mm, based on McAuliffe (1987). Properties assumed in the modeling are in Section D of Volumes III, VI, IX, XII, XV, XVIII, and XXI.

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

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

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

3.4.1 Whole oil

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

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

Whole oil droplets in the water column may affect fish and invertebrates by interfering with feeding or clogging gills. However, data quantifying a threshold level for effects has not been identified. A conservative threshold of 10 ppb for fish and invertebrates was used in the modeling as a minimum for inclusion in model outputs. This level is based on literature reviewed by Markarian et al. (1993) and French et al. (1996a).

3.4.2 Low molecular weight aromatics

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

percentage of PAHs has a significant influence on the model results. Thus, data for well-defined oils were used in the model runs, and the LC50s assumed were for total dissolved PAH concentrations in the water ($LC50_{mix}$).

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

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

3.4.3 Toxicity Thresholds of Concern

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

The model results show that the duration of water column exposures are on the order of hours. Thus, the exposures are acute rather than long-term, and the LC50 for infinite exposure time is very conservative in considering potential for effects. Sublethal effects would also be expected to vary by duration of exposure. Table 3-3 lists acute toxicity values for soluble fuel components in oil, and for sensitive (5th percentile) and average (50th percentile) species, at different durations of exposure at $25^{o}C$ (based on equations in French McCay, 2002). The LC50s for short exposure times are higher at colder temperatures (Figure 2-2).

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

The thresholds for effects were used in the stochastic model analysis to determine potential for impacts and the needed duration of model simulations. In the individual

model runs and biological model analysis, the LC50 is corrected for temperature and time of exposure.

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

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

3.5 Shoreline Oil Retention

Retention of oil on a shoreline depends on the shoreline type, width and angle of the shoreline, viscosity of the oil, the tidal amplitude, and the wave energy. In the NRDAM/CME (French et al., 1996a,b,c), shore holding capacity was based on observations from the *Amoco Cadiz* spill in France and the *Exxon Valdez* spill in Alaska (based on Gundlach (1987) and later work summarized in French et al., 1996a). These data are used here (Table 3-4). The shore width (intertidal zone width where oiling would occur) varies by shore type, based on the typical slope of the shore type and the average tide range. The shore widths were developed by French et al. (1996a) and used here.

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

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

3.6 Scenarios

Table 1-1 lists the scenarios examined, including 9 main stochastic scenarios and 27 alternate response scenarios for selected worst-case runs (i.e., most impact on sensitive sites and the largest amount of shoreline oiled) in the main stochastic scenario base case. Figures 1-1 and 1-2 show the hypothetical spill locations examined. For scenarios involving Alaskan North Slope crude oil, the spill volume is assumed to be 250,000 bbl; the spill volume for the diesel is 65,000 bbl, and for Bunker C fuel spills, the spill volumes are either 150,000 bbl (for the Outer Coast – Sea Lanes scenario) or 25,000 bbl (for scenarios related to shipping into harbors). All spills were assumed to be at or near the water surface and over 4 hours. In the upper Columbia River scenario and the Juan de Fuca scenario involving diesel fuel, the model was run for 4 weeks and 2 weeks, respectively, by which time most of the oil came ashore or dispersed. In all other scenarios, a 56-day model duration was used.

Specifics of the spill response scenarios were developed by Etkin (2005b) and Etkin et al. (2006) based on state and federal planning standards and assumptions provided by WDOE. In all scenarios, *excluding* no response, protective booming was included. The mechanical removal capacities were assumed to be one of three options (when included in the scenario), in increasing order of capacity: (1) US Coast Guard federal response capability standards, (2) current Washington State standards, and (3) a theoretical higher response capability, which is referred to as the third alternative throughout this report.

Modeled response capabilities for mechanical containment and recovery for each of the scenarios was based on the location type-specific response capability standard or guideline as described in Etkin (2005b) and Etkin et al. (2006). In the modeling, protective booms were located at sensitive areas as indicated in Geographic Response Plans (GRPs) according to the schedule of booming in the appropriate standards. It was assumed that enough boom was available to make the modeled placements at the times required and that the placements were performed successfully according to the plan. In Phase II, protective booms were assumed to have an effectiveness (keeping oil out) of 80% as opposed to 100% as assumed in Phase I (French McCay et al. 2004b), i.e., in Phase II modeling it is assumed that there would be some errors in deployment and boom condition, as would be seen in many actual applications in the field.

The Phase II mechanical recovery modeling (Etkin, 2005b; Etkin et al., 2006)) involved simulating (1) only the capacities of the *response planning standards* (not all equipment that might be used in a large spill such as those examined), (2) the decreasing efficiency of oil removal as time goes on and oil spreads making it more difficult to locate and recover, and (3) changes in the timing and capacities of removal activities only in the first 96 hours after the spill. Mechanical removal *from the water surface* was assumed to occur and be accomplished at the rates (EDRC rate times a reduction in efficiency that increases over time) in Tables 3-5 to 3-12 in the time intervals listed, as long as:

(1) oil was on the water surface in the designated area(s) in the time interval;
(2) current speed at the oil location did not exceed 1 knot (evaluated each time step) ;

(3) wave heights (calculated for each oil spillet and time step from wind speed, duration and fetch [distance upwind to land], using the algorithms in CERC, 1984) did not exceed 3 feet;
(4) oil on the water surface was of sufficient thickness for effective containment and skimming operations (13 microns, based on API, et al. 2001)

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

Note that the response requirements are based not on the spill volume but on the potential worst-case discharge (total release of oil cargo/fuel) from the hypothetical vessel involved (tankers or barges). This is the way in which both the state and federal response capability standards have been developed. There is a maximum capacity ("cap") at which the amount of equipment is not required to increase regardless of any increase in worst-case discharge size. (Note that the equipment amounts are cumulative, e.g., if at 24 hours there is 12,500 bpd recovery and 25,000 bpd is required at 48 hours, an additional 12,500 bpd worth of equipment arrives by 48 hours.)

Table 3-5. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Outer Coast at Duntz Rock Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			12,000
6			12,000
12			12,000
15		36,000	36,000
24	12,500	48,00	48,000
48	25,000	60,000	60,000

Table 3-6. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 25,000 bbl Bunker (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12	6,483	3,087	9,261
15	6,483	7,408.8	12,348
24	10,805	7,408.8	12,348
48	10,805	10,495.8	15,435

Table 3-7. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait of Juan de Fuca Spill 65,000 bbl Diesel (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			36,000
6		12,000	36,000
12	12,500	36,000	48,000
15	12,500	48,000	60,000
24	25,000	48,000	60,000
48	25,000	60,000	72,000

Table 3-8. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Strait Juan de Fuca Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			
6		5,000	12,500
12	12,500	12,500	37,500
15	12,500	30,000	50,000
24	25,000	30,000	50,000
48	25,000	42,500	62,500

Table 3-9. Modeled mechanical Spill Response Capability (bbl/day recovery rate): San Juan Islands Spill 250,000 bbl ANS Crude (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			
6		5,000	12,500
12	12,500	12,500	37,500
15	12,500	30,000	50,000
24	25,000	30,000	50,000
48	25,000	42,500	62,500

Table 3-10. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Columbia River Spill 25,000 bbl Bunker (Etkin, 2005b).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12		3,087	9,261
15	5,186	7,408.8	12,348
24	5,186	7,408.8	12,348
48	6,915	10,495.8	15,345

Table 3-11. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Outer Coast-Sea Lanes Spill 150,000 bbl Bunker (Etkin et al., 2006).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			12,000
6			12,000
12			12,000
15		36,000	36,000
24	12,500	48,000	48,000
48	25,000	60,000	60,000

Table 3-12. Modeled mechanical Spill Response Capability (bbl/day recovery rate): Grays Harbor Spill 25,000 bbl Bunker (Etkin et al., 2006).

Hour After Spill	Federal	State (WA)	3rd Alternative
2			
4			3,087
6		1,234.8	3,087
12	6,483	3,087	9,261
15	6,483	7,408.8	12,348
24	10,805	7,408.8	12,348
48	10,805	10,495.8	15,435

3.7 Biological Abundance

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

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

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

The NRDAM/CME (French et al., 1996c) contains mean seasonal or monthly abundances for 77 biological provinces in US coastal and marine waters. The biological data for wildlife, fish, invertebrates and lower trophic levels in the province of the spill are used for the SIMAP simulations in the lower Columbia River (province 48 in the NRDAM/CME), outer coast (province 49 in the NRDAM/CME, for Outer Coast at Duntz Rock, Outer Coast – Sea Lanes, and Grays Harbor scenarios) and Strait of Juan de Fuca and San Juan Islands area (province 51 in the NRDAM/CME) areas.

The bird densities for NRDAM/CME province 49 were updated for common murre abundance using data from Thompson (1999), which surveyed marbled murrelets and common murres on the outer coast of Washington from the summer of 1997 to the winter of 1998-1999. The wading bird and shorebird densities for the Strait of Juan de Fuca and San Juan Islands area were from NRDAM/CME province 51. However, the winter densities for diving bird species were updated from NRDAM/CME province 51 using Nysewander et al. (2001).

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

Tables 3-13 to 3-16 list the wildlife densities and Tables 3-17 through 3-20 and Tables 3-26 to 3-30 list the fish and invertebrate densities in the four biological databases used. Tables 3-21 to 3-25 describe the taxonomic codes that were used to define the behavior of fish and invertebrate species used in the model. Production rates of lower trophic levels are described in French et al. (1996b).

Table 3-13. Wildlife densities assumed for the Strait of Juan de Fuca to San Juan Islands area (seaward) and Puget Sound (landward), as seasonal means in number per km^2.

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

Table 3-14. Wildlife densities assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes and Grays Harbor scenarios) as seasonal means in number per km^2.

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

Northern fur seal	0.02	0.02	0.003	0.003
Species group	**Winter**	**Spring**	**Summer**	**Fall**
Northern sea lion	0.01	0.02	0.02	0.03
Sea otter	0.01	0.01	0.01	0.01
Group Totals:				
Waterfowl	157.6	156.3	0.2	0.1
Seabirds	16.7	40.4	66.4	19.2
Wading birds	4.0	12.7	12.7	4.0
Shorebirds	961.0	378.7	0.7	766.0
Raptors	0.0	0.0	0.0	0.0
Kingfishers	1.6	2.6	2.6	1.6
Cetaceans	1.7	1.5	1.5	1.5
Pinnipeds (seals)	0.3	0.3	0.3	0.3
Other mammals	0.0	0.0	0.0	0.0
Reptiles	0.0	0.0	0.0	0.0
Amphibians	0.0	0.0	0.0	0.0
Total all species	1142.9	592.6	84.4	792.7

Table 3-15. Wildlife densities assumed for the lower Columbia River, as seasonal means in number per km^2.

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

Table 3-16. Wildlife densities assumed for the upper Columbia River, as seasonal means in number per km^2. [lwd = landward, i.e., tributaries and bays; swd = seaward, i.e., main river; wetl = wetland]

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

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

Table 3-17. Fish and invertebrate densities (kg/km^2) assumed for the Strait of Juan de Fuca and San Juan Islands area (seaward) and Puget Sound (landward), as seasonal mean by habitat.

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

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

Table 3-18. Fish and invertebrate densities (kg/km^2) assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios) as seasonal mean by habitat.

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

Table 3-19. Fish and invertebrate densities (kg/km^2) assumed for the lower Columbia River, as seasonal mean by habitat.

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

Table 3-20. Fish and invertebrate densities (kg/km^2) assumed for the upper Columbia River, as seasonal mean by habitat.

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

Species group	Habitat	Winter	Spring	Summer	Fall
Mountain whitefish	Seaward Open Water	7752.0	7752.0	7752.0	7752.0
	Wetland and Seagrass	89.0	89.0	89.0	89.0
Pumpkinseed	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
Smallmouth bass	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Swd Wetland/Seagrass	18505.0	18505.0	18505.0	18505.0
White crappie	Seaward Open Water	7714.0	7714.0	7714.0	7714.0
	Wetland and Seagrass	18505.0	18505.0	18505.0	18505.0
White sturgeon	Seaward Open Water	50.0	50.0	50.0	50.0
Yellow perch	Landward Open Water	2252.0	2252.0	2252.0	2252.0
	Wetland and Seagrass	4504.0	4504.0	4504.0	4504.0
Razor clam	Seaward Open Water	884.0	884.0	884.0	884.0
	Landward Open Water	884.0	884.0	884.0	884.0
	Wetland and Seagrass	884.0	884.0	884.0	884.0
Softshell clams	Seaward Open Water	1037.0	1037.0	1037.0	1037.0
	Landward Open Water	1037.0	1037.0	1037.0	1037.0
Total all species	Seaward Open Water	111184.0	111184.0	111184.0	111184.0
	Landward Open Water	17687.0	17687.0	17687.0	17741.7
	Wetland and Seagrass	182382.0	182382.0	182382.0	182436.7

Table 3-21. Fish and invertebrate taxonomic grouping used in modeling.

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

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

Table 3-22. Fish and invertebrate taxa codes for species in Strait of Juan de Fuca, San Juan Islands, and Puget Sound.

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

Table 3-23. Fish and invertebrate taxa codes for species for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios).

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

Table 3-24. Fish and invertebrate taxa codes for species for the lower Columbia River.

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

Table 3-25. Fish and invertebrate taxa codes for species for the upper Columbia River.

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

Table 3-26. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the Strait of Juan de Fuca and San Juan Islands area (seaward) and Puget Sound (landward), as seasonal means by habitat.

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

Table 3-27. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the outer coast of Washington (Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor scenarios) as seasonal means by habitat.

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

Table 3-28. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the lower Columbia River, as seasonal means by habitat.

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

Table 3-29. Fish and invertebrate young-of-the-year densities (#/km^2) assumed for the upper Columbia River, as seasonal means by habitat.

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

Table 3-30. Intertidal invertebrate densities (kg/km^2) by location.

Location	NRDAM/CME Province	Species	kg/km^2
Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Grays Harbor	49	Hard Clams	7400
		Soft Shell Clams	1,037
		Pacific Razor Clam	1,893
		Total Clams	10,330
Straits of Juan de Fuca, San Juan Islands, and Puget Sound	51	Geoduck	164,000
		Hard Clams	7,400
		Soft Shell Clams	1,037
		Total Clams	172,437
Lower Columbia River	48	Soft Shell Clams	1,037
		Pacific Razor Clam	884
		Total Clams	1,921
Upper Columbia River	Inland	Total Clams	-

4. OIL FATES MODEL RESULTS

4.1 Explanation of Model Outputs

4.1.1 Stochastic Output to Estimate Probabilities and Degrees of Exposure

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

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

Section B of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains maps for each of the 9 main stochastic scenarios of the following statistics:

- Probability of exposure greater than the threshold listed above (probability that the threshold thickness or concentration will be exceeded at each location at any time following the spill). For surface oil, the model records if any oil of greater than that thickness (0.01 μm) passes through the grid cell, regardless of the area coverage of the oil. In addition, a map of the probability that dissolved aromatic concentrations will exceed 1 ppb is included in volumes describing scenarios in which the spill involved diesel fuel. For all other oil types, dissolved aromatic concentrations (averaged over a grid cell 0.03-0.14 km^2 in area and over the top 10 m) never exceeded the 1 ppb threshold during any model runs. The average concentration in the grid cell is used to determine if the threshold is exceeded.
- Time (hours) to first exceedance of the threshold at each location

These maps are the maximum exposure at any time after the spill. The time of exposure may be as short as 1 hour. In addition, the plots are composites of results for multiple runs for varying spill dates and times. These results may be used to determine what the highest possible exposure is at any time after a spill.

Floating oil thickness is calculated as g/m^2, where 1 g/m^2 is approximately 1 micron thick oil. Table 4-1 gives approximate thickness ranges for surface oil of varying appearance. Dull brown sheens are about 1000 mg/m^2 thick. Rainbow sheen is about 200-800 mg/m^2 and silver sheens are 50-800 mg/m^2 thick (NRC, 1985). Crude and heavy (Bunker C) fuel oil that is greater than 1mm thick appears as black oil. Light fuels and diesel that are

greater than 1mm thick are not black in appearance, but appear brown or reddish. Floating oil will not always have these appearances, however, as weathered oil would be in the form of scattered floating tar balls and tar mats where currents converge.

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

Minimum	Maximum	Appearance
0.05	0.2	Colorless and silver sheen
0.2	0.8	Rainbow sheen
1	4	Dull brown sheen
10	100	Dark brown sheen
1,000	10,000	Black oil

The thresholds for potential biological effects were discussed in Section 3.4.3. For surface floating oil, the threshold is 10 g/m^2 (about 10 microns thick). For shoreline oil, the threshold is 100 g/m^2 (about 100 microns thick). Since the exposures for dissolved aromatics are primarily to PAHs for hours to days, the threshold of concern would be that for acute effects of short exposures (for the most sensitive species) of about 10 ppb. For gasoline the threshold for potential effects would be 120 ppb. Exposures of < 1ppb would not be expected to have effects under any circumstances.

4.1.2 Estimated Exposure for the Sampled Range of Environmental Conditions

Model output for a scenario were saved for the following matrix:

- For each model run (i.e., for each of the runs in a scenario)
- For each habitat or shore type
- For each exposure level over 6 order-of-magnitude intervals (i.e., if H = threshold used in the modeling: 1H-10H, 10H-100H, 100H-1,000H, 1,000H-10,000H, 10,000H-100,000H, >100,000H)

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

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

The results for each oil constituent (water surface, shoreline, etc.) and resource (habitat or shore) type are analyzed over all 100 runs of the main stochastic scenarios to determine worst-case runs for shoreline oiling and selected sensitive sites for that scenario. [The worst case run is the most adverse of the 100 runs that were simulated, and, therefore, is the 99th percentile case. The "worst case" would have a likelihood of 1% for spills of the simulated size, i.e., 1% of spills would have more adverse impacts and 99% of spills would have less impact.] The runs producing the worst-case result for shoreline impact were indexed by shoreline cleanup cost. As noted above, the cleanup cost per unit area is higher for more difficult to clean and biologically sensitive habitats, such as wetlands and mud flats. Thus, shore cleanup costs (only the per area portion of the costs are used) are related to biological impacts on shorelines. Socioeconomic costs are also related to shoreline oiling. Therefore, total costs related to a spill are for the most part related to shoreline oiling.

Note that the same model run does not typically produce the worst-case impacts to water surface, shoreline, and water column impacts. In fact, when shoreline impacts are highest, water column impacts tend to be relatively low, and *visa versa*. The impact measures from the stochastic modeling provide a quantitative method for determining which runs are the worst-case runs for the resource of interest.

Birds and other wildlife are impacted in proportion to the water and shoreline surface area oiled above a threshold thickness for effects. Shoreline habitat impacts and intertidal mollusks are proportional to surface area oiled above a threshold thickness for effects. Impacts to fish and invertebrates in the water and on the sediments are related to water column and sediment pore water concentrations of dissolved aromatics, or more simply to the amount of oil entrained into the water column after the spill.

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

Recreational, tourism, boating/shipping, and other socioeconomic impacts are functionally related to the length of shore and area of water oiled. Cleanup costs are related to volume spilled, portion remaining on the water surface, and area (or length) of shore oiled. Response costs and socioeconomic damages were evaluated in companion

studies by Etkin (2005b,c), Etkin et al. (2006) and Etkin and French-McCay (2005) using the model outputs.

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

- Percent of spilled hydrocarbon mass eventually going ashore
- Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill

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

Section D of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains summary tables for the main stochastic scenarios of shoreline areas exposed above a range of threshold levels. The results are provided by shore type and for all shorelines. These data were used in the calculations of shoreline cleanup costs (Etkin, 2005b,c; Etkin et al., 2006).

4.1.3 Exposure Results for Individual Runs

Section E of Volumes IV, VII, X, XIII, XVI, XVIV, XXII**,** XXV, and XXVIII contains summary graphics for individual model runs for worst-case scenarios for either shoreline impacts or for selected sensitive sites. These maps display information on water surface exposure to floating hydrocarbons (g/ m^2). For scenarios in which diesel was modeled, there are also maps that contain information on the maximum water column exposure to dissolved aromatics at any time after the spill.

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

4.2 Stochastic Model Results

The general trajectory and fate of the oil may be summarized as follows:

- Outer Coast at Duntz Rock off Cape Flattery (crude): Oil reaches Vancouver Island or the outer coast of Washington, depending on wind direction after the spill, after days or weeks of drifting. Because the spill site is at the entrance of the Strait of Juan de Fuca, extensive oiling of the outer coast further south than the Cape Flattery area is not simulated.

- Strait of Juan de Fuca (crude and Bunker): Requires winds of consistent direction and several days to first reach shore; widespread oiling
- Strait of Juan de Fuca (diesel): Most of the diesel evaporates before it reaches shore.
- San Juan Islands (crude): Oil reaches shore in a few hours to two days; widespread oiling
- Columbia River (Bunker): Oil may reach shore in a few hours (inside the river) or after days (if spilled offshore of river mouth)
- Outer Coast-Sea Lanes (Bunker): Oil reaches the shore parallel to the release line along Sea Lanes within six hours to two days, and reaches Grays Harbor, Willapa Bay, the Columbia River, and the Strait of Juan de Fuca in greater than two days.
- Grays Harbor (Bunker): Oil reaches the shore in a few hours (inside Grays Harbor) or within a few hours to days (outside Grays Harbor).

The time before oil first reached shore varied by each of the 100 runs within a scenario. Figures 4-1 to 4-9 plot the distribution of times for oil to come ashore for the 100 runs. These figures are rank ordered, such that the run with the minimum time to shore is on the left, and the run with the longest time to shore is on the right end of the histogram. Differences between scenarios are primarily due to the proximity of the shorelines to the spill locations.

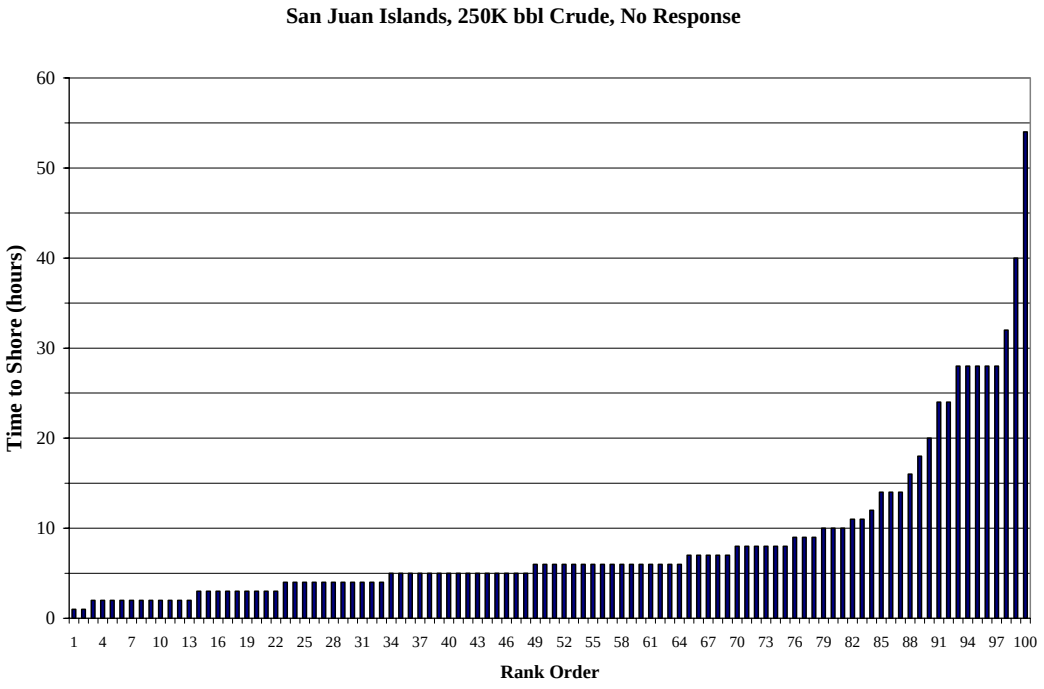


Figure 4-1. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the San Juan Island crude oil spill (no response assumed).

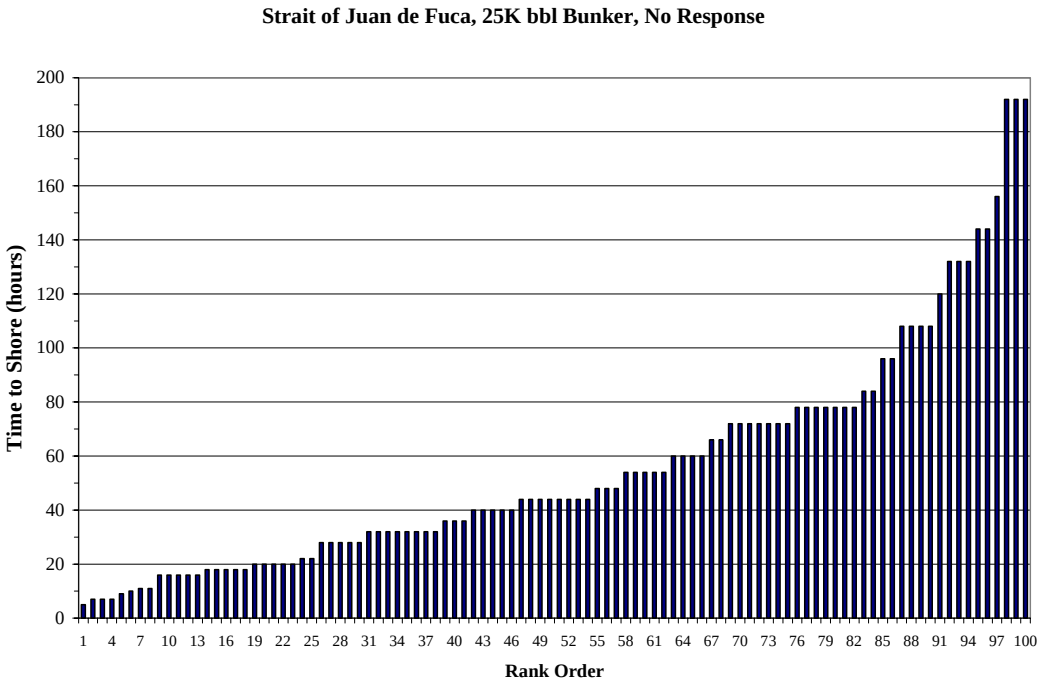


Figure 4-2. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca bunker fuel spill (no response assumed).

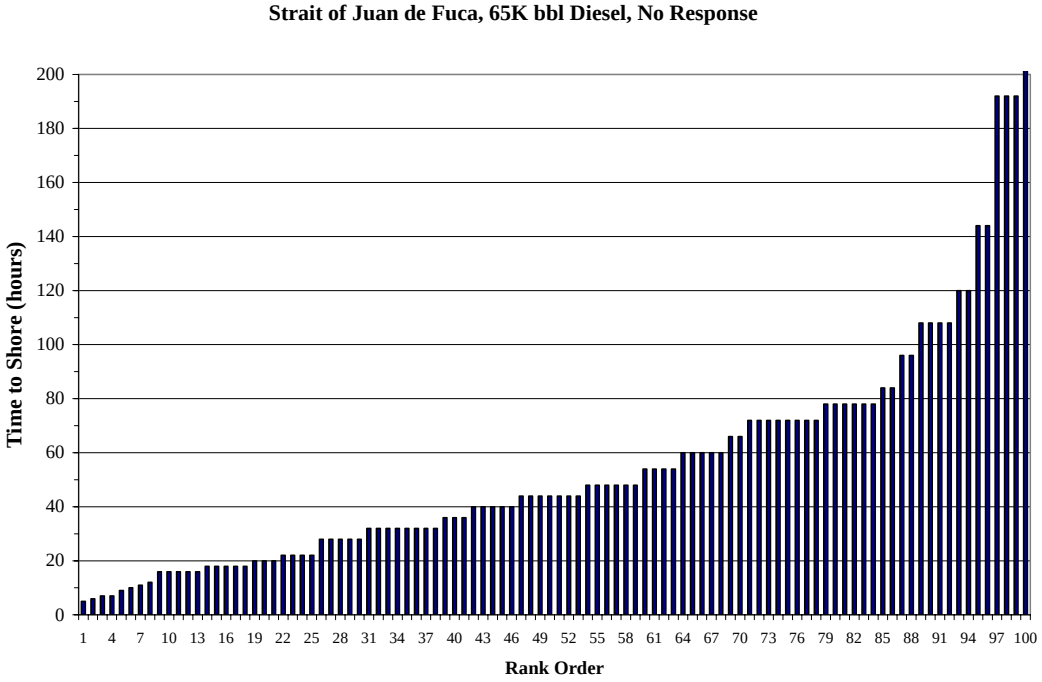


Figure 4-3. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca diesel fuel spill (no response assumed).

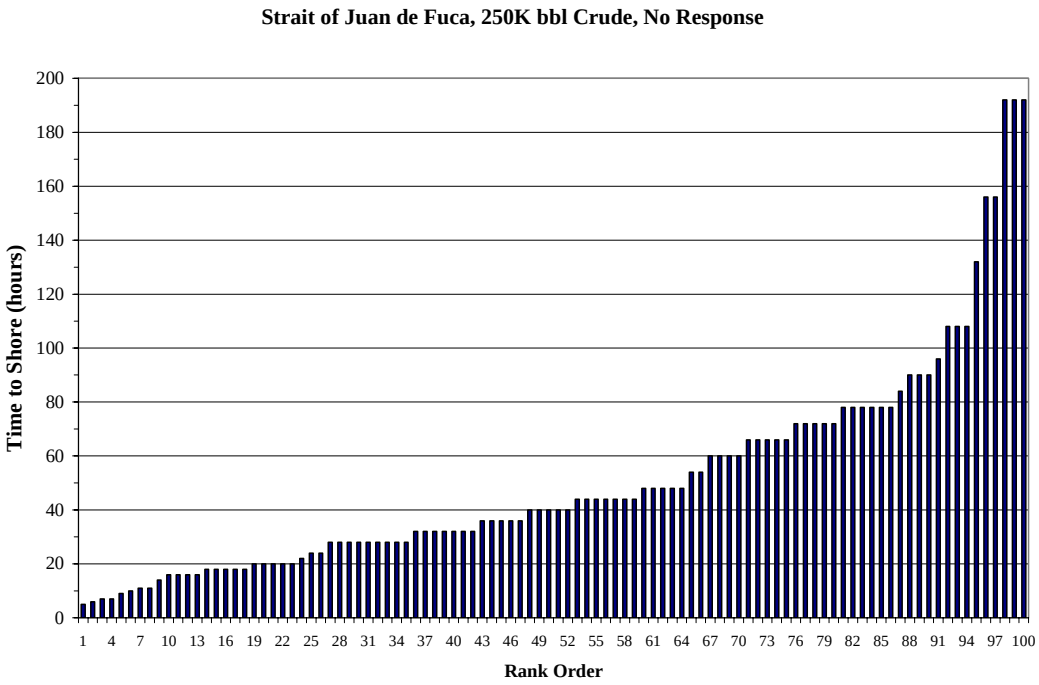


Figure 4-4. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Strait of Juan de Fuca crude oil spill (no response assumed).

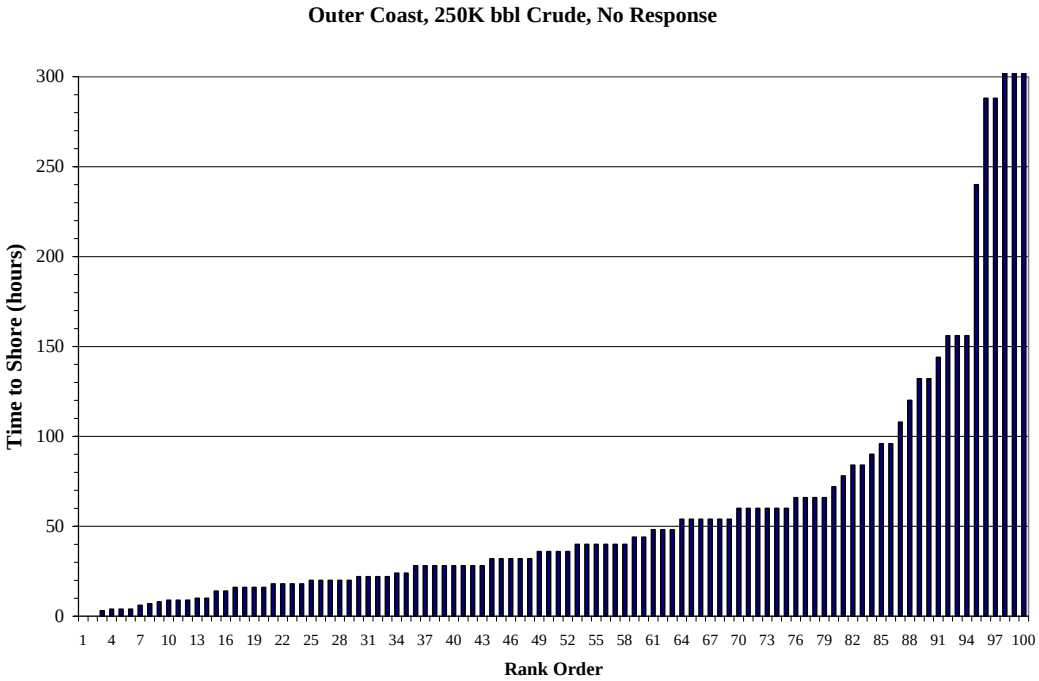


Figure 4-5. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast at Duntz Rock crude oil spill (no response assumed).

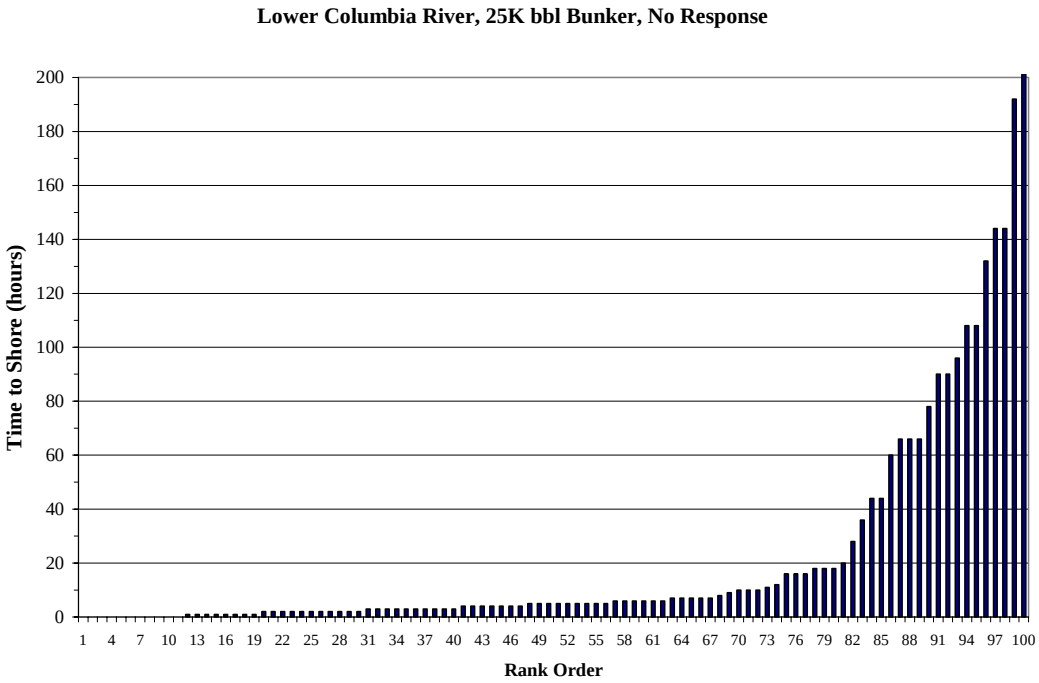


Figure 4-6. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Lower Columbia River bunker fuel spill (no response assumed).

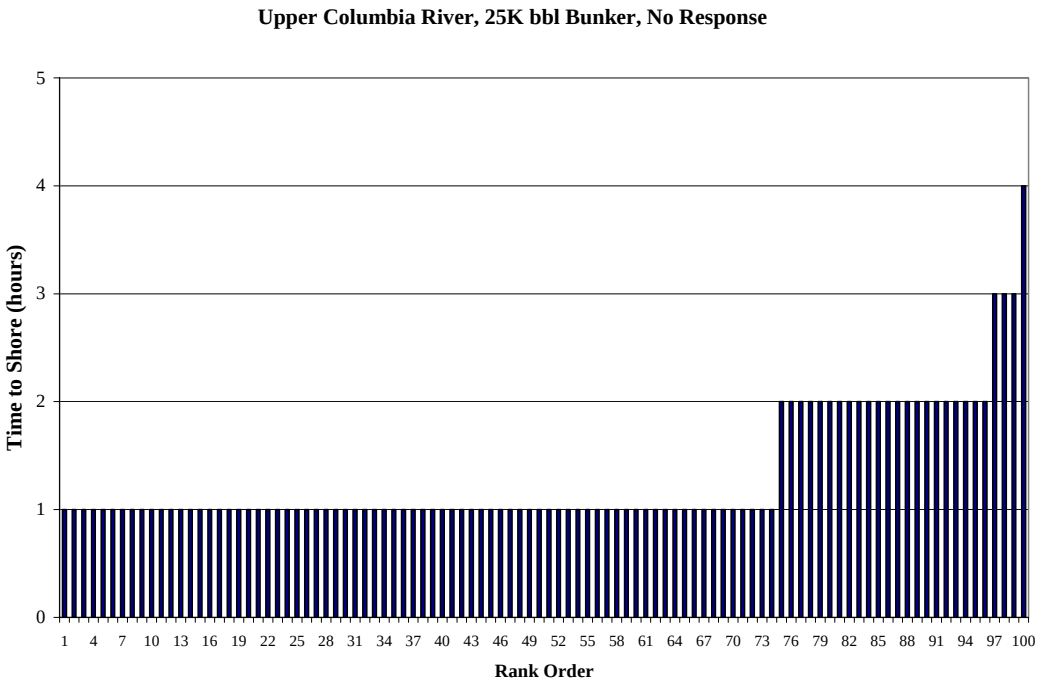


Figure 4-7. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Upper Columbia River bunker fuel spill (no response assumed).

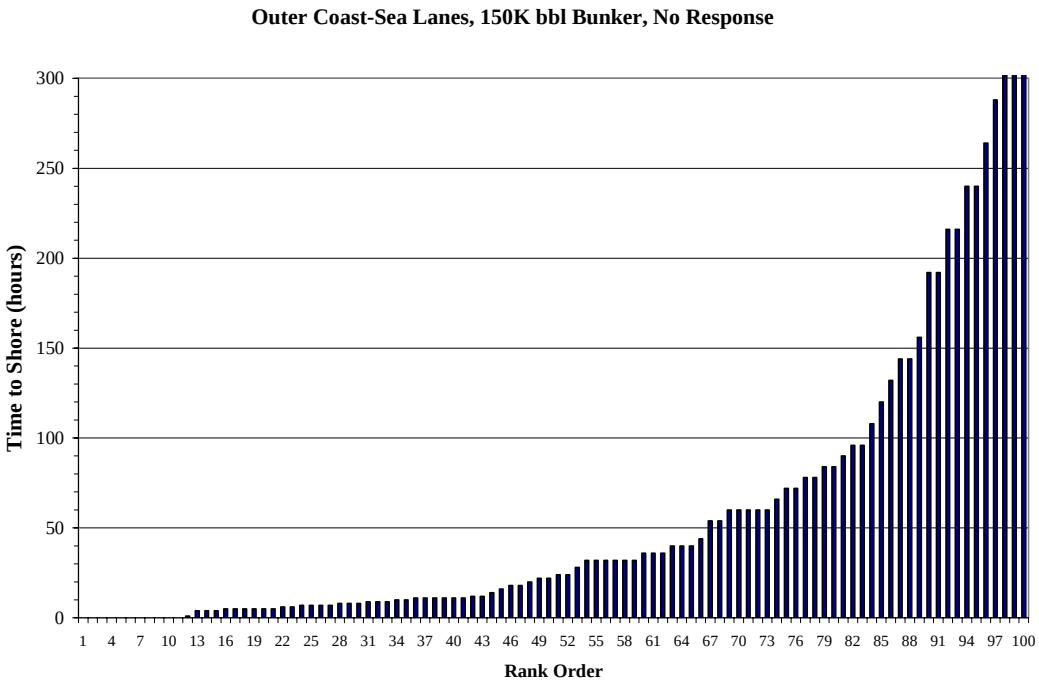


Figure 4-8. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Outer Coast-Sea Lanes bunker spill (no response assumed).

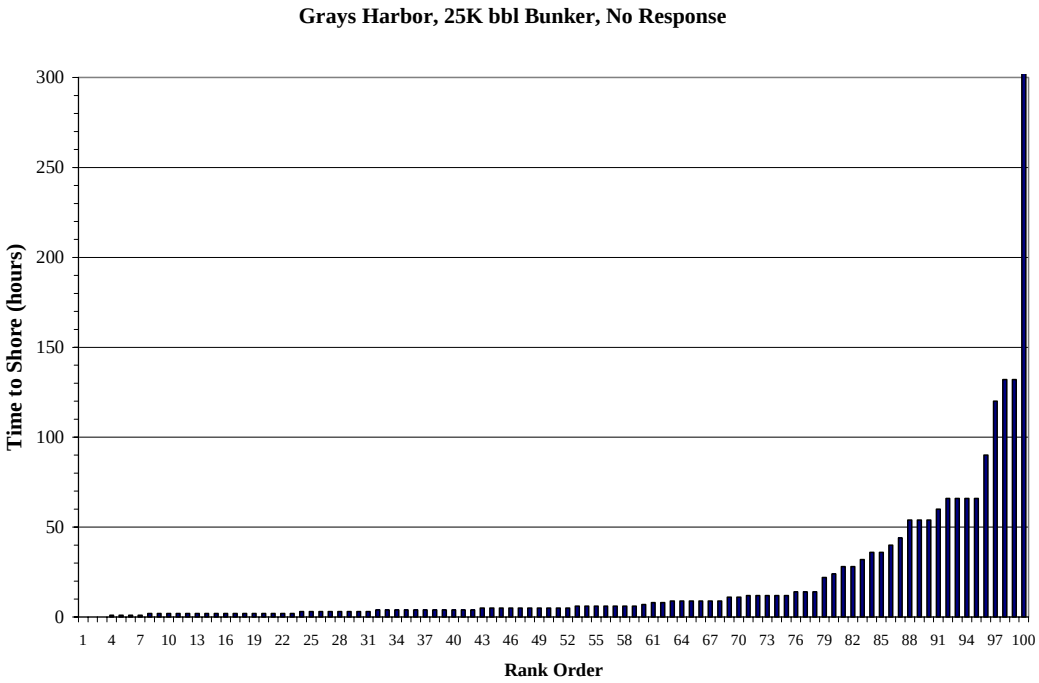


Figure 4-9. Rank ordered results for 100 model runs: Time (hours after the spill) oil first reached shore for the Grays Harbor spill (no response assumed).

Volume II, Section 2 contains summary tables of water surface, shoreline, water column and sediment areas oiled or contaminated for the 9 main stochastic scenarios. The tables contain mean; standard deviation; mean plus or minus two standard deviations (the range for 95 percent of results, assuming a normal (Gaussian) distribution) and the expected 5th, 50th, and 95th percentile result based on the specific exposure index being tabulated. The tables in this section summarize these results for some of the exposure indices examined.

Tables 4-2 and 4-3 summarize the shoreline oiling, listing the percent of oil coming ashore and the length of shore where cleanup would occur. Areas and lengths of shoreline oiling for other thresholds are summarized in Section 2 of Volume II, as are the per area portion of the cleanup costs. The scenario run for the Straits of Juan de Fuca using diesel fuel resulted in the lowest percentage of spilled hydrocarbons eventually coming ashore. This reflects the fact that diesel is more volatile and soluble than the other types of oil that were modeled. While a high percentage of Bunker fuel typically hit the shore, the overall area affected by shoreline oiling was largest in spills of crude oil due to the greater volume of spilled crude that was modeled. The Outer Coast – Sea lanes scenario of 150,000 bbl of bunker would oil more shoreline than the 25,000 bbl Grays Harbor scenario. Furthermore, locations where shipping routes are closer to land (i.e., San Juan Islands and the Lower and Upper Columbia River) usually had a higher percentage of oil coming ashore.

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	11.7	7.3	-	26.3
JF-Bunk-N	54.7	9.1	36.6	72.8
JF-Dies-N	4.2	4.0	-	12.2
JF-Crud-N	18.2	7.3	3.6	32.7
SJ-Crud-N	26.0	6.6	12.7	39.3
CL-Bunk-N	54.6	23.9	6.7	102.5
CU-Bunk-N	69.1	9.8	49.6	88.7
OL-Bunk-N	29.0	15.7	-	60.5
GH-Bunk-N	61.2	15.8	29.6	92.7

Table 4-3. Summary of results for all stochastic scenarios of 100 runs each: Shoreline length (km) oiled by > 0.01 g/m2 (where cleanup would occur).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,040	2,020	-	6,079
JF-Bunk-N	428	217	-	863
JF-Dies-N	588	481	-	1,550
JF-Crud-N	2,647	1,576	-	5,799
SJ-Crud-N	4,958	2,340	278	9,638
CL-Bunk-N	635	491	-	1,617
CU-Bunk-N	296	115	67	525
OL-Bunk-N	1,034	729	-	2,491
GH-Bunk-N	539	383	-	1,305

The percentage of the spilled oil reaching the sediments is smallest in offshore regions, such as for the Outer Coast at Duntz Rock scenario (Table 4-4), because the spills examined occurred in open, deep water with low suspended sediment concentrations. The percent settling is much higher in the upper Columbia River scenario, because of the shallower water and more extensive shoreline interaction. Also, oil type had a large effect on the percentage of spilled hydrocarbon that eventually settles to the sediment. Due to its characteristic volatility, a very small percentage of diesel tends to enter the sediments. In contrast, approximately one-third or more of the oil from Bunker spills reached subtidal and intertidal sediments (in part after erosion off the oiled shorelines).

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	4.9	3.8	-	12.4
JF-Bunk-N	33.8	9.2	15.4	52.2
JF-Dies-N	0.076	0.57	-	1.2
JF-Crud-N	12.8	5.1	2.5	23.0
SJ-Crud-N	14.9	6.2	2.5	27.2
CL-Bunk-N	31.2	20.5	0	72.2
CU-Bunk-N	38.7	14.8	9.0	68.4
OL-Bunk-N	29.2	16.4	-	62.0
GH-Bunk-N	51.2	16.4	18.5	83.9

The maximum percent of the oil mass entrained in the water column at any time after the spill (Table 4-5) gives an indication of the amount of oil dispersed naturally. The diesel is much more easily dispersed, being a light non-viscous fuel, and so the amount in the water column is the highest for this scenario.

Table 4-5. Summary of results for all stochastic scenarios of 100 runs each: Maximum percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7.0	3.6	-	14.2
JF-Bunk-N	1.4	0.9	-	3.2
JF-Dies-N	44.4	12.9	18.5	70.2
JF-Crud-N	1.5	1.2	-	3.8
SJ-Crud-N	1.1	1.6	-	4.3
CL-Bunk-N	5.2	3.9	-	13.1
CU-Bunk-N	1.6	0.9	-	3.5
OL-Bunk-N	7.0	4.5	-	15.9
GH-Bunk-N	3.4	2.2	-	7.8

The water surface areas swept by floating oil are listed in Tables 4-6 and 4-7. Sheen has a thickness of >0.01 g/m^2. The thresholds for mechanical removal (skimming), effective dispersant use, in situ burning, and biological effects (on wildlife) are all about 10 g/m^2 (10 microns thick). In all scenarios, except for the spills of bunker fuel (which does not spread significantly thinner than 10 microns), the area of the water surface covered by oil with a thickness greater than 10 g/m^2 was smaller than the area covered by a thinner sheen or by scattered tar balls later in the simulation after the oil weathered. The area covered by sheen or tarballs was largest in the outer coast scenarios, due to the unrestricted waters and because less of the oil came ashore due to the offshore location of the modeled spills. Scenarios in which crude was spilled typically resulted in the largest area swept due to the larger volume spilled (the bunker spills were of 1/10th the volume) and the fact that crude is a more viscous oil than diesel that will not readily volatize or become entrained into the water column in large amounts.

Table 4-6. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,255	10,391	-	30,037
JF-Bunk-N	533	238	57	1,010
JF-Dies-N	396	228	-	852
JF-Crud-N	1,945	897	152	3,739
SJ-Crud-N	1,201	954	-	3,110
CL-Bunk-N	199	171	-	541
CU-Bunk-N	6	3	-	12
OL-Bunk-N	2,279	1,756	-	5,791
GH-Bunk-N	300	351	-	1,003

Table 4-7. Summary of results for all stochastic scenarios of 100 runs each: Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	7,101	8,167	-	23,436
JF-Bunk-N	530	237	56	1,005
JF-Dies-N	326	204	-	734
JF-Crud-N	1,529	727	76	2,983
SJ-Crud-N	771	649	-	2,070
CL-Bunk-N	196	166	0	527
CU-Bunk-N	6	3	-	11
OL-Bunk-N	2,256	1,715	-	5,685
GH-Bunk-N	295	340	-	976

4.3 Results for Individual Scenarios

Results for alternate response scenarios are tabulated in Volume II, Sections II.3 to II.11, as well as in Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX, . The percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations (Tables 4-8 to 4-16). However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in Grays Harbor and the Strait of Juan de Fuca. The capacity standards input to the model were larger relative to the spill volume for the 25,000 bbl bunker fuel scenarios than for those using the other two oil types or for the Outer Coast-Sea Lanes 150,000 bbl bunker fuel spill scenario. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Grays Harbor and the Strait of Juan de Fuca scenarios. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

These recovery amounts are much less than those simulated in Phase I, because (1) the recovery efficiencies were assumed to decrease as time progressed, and (2) removal was only simulated for the first 72 hours because the efficiencies become very low after that time and no more equipment is assumed to be brought in and applied. In Phase I the capacities were assumed operational at optimal efficiencies indefinitely. In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

Table 4-8. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast spills of crude oil at Duntz Rock.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
OC-C250K-N	-	-	-
OC-C250K-Fed	0.04	0.72	0.95
OC-C250K-WA	0.04	3.30	3.54
OC-C250K-3	0.48	3.95	4.31

* The Federal and Washington State responses involved the same removal amounts and timing.

Table 4-9. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-B25K-N	-	-	-
JF-B25K-Fed	5.8	5.8	12.7
JF-B25K-WA	8.5	14.6	28.4
JF-B25K-3	11.6	24.1	42.1

Table 4-10. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of diesel fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-D65K-N	-	-	-
JF-D65K-Fed	2.8	4.1	3.8
JF-D65K-WA	3.9	9.2	8.4
JF-D65K-3	4.8	13.3	12.2

Table 4-11. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Strait of Juan de Fuca spills of crude oil fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
JF-C250K-N	-	-	-
JF-C250K-Fed	2.0	0.9	1.9
JF-C250K-WA	4.5	2.3	4.2
JF-C250K-3	6.7	3.6	6.3

Table 4-12. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for San Juan Island spills of crude oil.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	Worst run for Lummi Island	Worst run for Padilla Bay	50th Percentile Run (based on shore cost)
SJ-C250K-N	-	-	-	-	-	-
SJ-C250K-Fed	1.8	2.0	2.0	1.6	1.8	1.3
SJ-C250K-WA	4.2	4.6	4.4	3.7	3.6	3.4
SJ-C250K-3	5.9	6.8	6.5	5.5	5.2	5.0

Table 4-13. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Lower Columbia River spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Columbia National Wildlife Refuge
CL-B25K-N	-	-	-
CL-B25K-Fed	1.6	2.2	1.6
CL-B25K-WA	3.4	4.4	3.4
CL-B25K-3	6.7	8.1	6.7

Table 4-14. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Upper Columbia River spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (#1)	Worst run for Ridgefield National Wildlife Refuge (#2)
CU-B25K-N	-	-	-
CU-B25K-Fed	1.8	2.2	2.2
CU-B25K-WA	3.3	3.3	3.8
CU-B25K-3	5.3	6.6	7.4

Table 4-15. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Outer Coast-Sea Lanes spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
OL-B150K-N	-	-	-
OL-B150K -Fed	1.9	1.7	1.8
OL-B150K -WA	6.6	5.6	5.6
OL-B150K -3	6.8	6.1	5.7

Table 4-16. Percent of spilled hydrocarbon mass mechanically removed (%) for alternate response scenarios for Grays Harbor spills of Bunker C fuel.

Scenario	99th Percentile Run (based on shore cost)*	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for GRPs
GH-B25K-N	-	-	-
GH-B25K -Fed	9.8	3.8	6.4
GH-B25K -WA	25.8	8.4	11.1
GH-B25K-3	42.5	14.2	15.5

Figures 4-10 to 4-12 summarize the mass balance of oil over time after the spill for three representative runs assuming no response, one for each of the oil types. About 55% of the crude oil evaporated after weathering for 2 weeks, which substantially decreased the amount of oil on the water surface and coming ashore (Figure 4-10). Only about 15% of the bunker fuel evaporated (Figure 4-11), while 50% of the diesel evaporated by 6 days after release (Figure 4-12). Most of the crude oil and bunker fuel that did not volatilize (evaporate), eventually came ashore. A considerable percentage of the diesel was entrained in the water column (40% in the example scenario, Figure 4-12) because of its low viscosity making it easily dispersed.

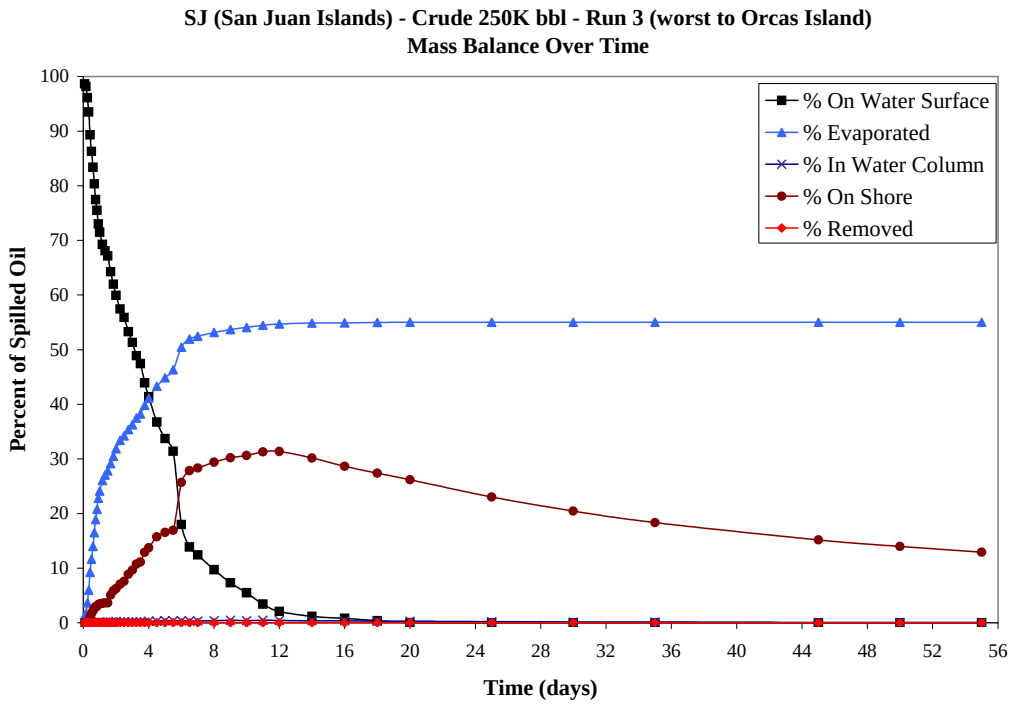


Figure 4-10. Mass balance over time for a crude oil spill simulation in the San Juan Island location (worst run for impacts on Orcas Island).

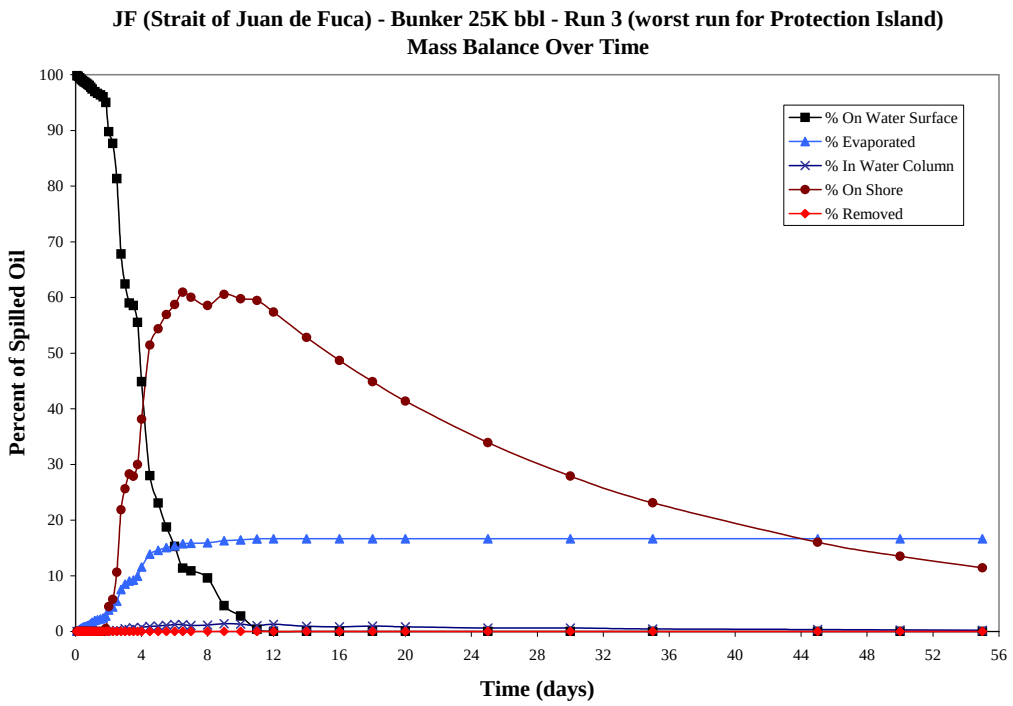


Figure 4-11. Mass balance over time for a bunker fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

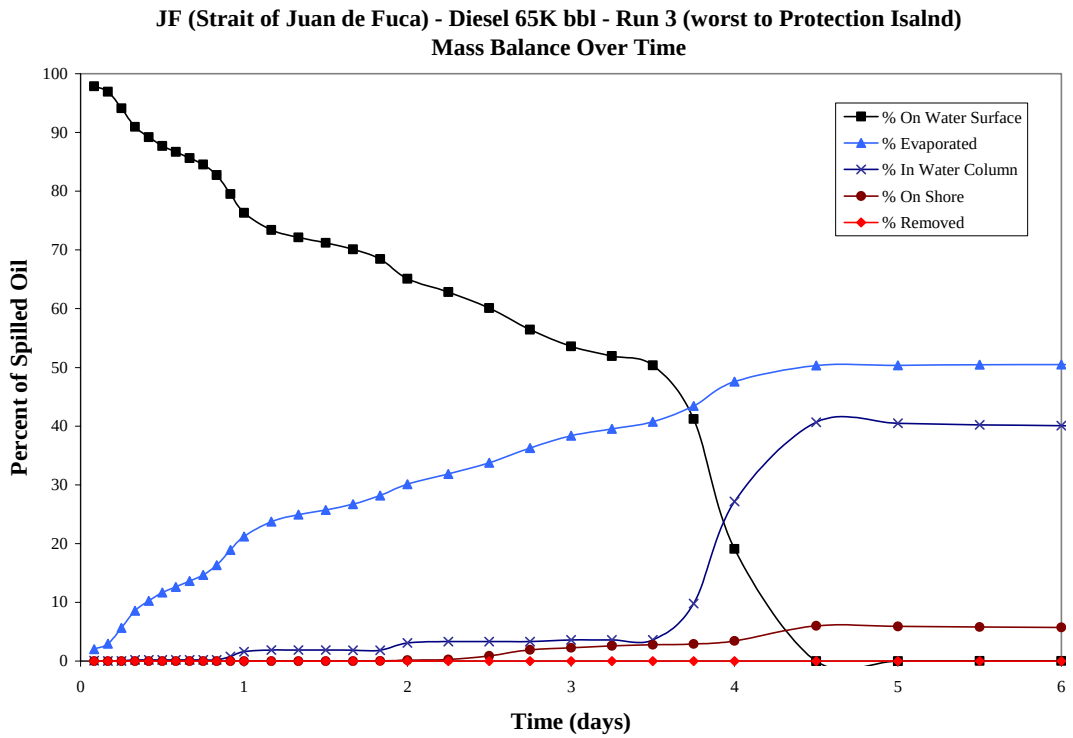


Figure 4-12. Mass balance over time for a diesel fuel spill simulation in the Strait of Juan de Fuca location (worst run for impacts on Protection Island).

Section B in Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contain figures summarizing the mass balance of oil over time after the spill and comparing the four alternative response simulations (no response, federal standards, WA standards and the 3rd alternative standard). There are 3 or 4 figures for each of the individual runs examined, containing results for the four alternative response runs on a single graph so they may be compared:

- Percent of oil floating on the water surface
- Percent of oil on the shoreline
- Percent of oil mechanically removed
- Amount of oil coming ashore within the sensitive site of interest for that run (for worst-case runs for sensitive sites)

The results generally show the expected pattern of less oil on the water surface and on shore at a given time related to higher removal capacity deployed sooner (i.e., in the order no response > federal > WA > 3rd alternative). The bunker fuel results for the Strait of Juan de Fuca and Grays Harbor show these patterns most clearly. However, for many of the runs examined, the differences between the response alternatives are small.

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

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to "hold" oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

The results of the modeling of the alternative response scenarios are summarized in the tables in Section II.3 to II.11 of Volume II, organized by location. More detailed results of the alternate response scenarios are in Volumes V, VIII, XI, XIV, XVII, XX, XXIII, , XXVI, and XXIX including the mass balance figures described above.

The results in Section II.3 to II.11 of Volume II are tabulations of percentage of oil in various environmental compartments *at the end of the simulation*, the maximum areas impacted above various thresholds *at any time after the spill* (the timing of which may vary from one run to the next), numbers or weights of organisms impacted by the end of the simulation, and estimated natural resource damage costs using various methods (see Section 6 below).

Changes in the specific locations where spillets hit shore may result in differences in the amount of shoreline oiled by more than or less than selected thresholds. For example, in one simulation two spillets might hit a single location and be additive in the amount of oil on shore in that segment, while in another simulation the two spillets might hit adjacent shorelines and be additive in area of shore oiled, but not in thickness of oiling. This results in different thicknesses of oil on each shore segment from one simulation to the next. Thus, it should be noted that impact to the shoreline at any threshold level is not necessarily proportional to the shore length or area oiled. This explains some of the variability seen in the results.

Since the Phase II modeling involved simulating (1) only the capacities of the *response planning standards* (not all equipment that might be used in a large spill such as those examined), (2) the decreasing efficiency of oil removal as time goes on, and (3) changes in the timing and capacities of removal activities only in the first 96 hours after the spill, the differences in amounts of oil removed are small. Thus, in many cases, the differences between runs as shown in the figures and listed in the tables in Volume II are less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. In addition, Figures 4-1 to 4-9 (above) summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

5. BIOLOGICAL EFFECTS MODEL RESULTS

5.1 Intertidal Habitats

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

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

Table 5-1 summarizes the results for the 9 main stochastic scenarios. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

Results for the alternate response scenarios may be found in Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX in Section D. Differences between the three alternative responses in terms of intertidal invertebrate mortality are small and can be largely attributed to the randomized variability that is incorporated into this model. This randomization can cause oil to move closer or farther away from shorelines even when the same speed and direction of wind and currents are used. This can result in near misses of some shoreline areas, thus, affecting the number of geoducks and other intertidal invertebrates affected by an oil spill.

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	9,026	10,561	-	30,149
JF-Bunk-N	33,955	35,399	-	104,752
JF-Dies-N	28,928	41,555	-	112,038
JF-Crud-N	174,703	117,105	-	408,913
SJ-Crud-N	305,639	130,644	44,351	566,926
CL-Bunk-N	1,086	860	-	2,805
CU-Bunk-N	-	-	-	-
OL-Bunk-N	7,986	6,753	-	21,492
GH-Bunk-N	5,181	3,769	-	12,718

5.2 Wildlife

Tables 5-2 and 5-3 summarize the model-estimated bird and mammal kills for the main stochastic scenario simulations. Section F of Volumes IV, VII, X, XIII, XVI, XVIV, and XXII contains the impact estimates by species group for the main 9 scenarios. Section C of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains impact estimates for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

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

Table 5-2. Summary of results for all stochastic scenarios of 100 runs each: Total number of birds oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	488,751	611,866	-	1,712,483
JF-Bunk-N	23,120	8,247	6,627	39,613
JF-Dies-N	31,010	13,852	3,306	58,714
JF-Crud-N	163,739	87,505	-	338,749
SJ-Crud-N	93,384	28,122	37,140	149,627
CL-Bunk-N	60,349	50,185	-	160,718
CU-Bunk-N	1,263	800	-	2,864
OL-Bunk-N	121,305	97,079	-	315,464
GH-Bunk-N	31,669	38,202	-	108,073

Table 5-3. Summary of results for all stochastic scenarios of 100 runs each: Total number of mammals oiled.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	234	156	-	545
JF-Bunk-N	1.8	0.6	0.6	3.0
JF-Dies-N	2.4	1.3	-	5.1
JF-Crud-N	15.7	9.4	-	34.5
SJ-Crud-N	8.2	2.1	4.0	12.5
CL-Bunk-N	10.2	8.1	-	26.5
CU-Bunk-N	97.1	23	50	144
OL-Bunk-N	55.6	27	0.9	110
GH-Bunk-N	7.4	7.4	-	22.3

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). The breakdowns by species groups are available in Volume II for the 9 main scenarios (Section II.2) and alternate scenarios (Sections II.3 to II.11). The worst impacts to birds were observed during spills of crude oil. This, in turn, reflects the fact that crude oil swept a large area of the water surface (owing to the large spill volume) as shown in Tables 4-6 and 4-7 of this volume. The highest level of bird mortality was seen in the outer coast region, because the oil remained at sea longer and there were higher abundances of birds on the outer coast compared to other areas, such as the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas. As was the case with intertidal invertebrates, the differences between the three alternate responses in terms of impacts to birds were frequently less than the randomized variability in the model.

The Alaskan North Slope crude oil spill scenario examined here is the same spill volume as the *Exxon Valdez* oil spill in Prince William Sound, Alaska (March 1989). The mean model-estimated impacts to birds for the Outer Coast at Duntz Rock spill are of the same

order as those that occurred after the *Exxon Valdez* (Exxon Valdez Oil Spill Trustee Council, 1989 Piatt et al., 1990) while the 95% confidence range is very large, from only a few to 1.7 million birds killed. Piatt et all. (1990) estimated 100-690 thousand birds (best estimate 250 thousand) were oiled and died as the result of the *Exxon Valdez* oil spill. The model variability is due to the different possible trajectories depending upon weather and current conditions immediately after a spill. There is similar uncertainty in the densities of birds in the path of a spill, depending on season and natural variability in distributions. Fewer birds are predicted to be oiled by 250,000 bbl crude oil spills in the straits (Strait of Juan de Fuca and near the San Juan Islands) because of lower densities there than on the outer coast and in Prince William Sound.

Table 5-3, which summarizes the results for the 9 main stochastic scenarios, shows that the mammal impacts are projected to be minor, with the exception of the Outer Coast at Duntz Rock, Outer Coast-Sea Lanes, and Upper Columbia River scenarios. The mammals primarily impacted in the Outer Coast at Duntz Rock and Outer Coast-Sea Lanes scenarios would be sea otters and fur seals, with lesser impacts to harbor seals and harbor porpoises. In the Upper Columbia River, the mammals impacted would be mostly muskrat and mink.

5.3 Fish and Invertebrates

Table 5-11 summarizes estimated impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations) for the 9 main stochastic scenarios. Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the impact estimates by species group for the main 9 scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios.

Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts are projected to be much higher for diesel than for the same volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water.

The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

It should be noted that these fish and invertebrate impacts were calculated assuming all the species were of average sensitivity to dissolved aromatics. Some species will be much more sensitive, and impacts to those species would be higher. There would also

likely be species less sensitive than average. As there are insufficient toxicity data available to quantify the degree of sensitivity to aromatics for all species in Washington waters, there is considerable uncertainty around the results based on average sensitivity. Experience with past modeling efforts indicate the uncertainty in the impact estimate related to species sensitivity is on the order of a factor ten higher or lower (95% confidence range). As there is a mix of species sensitivity present, the uncertainty in the total fish and invertebrate impact would be less than a factor ten.

Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains impact estimates for the alternate response scenarios. These results are also summarized in Sections II.3 to II.11 of Volume II. Frequently, differences between the alternate responses are smaller than the randomized variability incorporated into this model. Also, when booming is applied, the oil that is deflected offshore stays on the water surface for longer, thus, allowing more oil to be potentially entrained into the water column. This can result in a higher rate of mortality to subtidal fishes and invertebrates.

Table 5-4. Summary of results for all stochastic scenarios of 100 runs each: Total impact (kg) to subtidal fish and invertebrates.

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,376	1,388	-	4,152
JF-Bunk-N	62	10	41	82
JF-Dies-N	49,500	29,488	-	108,476
JF-Crud-N	14,544	8,834	-	32,212
SJ-Crud-N	6,807	9,599	-	26,005
CL-Bunk-N	6	9	-	24
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	82	31	20	145
GH-Bunk-N	17	4	8	25

Table 5-5 contains a summary of the total estimated impacts to fish and invertebrates in all subtidal and intertidal habitats. Again, Section G of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the impact estimates by species group for the main 9 scenarios and Section D of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

With two notable exceptions, the majority of impacts to fishes and invertebrates affected intertidal biota. Due to diesel's high solubility and toxicity, spills involving this type of oil result in greater mortality to subtidal organisms. In the Juan de Fuca scenario in which diesel was used, 63% of the impacted organisms were subtidal fishes and invertebrates. All of the impacted biota in the upper Columbia River spill were subtidal, because no intertidal losses were assessed for this scenario.

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	10,403	11,949	-	34,301
JF-Bunk-N	34,016	35,409	41	104,834
JF-Dies-N	78,428	71,042	-	220,513
JF-Crud-N	189,247	125,939	-	441,125
SJ-Crud-N	312,446	140,243	44,351	592,931
CL-Bunk-N	1,092	868	-	2,829
CU-Bunk-N	3,382	343	2,695	4,069
OL-Bunk-N	8,068	6,784	20	21,637
GH-Bunk-N	5,198	3,773	8	12,743

6. POTENTIAL NATURAL RESOURCE DAMAGES

6.1 NRD Based on Restoration Costs

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

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

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

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

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

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

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

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

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

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

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

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

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

The needed data for the scaling calculations are:

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

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

6.1.1 Saltmarsh Restoration

HEA calculations for saltmarsh are performed following the methods in French McCay and Rowe (2003). It is assumed that the saltmarsh requires 15 years to reach 99% of full function (based on PERL, 1990; Zedler, 1992; Seneca and Broome, 1992; French et al., 1996a), ultimately reaching 80% of natural habitat productivity, the restoration begins 3 years after the spill, and the project lifetime is 50 years.

Above-ground primary production rate of saltmarsh cord grasses on the Oregon coast was estimated from data in Continental Shelf Associates (1991) as 2,636 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in saltmarshes is 2,729 g dry weight m^{-2} yr^{-1}. It is assumed that created marshes reach 80% of the production rate in natural marshes, i.e., 2,184 g dry weight m^{-2} yr^{-1}.

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

The amounts of saltmarsh required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 9 main stochastic scenarios in Tables 6-3 and 6-4. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the restoration scale (area required for compensation) and cost estimates by species group for the main 9 scenarios. The results are summarized in Volume II, Section II.2. The executive summary also contains summary tables of the NRDA cost estimates for all species groups, so that these costs may be carried forward into the cost-benefit analysis performed by the Department of Ecology.

According to HEA-scaled calculations, the offshore crude oil scenario would be the most expensive to provide compensatory restoration because of the relatively large impact on birds. In general, spills of crude oil required larger amounts of wetland creation, while spills of Bunker C typically resulted in the smallest restoration efforts. These patterns reflect both the impacts to biota and the spill volume that was modeled.

Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI, and XXIX contains those for the alternate response scenarios, which are also summarized in Sections II.3 to II.11 of Volume II. As was the case with most of the biological response variables considered in this report, the differences between the three alternative responses in terms of the cost of saltmarsh creation was smaller than the amount of randomized variability that was incorporated into this model.

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	2,677	3,114	-	8,905
JF-Bunk-N	137	68	13	273
JF-Dies-N	436	273	17	981
JF-Crud-N	953	396	284	1,744
SJ-Crud-N	527	156	283	838
CL-Bunk-N	221	212	0	645
CU-Bunk-N	7	3	2	13
OL-Bunk-N	598	454	0.6	1,506
GH-Bunk-N	133	169	0.1	472

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	502	584	-	1,669
JF-Bunk-N	26	13	2.4	51
JF-Dies-N	82	51	3.3	184
JF-Crud-N	179	74	53	327
SJ-Crud-N	99	29	53	157
CL-Bunk-N	41	40	0	121
CU-Bunk-N	1.3	0.6	0.4	2.4
OL-Bunk-N	112	85	0.1	282
GH-Bunk-N	25	32	0.01	88

6.1.2 Seagrass Bed Restoration

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

The estimated primary production rate for eelgrass in Puget Sound (Phillips 1984) is 1,079 g dry weight m^{-2} yr^{-1}. In addition, benthic microalgal production provides another 93 g dry weight m^{-2} (Phillips, 1984). Thus, estimated total primary production rate in seagrass beds is 1,172 g dry weight m^{-2} yr^{-1}. It is assumed that created seagrass bed reach 80% of the production rate in natural beds, i.e., 938 g dry weight m^{-2} yr^{-1}.

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

The amounts of seagrass bed required in compensation for the quantified wildlife, fish and invertebrate injuries and the cost of the restoration are summarized for the 9 main stochastic scenarios in Tables 6-5 and 6-6. Section H of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, and XXVIII contains the restoration scale and cost estimates by species group for the main 9 scenarios and Section E of Volumes V, VIII, XI, XIV, XVII, XVV, XXIII, XXVI,and XXIX contains those for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios.

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

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	1,673	1,946	-	5,565
JF-Bunk-N	85	43	8	171
JF-Dies-N	272	170	11	613
JF-Crud-N	595	247	177	1,090
SJ-Crud-N	329	97	177	524
CL-Bunk-N	138	132	0	403
CU-Bunk-N	4.4	1.9	1.3	8.2
OL-Bunk-N	374	284	0.4	941
GH-Bunk-N	83	106	0.0	295

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	200	232	-	664
JF-Bunk-N	10	5	1.0	20
JF-Dies-N	33	20	1.3	73
JF-Crud-N	71	30	21	130
SJ-Crud-N	39	12	21	63
CL-Bunk-N	16.5	15.8	0	48.1
CU-Bunk-N	0.5	0.2	0.2	1.0
OL-Bunk-N	45	34	43	112
GH-Bunk-N	10	13	0.004	35

6.2 Washington State Compensation Schedule

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

The resource damage assessment using Compensation Schedule includes:

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

The Compensation Schedule procedures for marine and estuarine waters, excluding the estuarine waters of the Columbia River, were applied using the spill volume less the amount of oil mechanically recovered in the first 24 hours. The results, including $/gal, percent removed in the first 24 hours, and total damages (in millions of dollars) are listed in Section I of Volumes IV, VII, X, XIII, XVI, XVIV, XXII, XXV, XXVII for the main 9 scenarios and Section F of Volumes V, VIII, XI, XIV, XVII, XVV, and XXIII, XXVI, and XXIX for the alternate response scenarios. The results are summarized in Volume II, Section II.2 for the main stochastic scenarios, and Sections II.3 to II.11 for the alternate response scenarios. Table 6-7 summarizes the results for the 9 main stochastic scenarios. The Compensation Schedule was not applied to the upper Columbia River spills as that application is performed by field observations and so cannot be easily modeled. Since the damages calculated by the Washington Compensation Schedule are based on $/gallon figures that are related to the sensitivity of geographical regions (as well as habitat, biota and oil type) and the area of impact can be fairly similar for the 100 runs within a given

scenario, there is little variability between the results of different runs within a scenario. This is also the case when comparing the alternate response scenarios for a single run (summarized in Sections II.3 to II.11 of Volume II): there is almost no variation between them because they impact the same resources geographically and the spill volume is the same.

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

Scenario	Mean	Standard Deviation (SD)	Mean - 2SD	Mean + 2SD
OC-Crud-N	246	8	230	261
JF-Bunk-N	29.1	1.5	26.1	32.0
JF-Dies-N	45.8	1.9	42.1	49.5
JF-Crud-N	238	15	208	267
SJ-Crud-N	249	17	214	284
CL-Bunk-N	19.9	12.3	0.0	44.6
CU-Bunk-N	*	*	*	*
OL-Bunk-N	174	23.8	126	222
GH-Bunk-N	30.4	5.5	19.4	41.4

* WA Compensation Schedule damages were not calculated for the Upper Columbia River.

7. DISCUSSION AND CONCLUSIONS

7.1 Use of the Probabilistic Approach – Stochastic Modeling

The use of stochastic modeling in this project to produce results and statistics for multiple model runs under various possible environmental conditions demonstrates a statistically quantifiable method for estimating potential impacts and financial consequences that may be used in ecological risk assessment and cost-benefit analyses. The statistically-defined consequences provide an objective measure of the magnitude, range and variability of impacts to wildlife, aquatic organisms and shorelines, and of damages that could be claimed by (US) federal and state natural resource trustees.

7.2 Oil Recovery Rates

The Phase I modeling results, assuming recovery operations at the Effective Daily Recovery Capability (EDRC) rate, indicated that the mechanical removal capacities examined would be sufficient for cleaning up much of the spill volumes evaluated and could reduce impacts to biota and shorelines. However, the Phase I simulations assumed that everything goes according to plan and responders know where the oil is at all times. In reality, people and equipment will not be able to meet the schedules exactly and there will not be perfect knowledge of the oil movements allowing the responders to mechanically clean up as much oil as the results suggest. Thus, the percentage removed mechanically is the maximum possible given the equipment capacities. In addition, dispersant use, if performed with mechanical recovery, would likely account for more of the oil removal from the water surface in an actual spill event than is reflected by the Phase I results.

In Phase II modeling, the mechanical recovery rates were adjusted to take into account inefficiencies in applying mechanical recovery methods as observed in many actual spill responses and as indicated by research done by experts in the field (Etkin, 2005b). The modeled removal rate decreased over time due to the spreading of the oil on the water surface and decreasing opportunities to effectively corral and remove oil. As a result, most of the removal would occur in the first 72 hours, and the percent of oil removed by mechanical recovery was for most scenarios <10% of the spilled oil in the Phase II model simulations. However, recovery was a higher percentage of the spilled oil for the Bunker scenarios in the Strait of Juan de Fuca and Grays Harbor. The capacity standards input to the model were larger relative to the spill volume for bunker fuel than the other two oil types. In the Columbia River, the oil came ashore rapidly because of the relatively confined water body, often limiting the on-water recovery. There was not this limitation in the Strait of Juan de Fuca or near/in Grays Harbor. For all scenarios, the pattern is apparent where the amount of oil mechanically removed assuming the federal standards was lower, and the amount removed under the 3rd alternative higher, than in the WA state standard simulation.

In both phases of the modeling, only the planning standard capacities were assumed deployed. With the high recovery efficiencies assumed in Phase I, this would appear

sufficient. However, accounting for the increasing difficulties in recovering oil over time, more equipment would be needed to increase recovery, or, alternatively, recovery efficiency would need to be higher. The latter is the goal of spill planning, and the reality is that more equipment than the standard capacities require would be deployed in the event of spills as large as those simulated in this study.

7.3 Differences in Impacts with Alternative Response Scenarios

Because the oil transport model includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability in the movements of oil spillets in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

In addition, protection booming input to the model deflects oil offshore from the boomed site. In many cases the booms are located to protect inlets, coves and wetlands with small linear shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to “hold” oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be increased by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

Because the differences in amounts of oil removed are small in the Phase II simulations, the differences between runs are in many cases less than the randomized variability in the model and are not significant. However, in some cases, the timing of oil removal and arrival on shore changes, as may be seen in the figures showing oil amounts in various environmental compartments (i.e., mass balance) as a function of time in Section B of Volumes V, VIII, XI, XIV, XVII, XX, XXIII, XXVI, and XXIX. The figures in Section B of these volumes are those Washington Department of Ecology will find most useful in evaluating the various planning standards. There are also figures in Section 4 of this volume (Figures 4-1 to 4-9) that summarize the time (hours after the spill) oil first reached shore for 100 runs of each of the no-response stochastic scenarios.

7.4 Biological Impacts

The majority of the biological impacts are to birds, particularly to seabirds and waterfowl (diving ducks). The highest level of bird mortality occurred in the outer coast region, because the oil remained at sea longer and there were higher abundance of birds there

compared to other areas, such as in the Straits of Juan de Fuca. The Upper Columbia River scenario impacted the fewest birds, since seabird and waterfowl density was less than along the Lower Columbia River and other areas.

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

Diesel is much more readily dispersed naturally into the water column than crude oil, and so the impacts to subtidal fish and invertebrates (those in the water exposed to water and submerged sediment concentrations) are projected to be much higher for diesel than for a larger volume of crude oil. This is because Alaskan crude oil emulsifies rapidly, minimizing entrainment and dissolution into the water. The Bunker C spills had low content of soluble and toxic components, and were not readily dispersed naturally into the water because of the high viscosity of the oil. For these reasons, the effects on fish and invertebrates for the Bunker C spills were very minimal in areas where there is rapid dilution, i.e., on the outer coast, in the Straits of Juan de Fuca, or in the lower Columbia River. In the upper Columbia River, the impacts were primarily on demersal fish such as suckers, catfish and sunfishes. Once the effect of oil type on impacts to subtidal fish and invertebrates is filtered out, it is apparent that the outer coast scenarios (including Grays Harbor) had the least impacts because of the large dilution volumes involved.

Impacts to intertidal invertebrates were evaluated for clams in soft shoreline habitats (wetlands, mud flats and sand beaches). The impacts to clams are proportional to the shoreline area heavily oiled. Trends in the mortality of intertidal invertebrates closely followed the spatial distribution of geoduck clam abundance, resulting in greater mortality in areas, such as the Straits of Juan de Fuca, and the San Juan Islands, where geoduck density is highest. By examining the three Straits of Juan de Fuca scenarios, it becomes evident that spills of crude have the largest impact on intertidal mollusks. This reflects the facts that the spill volume of crude was greater and crude covered a larger shoreline area than the other two types of oil. Within the Juan de Fuca region, intertidal invertebrates experienced the lowest mortality levels in the diesel spill. The low impact of the diesel spill on mollusks can again be attributed to this oil's volatile nature, which causes smaller volumes of it to come ashore.

7.5 Natural Resource Damages

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

and invertebrates, and equivalency is assumed if equal production of similar species (i.e., the same general taxonomic group and trophic level) results.

The estimated costs of saltmarsh restoration required in compensation for the quantified wildlife, fish and invertebrate injuries are summarized for the 9 stochastic scenarios in the executive summary. The total costs for saltmarsh compensation are 2.5 times those estimated assuming seagrass beds would be restored in compensation. However, it is likely that saltmarsh would be the restoration option selected by NRD trustees because it is more likely to be successfully implemented. Thus, the saltmarsh costs, and not the seagrass costs, are the best and most conservative estimates to carry forward to a cost-benefit analysis.

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 III: Model Inputs for Outer Coast Scenarios at Duntz Rock off Cape Flattery – 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

III.A. Introduction 1
III.B. Geographical Data 2
III.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
III.B.2. Gridded Habitat Mapping 3
III.B-3. Gridded Depth Data 4
III.B-4. Areas Where Response Actions Assumed 5
III.C. Current Data 7
III.C.1. Basis of Current Data 7
III.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 8
III.D: Oil Properties 11
III.E: Inputs to the SIMAP Physical Fates Model 14

List of Figures

Figure III.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure III.B.2-1 Habitat grid used for modeling the potential spills. 3
Figure III.B.2-2 Habitat grid used for modeling the potential spills (closer view). 3
Figure III.B.3-1 Depth grid used for modeling the potential spills. 4
Figure III.B.3-2 Depth grid used for modeling the potential spills (closer view). 4
Figure III.B.4-1 Jurisdictions in the area of the potential spills..... 5
Figure III.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure III.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure III.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure III.C.1-1 Grid used for the hydrodynamic model-generated current data. 7
Figure III.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – Duntz Rock off Cape Flattery). 8
Figure III.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 Duntz Rock off Cape Flattery. 9
Figure III.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 Duntz Rock off Cape Flattery. 9
Figure III.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 Duntz Rock off Cape Flattery. 10
Figure III.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 Duntz Rock off Cape Flattery. 10
Figure III.E-1. Wind Station Locations. 20

List of Tables

Table III.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 11
Table III.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil..... 12
Table III.E-1. Inputs to the Fates Model for Stochastic Scenarios 14
Table III.E-2. Time, date and location inputs for each of the 100 stochastic runs. 17
Table III.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 19
Table III.E-4. Water temperature by month of the year (from French et al., 1996b). 19
Table III.E-5. Wind data sources and records used. 20

III.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.

III.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.

III.B.1. Maps of the Vicinity of the Modeled Spill Locations

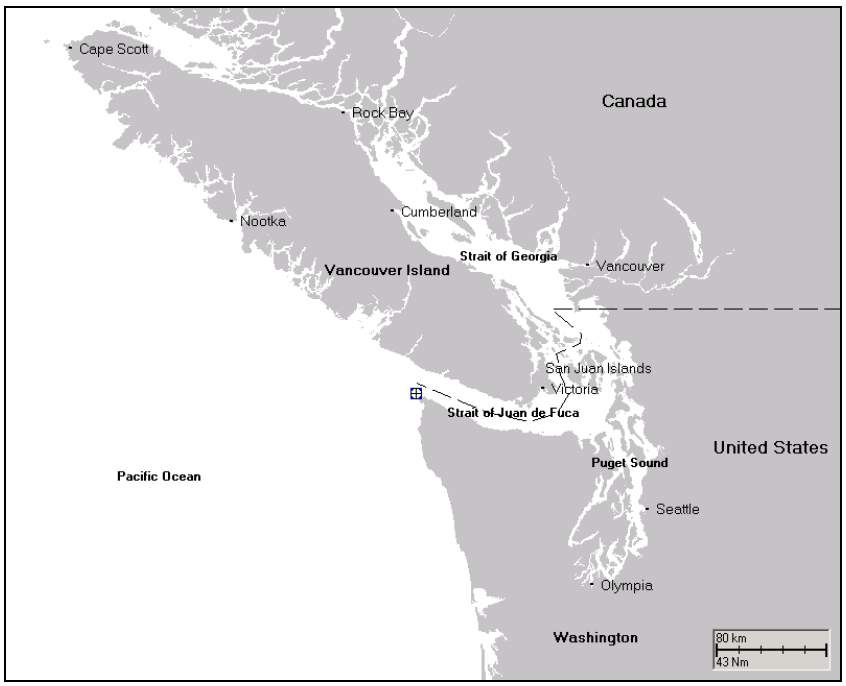


Figure III.B.1-1 Map of the vicinity of the potential spill locations.

III.B.2. Gridded Habitat Mapping

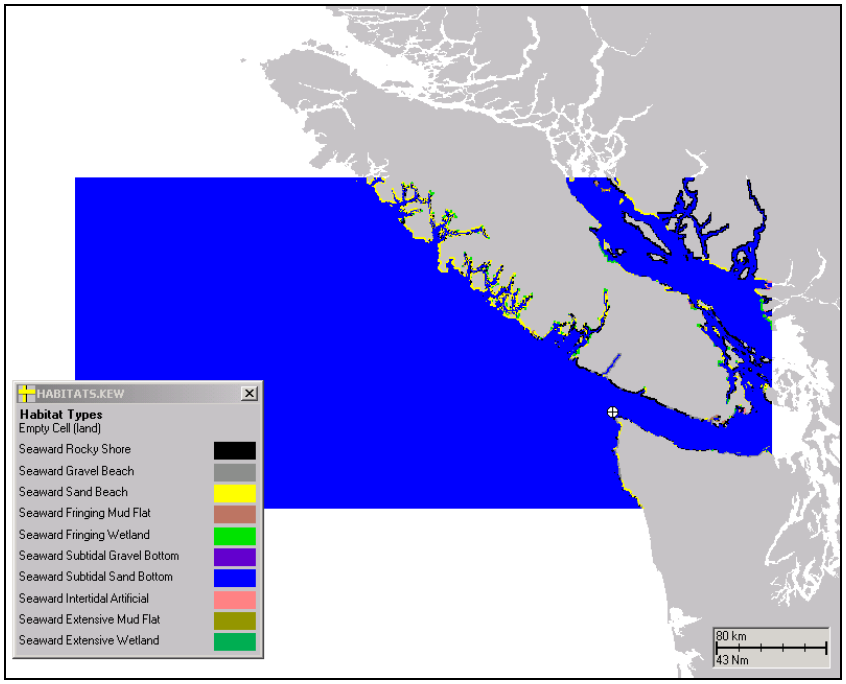


Figure III.B.2-1 Habitat grid used for modeling the potential spills.

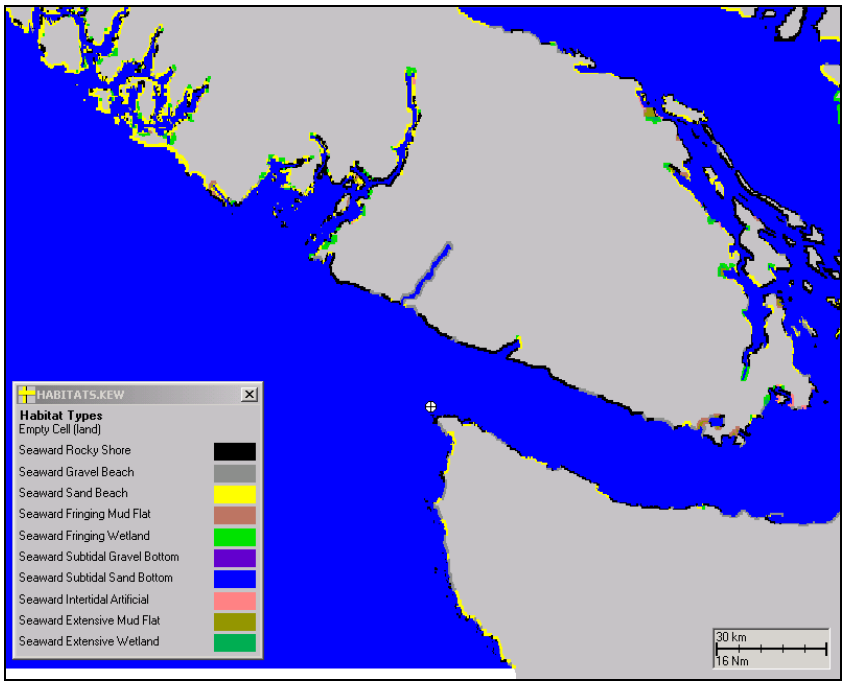


Figure III.B.2-2 Habitat grid used for modeling the potential spills (closer view).

III.B-3. Gridded Depth Data

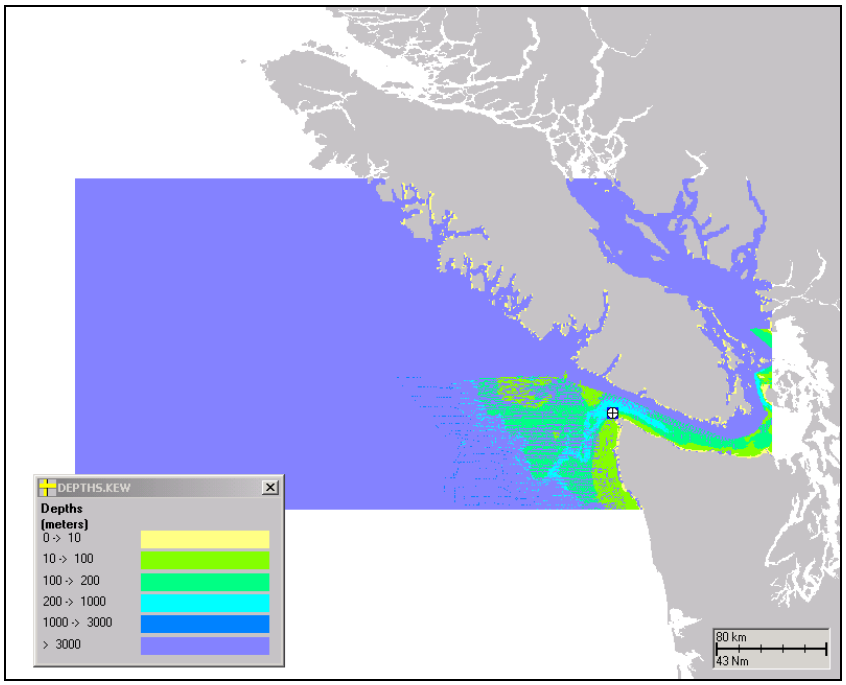


Figure III.B.3-1 Depth grid used for modeling the potential spills.

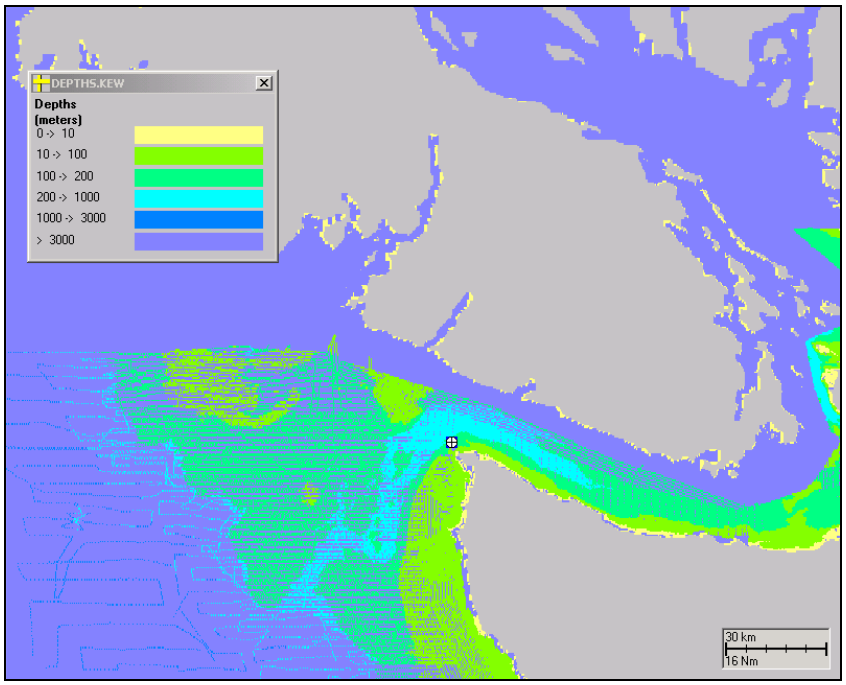


Figure III.B.3-2 Depth grid used for modeling the potential spills (closer view).

III.B-4. Areas Where Response Actions Assumed

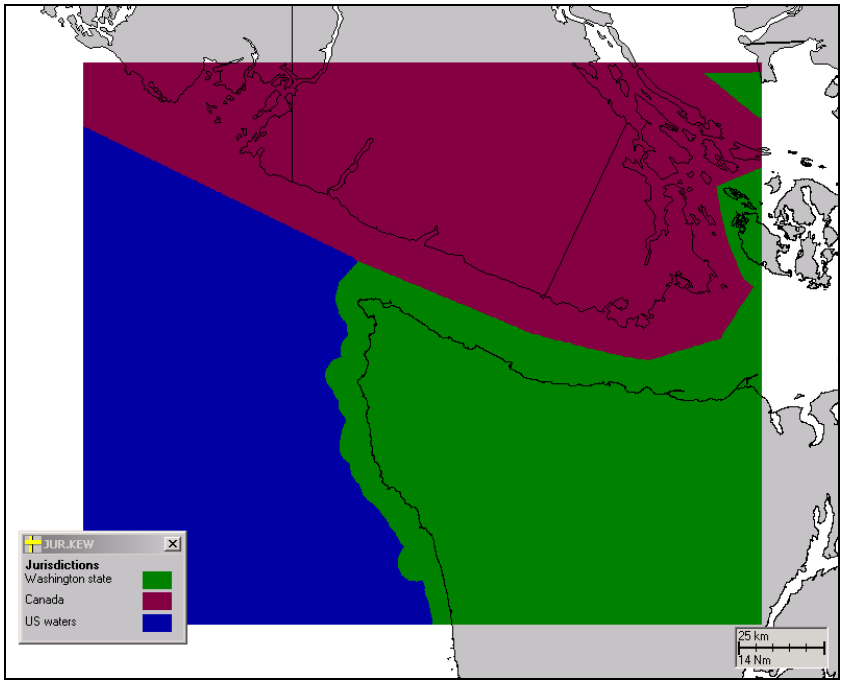


Figure III.B.4-1 Jurisdictions in the area of the potential spills.

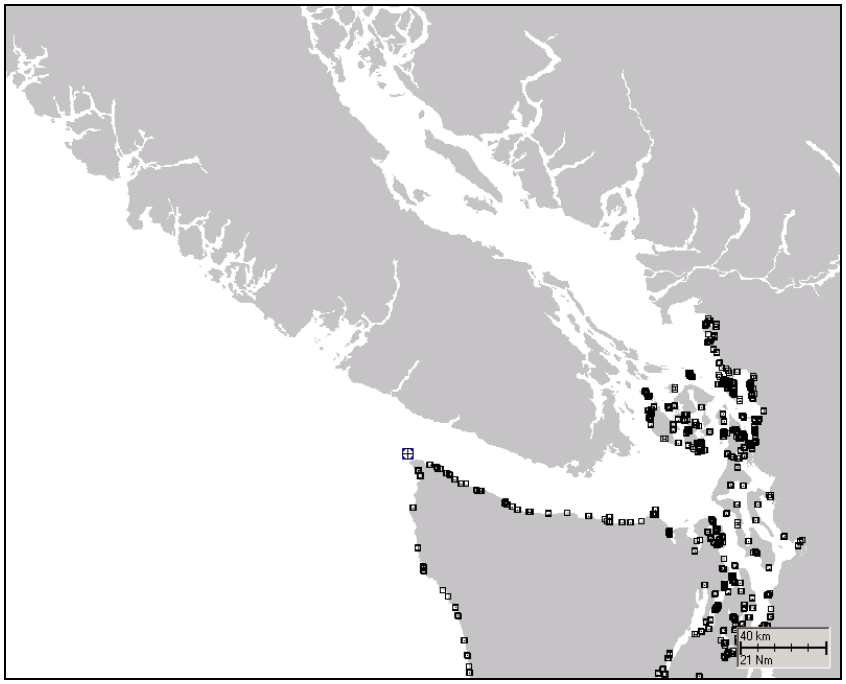


Figure III.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

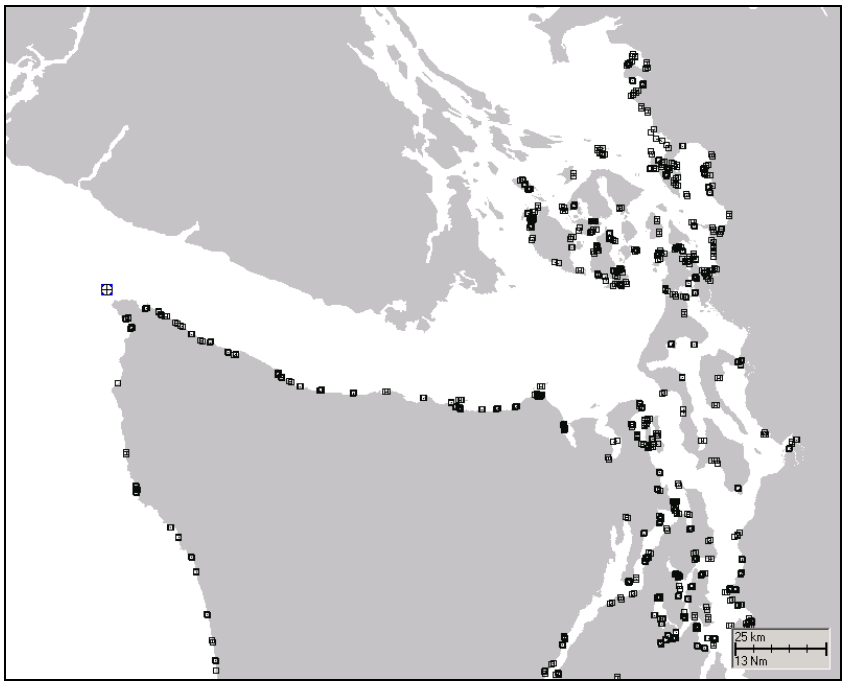


Figure III.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

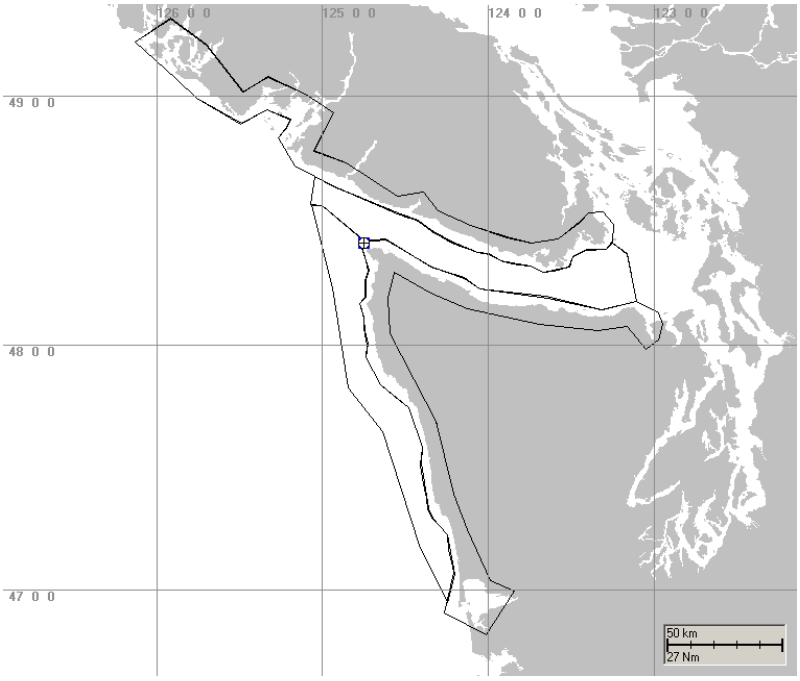


Figure III.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

III.C. CURRENT DATA

III.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).

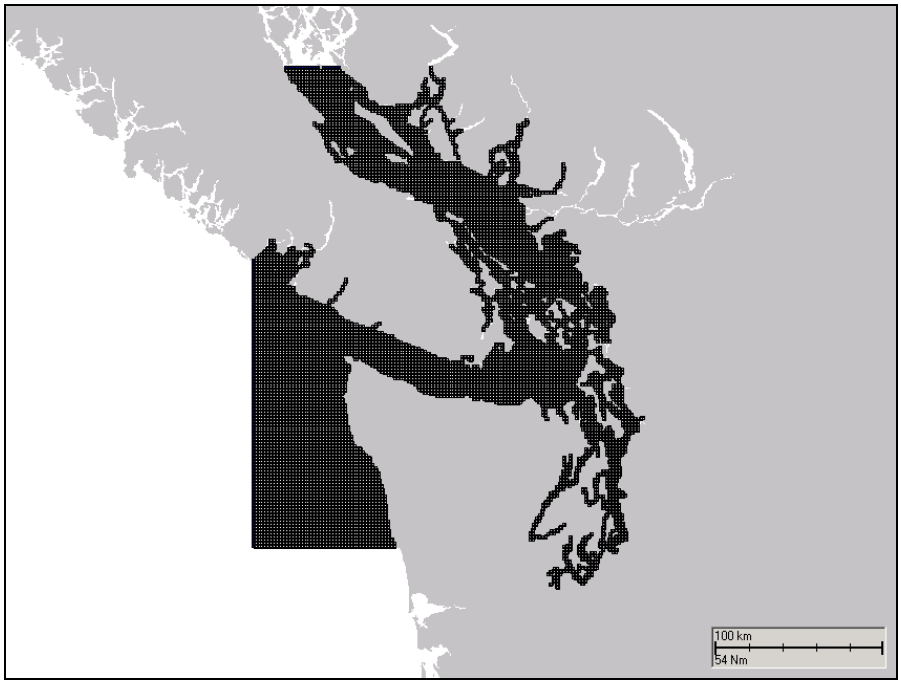


Figure III.C.1-1 Grid used for the hydrodynamic model-generated current data.

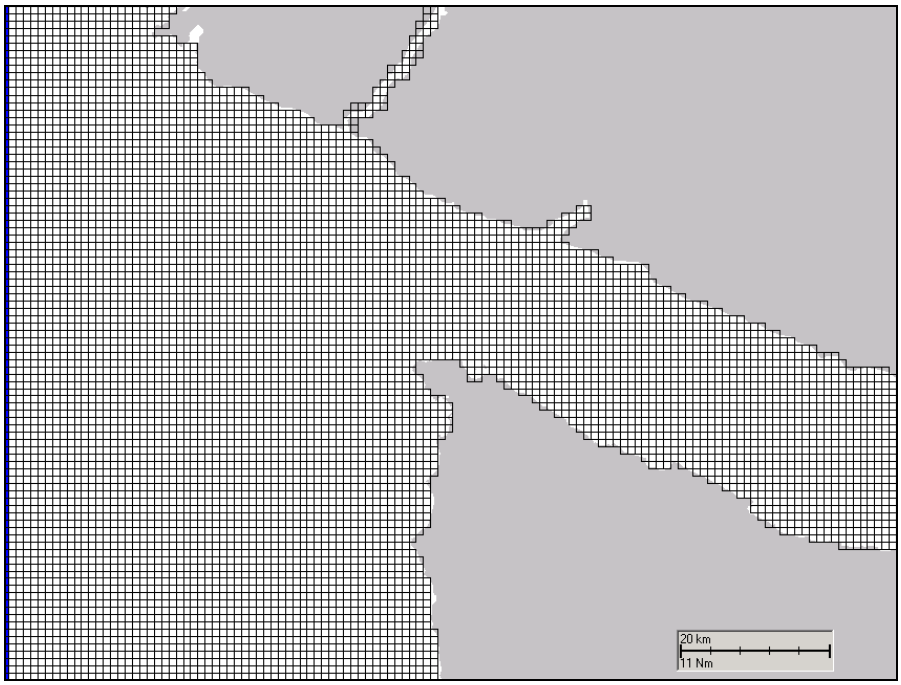


Figure III.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – Duntz Rock off Cape Flattery).

III.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.

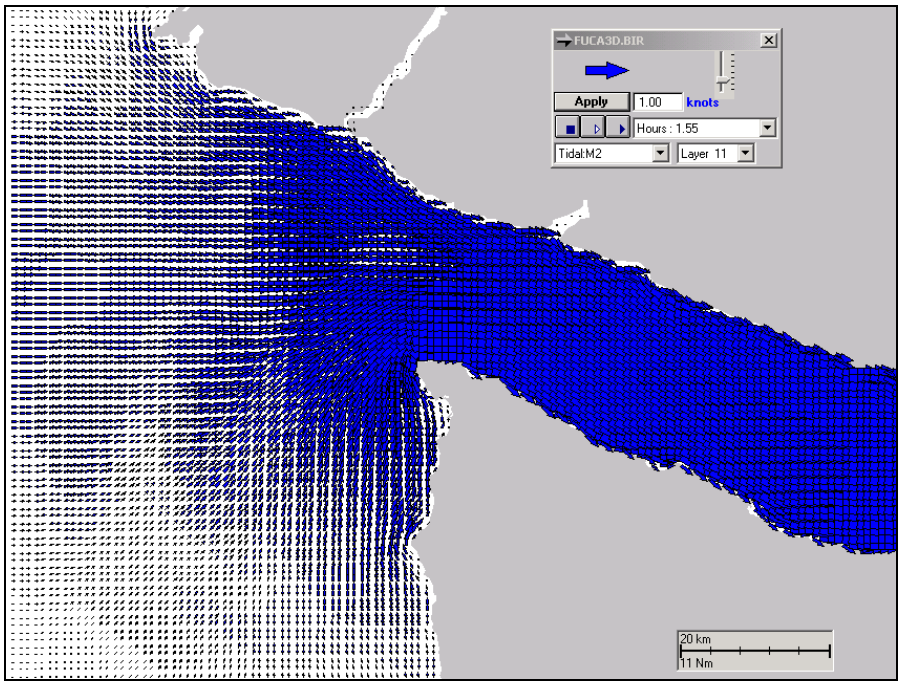


Figure III.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Duntz Rock off Cape Flattery.

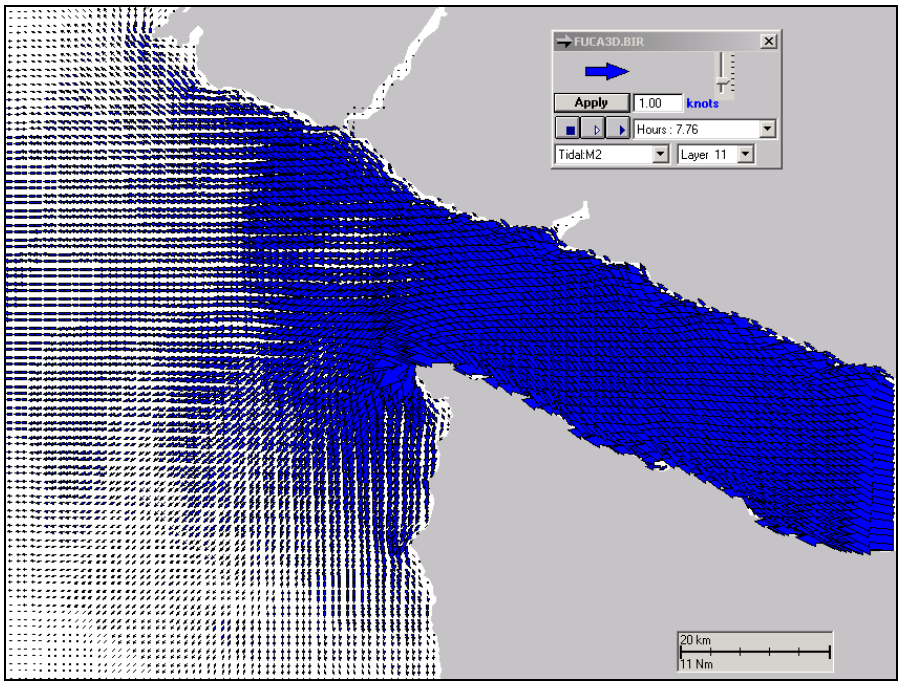


Figure III.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Duntz Rock off Cape Flattery.

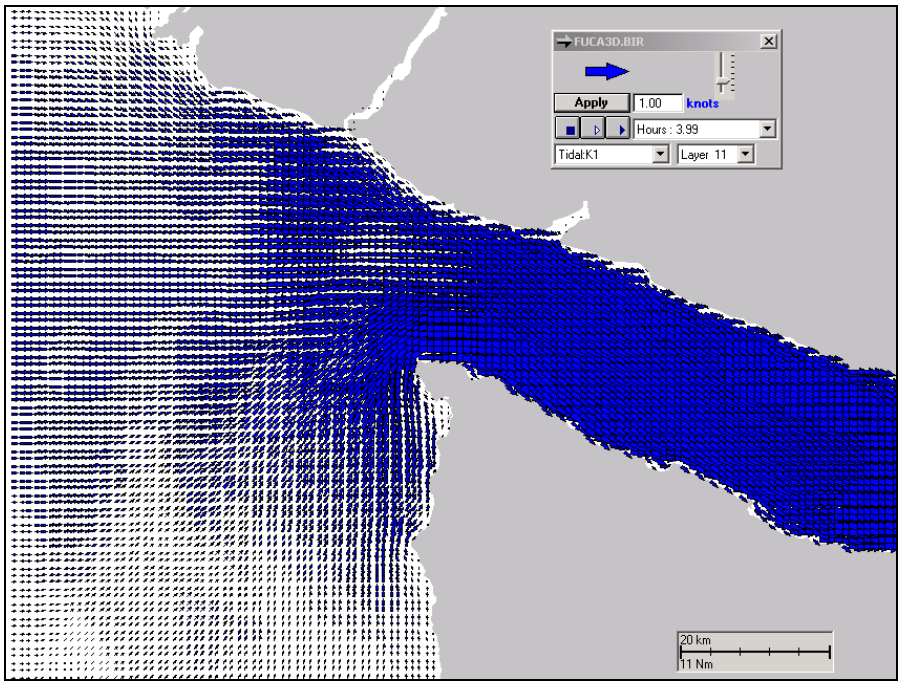


Figure III.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Duntz Rock off Cape Flattery.

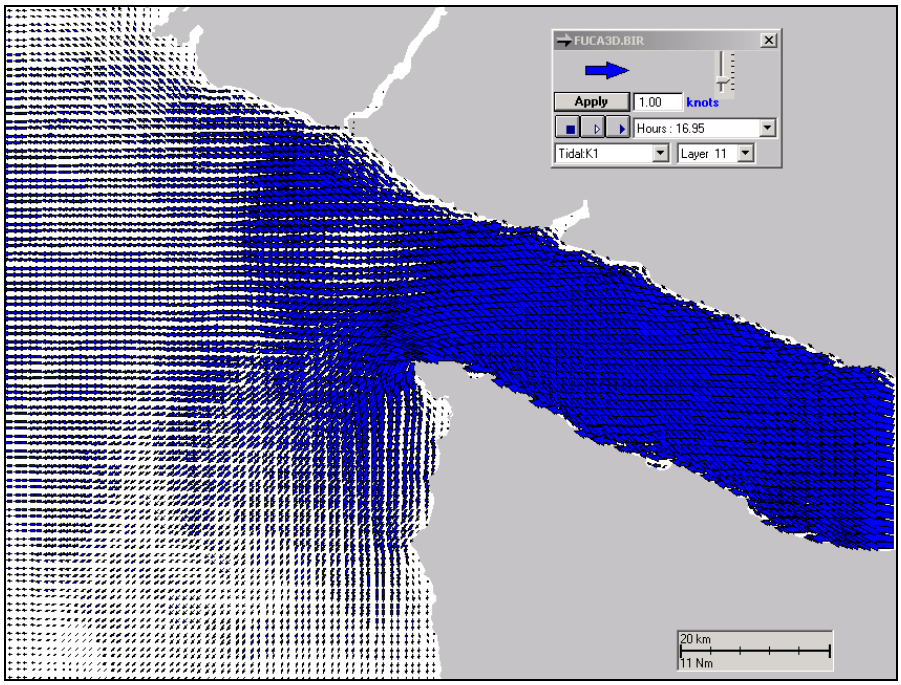


Figure III.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Duntz Rock off Cape Flattery.

III.D: OIL PROPERTIES

Table III.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 III.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 III.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).

III.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 III.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	At Duntz Rock NW of Cape Flattery
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	48° 24.781’ N
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	124° 44.718’ W
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 III.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table III.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 49	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 49	monthly means (see Table III.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 49	monthly means (see Table III.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

Table III.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	1993	9	28	9	48.41302	124.745
2	1993	6	14	15	48.41302	124.745
3	1993	10	1	4	48.41302	124.745
4	1999	4	7	19	48.41302	124.745
5	2002	4	14	21	48.41302	124.745
6	2000	11	15	8	48.41302	124.745
7	1996	5	20	6	48.41302	124.745
8	1997	1	1	9	48.41302	124.745
9	2000	5	15	1	48.41302	124.745
10	1992	11	14	13	48.41302	124.745
11	1995	5	30	15	48.41302	124.745
12	2003	12	6	19	48.41302	124.745
13	2000	3	9	1	48.41302	124.745
14	1998	7	16	13	48.41302	124.745
15	1998	6	13	9	48.41302	124.745
16	1992	1	15	14	48.41302	124.745
17	1994	6	15	23	48.41302	124.745
18	1992	9	20	15	48.41302	124.745
19	1995	5	21	6	48.41302	124.745
20	1994	3	21	19	48.41302	124.745
21	2000	6	14	23	48.41302	124.745
22	1993	7	7	2	48.41302	124.745
23	1992	5	31	19	48.41302	124.745
24	2000	8	17	18	48.41302	124.745
25	1998	7	7	21	48.41302	124.745
26	1998	8	22	21	48.41302	124.745
27	1999	3	14	21	48.41302	124.745
28	1996	3	12	20	48.41302	124.745
29	2003	6	30	13	48.41302	124.745
30	1999	1	15	15	48.41302	124.745
31	1994	5	3	23	48.41302	124.745
32	1992	7	4	2	48.41302	124.745
33	2000	11	13	17	48.41302	124.745
34	2001	1	17	7	48.41302	124.745
35	2000	6	10	3	48.41302	124.745
36	1997	2	10	21	48.41302	124.745
37	2000	6	19	3	48.41302	124.745
38	2002	5	27	19	48.41302	124.745
39	1996	6	3	21	48.41302	124.745
40	2000	5	6	8	48.41302	124.745
41	1995	1	30	23	48.41302	124.745
42	2000	11	29	17	48.41302	124.745
43	2001	1	8	22	48.41302	124.745
44	1993	1	3	11	48.41302	124.745
45	2002	1	22	1	48.41302	124.745
46	1993	8	25	9	48.41302	124.745
47	2003	12	8	3	48.41302	124.745
48	2003	5	23	19	48.41302	124.745
49	1992	11	25	10	48.41302	124.745
50	2003	12	21	15	48.41302	124.745

51	2000	10	7	20	48.41302	124.745
52	2003	4	18	2	48.41302	124.745
53	1992	12	23	7	48.41302	124.745
54	2003	12	25	20	48.41302	124.745
55	1993	4	8	1	48.41302	124.745
56	1995	4	11	18	48.41302	124.745
57	1999	1	10	11	48.41302	124.745
58	1993	4	3	3	48.41302	124.745
59	1994	4	7	21	48.41302	124.745
60	1996	7	3	0	48.41302	124.745
61	2001	1	24	2	48.41302	124.745
62	2002	2	15	22	48.41302	124.745
63	1993	7	31	8	48.41302	124.745
64	1999	6	3	14	48.41302	124.745
65	2003	4	26	20	48.41302	124.745
66	1992	3	1	16	48.41302	124.745
67	1996	7	3	15	48.41302	124.745
68	1995	5	17	8	48.41302	124.745
69	2000	11	14	10	48.41302	124.745
70	1998	1	2	9	48.41302	124.745
71	1992	6	16	13	48.41302	124.745
72	2003	2	3	4	48.41302	124.745
73	1999	5	28	18	48.41302	124.745
74	1998	6	10	22	48.41302	124.745
75	2002	5	23	15	48.41302	124.745
76	1995	2	14	17	48.41302	124.745
77	2000	1	8	2	48.41302	124.745
78	2003	10	20	17	48.41302	124.745
79	1999	5	26	11	48.41302	124.745
80	1992	2	8	11	48.41302	124.745
81	2000	2	3	21	48.41302	124.745
82	1992	8	19	2	48.41302	124.745
83	1993	1	5	10	48.41302	124.745
84	2002	2	4	11	48.41302	124.745
85	1993	8	24	4	48.41302	124.745
86	1992	5	16	23	48.41302	124.745
87	2002	3	14	11	48.41302	124.745
88	1996	3	26	2	48.41302	124.745
89	2002	4	18	22	48.41302	124.745
90	1994	7	11	15	48.41302	124.745
91	2000	1	9	10	48.41302	124.745
92	1992	11	27	6	48.41302	124.745
93	1996	5	27	21	48.41302	124.745
94	1992	9	2	6	48.41302	124.745
95	2000	8	28	21	48.41302	124.745
96	2000	2	11	2	48.41302	124.745
97	1999	2	22	1	48.41302	124.745
98	1994	5	10	18	48.41302	124.745
99	2000	9	11	17	48.41302	124.745
100	2000	6	27	3	48.41302	124.745

Table III.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	OC_HABS-COARSE.HAB
Grid W edge	130° 22.1'W
Grid S edge	47° 44.9' N
Cell size (^{o}longitude)	0.004161^{o} W
Cell size (^{o}latitude)	0.004161^{o} N
Cell size (m) west-east	310.59
Cell size (m) south-north	457.72
# cells west-east	1750
# cells south-north	550
Water cell area (m^2)	142,165.64
Shore cell length (m)	377.05
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 III.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	9	8	20
February	8	8	20
March	9	8	20
April	10	8	20
May	12	8	20
June	13	8	20
July	13	7	10
August	15	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	9	7	20

Table III.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
TTIW1_1992_2003_ LST.WNE	Station TTIW1 - Tatoosh Island, WA	48.39 ºN 124.74 ºW	1991-2003	National Data Buoy Center

The TTIW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station TTIW1 - Tatoosh Island, WA. Figure III.E-1 displays where the buoy is located along with surrounding buoys. TTIW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

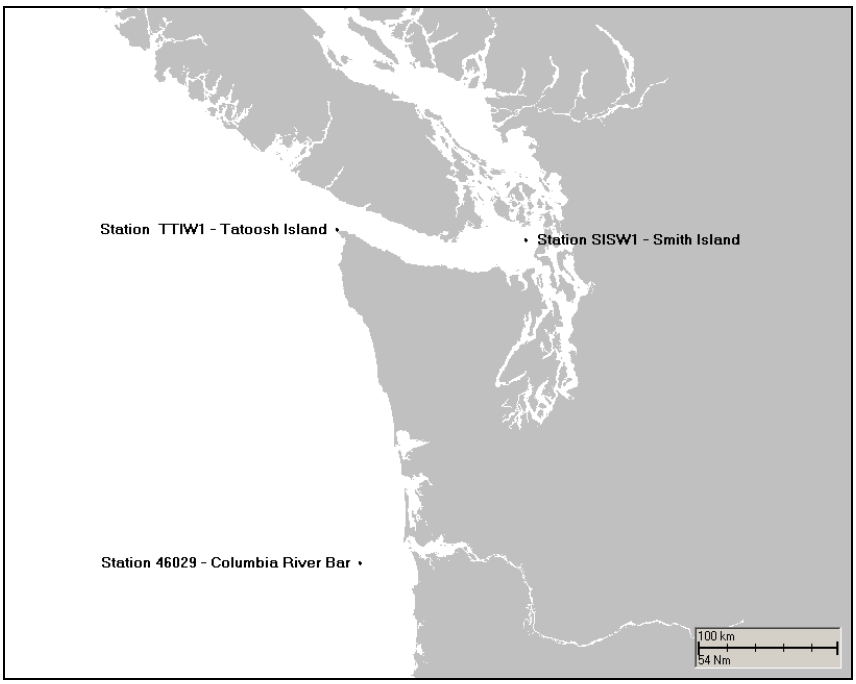


Figure III.E-1. Wind Station Locations.

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 IV: Model Results for Runs Assuming No Response for Outer Coast at Duntz Rock off Cape Flattery – 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

IV.A. Introduction..... 1
IV.B. Maps of Exposure Probability and Time First Exposed 1
IV.C. Statistics for All Model Runs..... 3
IV.D. Shoreline Areas Exposed by Shore Type 6
IV.E. Exposure for Representative Individual Model Runs. 8
IV.F. Estimated Biological Impacts: Wildlife 11
IV.G. Estimated Biological Impacts: Fish and Invertebrates 14
IV.H. Estimated NRDA Costs: Habitat Restoration Costs..... 16
IV.I. Estimated NRDA Costs: Washington Compensation schedule 19

List of Figures

Figure IV.B-1. Outer Coast, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure IV.B-2. Outer Coast, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. 2
Figure IV.C-1. Outer Coast, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 5
Figure IV.C-2. Outer Coast, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill. 5
Figure IV.E-1. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 9
Figure IV.E-2. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary..... 9
Figure IV.E-3. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island. 10

List of Tables

Table IV.C-1. Outer Coast, No removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 4
Table IV.D-1. Outer Coast, No removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 6
Table IV.D-2. Outer Coast, No removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 6
Table IV.D-3. Outer Coast, No removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 7
Table IV.D-4. Outer Coast, No removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 7
Table IV.F-1. Outer Coast, no removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose. 12
Table IV.F-2. Outer Coast, no removal: Wildlife injury (as numbers lost). 13
Table IV.G-1. Outer Coast, no removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column... 15
Table IV.G-2. Outer Coast, no removal: Fish and invertebrate injury (as biomass lost in kg). 15
Table IV.H-1. Outer Coast, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 17
Table IV.H-2. Outer Coast, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 18
Table IV.I-1. Outer Coast, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 19

IV.A. INTRODUCTION

The results of the stochastic scenario for the Outer Coast at Duntz Rock off Cape Flattery 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).

IV.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)

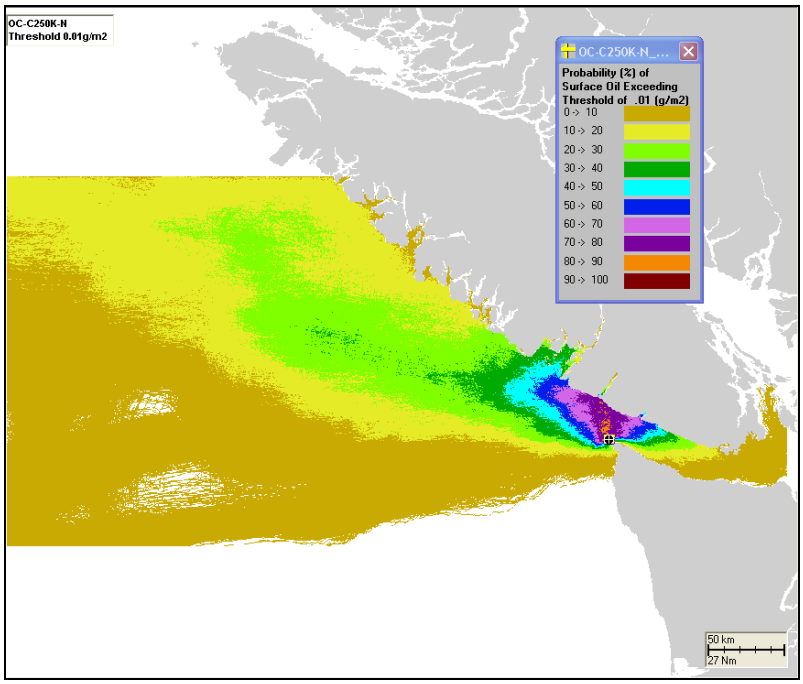


Figure IV.B-1. Outer Coast, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

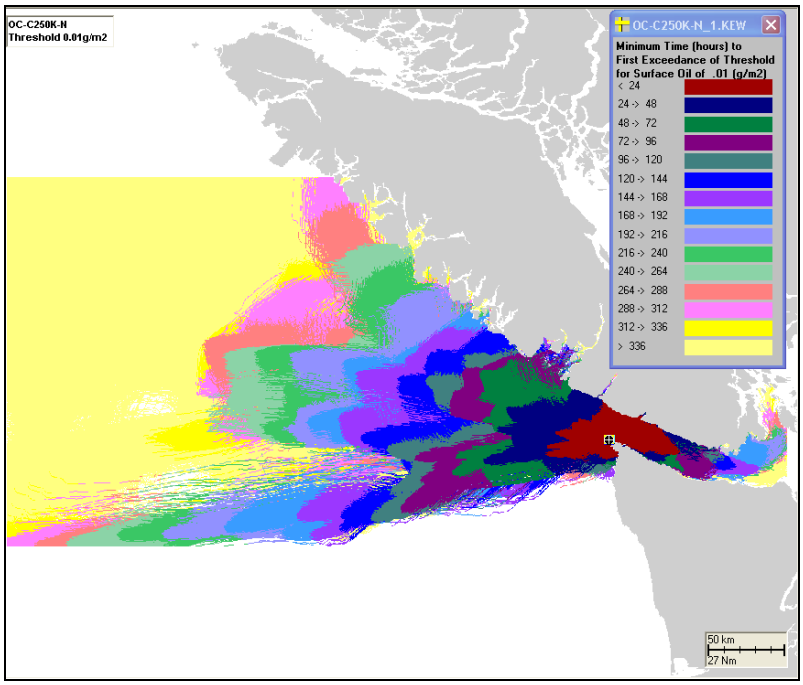


Figure IV.B-2. Outer Coast, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed for the Outer Coast location, maximum water column exposure of dissolved aromatic concentration never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

IV.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 IV.C-1. Outer Coast, No 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)	2,361	1,004	4,369	0	2,158	4,480	5,634
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	1,684	695	3,073	0	1,569	3,069	3,802
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	43,444	14,781	73,006	0	40,805	74,589	84,822
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	43,362	14,765	72,891	0	40,738	74,468	84,766
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	41,671	14,221	70,112	0	38,453	70,047	83,221
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	31,730	10,799	53,327	0	30,483	53,631	65,568
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	13,372	4,469	22,309	0	12,909	21,552	25,957
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	2,311	585	3,481	0	2,322	3,381	4,268
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 (%)	11.74	7.29	26.33	2	11.57	23.89	25.37
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	4.9027	3.7730	12.4487	1	4.3520	11.9411	18.0873
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	7.00	3.62	14.23	0	7.04	16.11	17.74

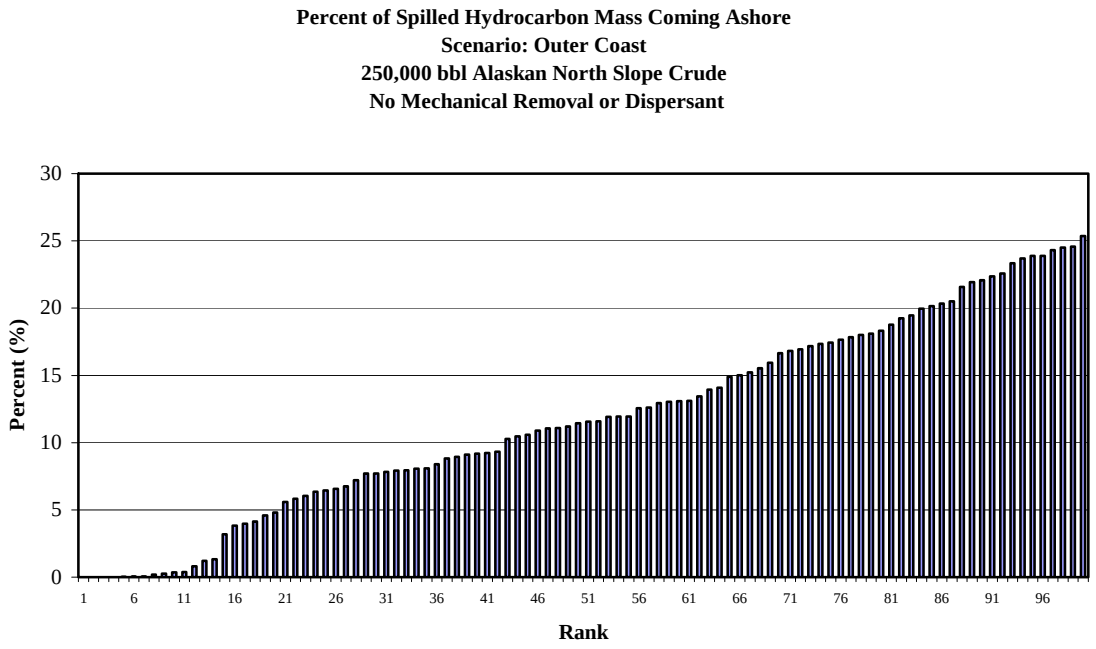


Figure IV.C-1. Outer Coast, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

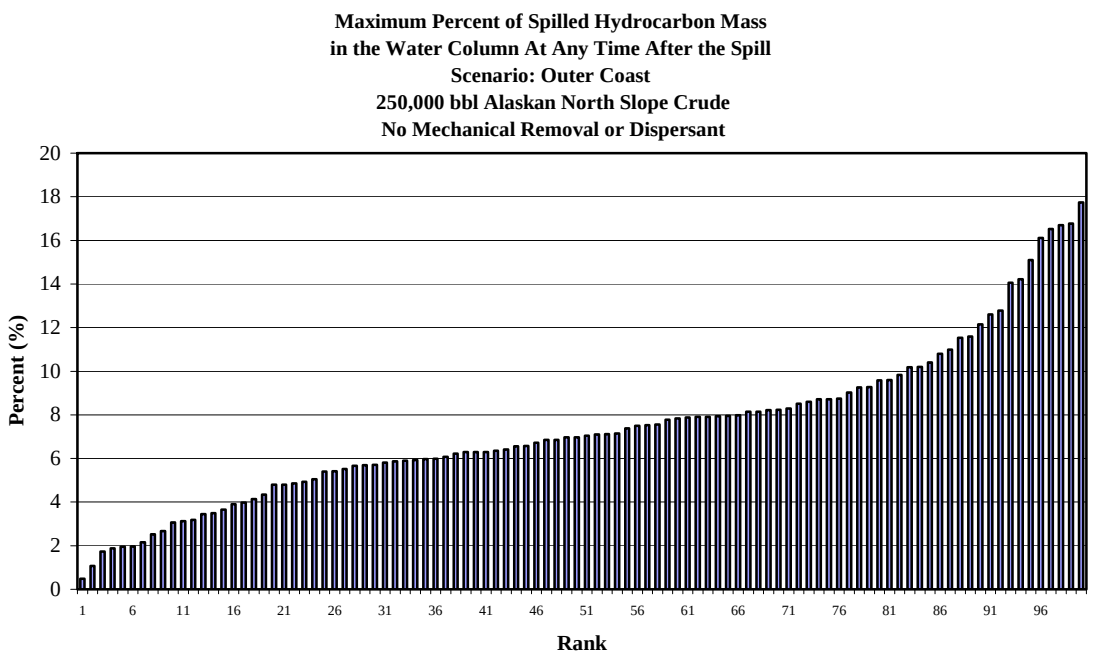


Figure IV.C-2. Outer Coast, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

IV.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 IV.D-1. Outer Coast, No 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	1,596,047	275,999	87,098	837,049	0	395,901	0
95th	5,878,569	630,048	253,377	1,747,624	316,721	2,929,668	1,131
Maximum	9,051,064	920,747	575,376	4,094,760	1,266,883	3,483,930	32,803
Mean	2,261,125	347,963	230,626	815,727	113,228	753,004	577
Std. Dev.	1,987,060	213,413	154,614	974,787	218,301	962,973	3,320
Mean + 2 Std. Dev.	6,235,245	774,789	539,854	2,765,301	549,830	2,678,950	7,217

Table IV.D-2. Outer Coast, No 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	1,525,541	484,132	464,524	260,164	79,180	237,541	0
95th	5,642,161	625,524	253,377	1,674,100	316,721	2,771,308	1,131
Maximum	7,602,818	899,256	572,737	3,551,808	1,266,883	3,325,570	30,541
Mean	1,954,395	338,609	214,895	679,141	95,016	626,315	419
Std. Dev.	1.708,383	210,853	151,006	780,637	187,307	833,805	3,070
Mean + 2 Std. Dev.	5,371,161	760,315	516,907	2,240,415	469,630	2,293,925	6,559

Table IV.D-3. Outer Coast, No 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	1,017,654	311,065	401,180	147,049	0	158,360	0
95th	3,283,718	614,212	197,951	1,125,492	0	1,346,063	0
Maximum	4,423,161	799,717	472,442	2,369,757	950,162	2,217,046	23,754
Mean	1,270,349	293,137	167,097	413,151	47,508	349,185	271
Std. Dev.	1,040,233	192,053	127,280	427,908	122,769	496,473	2,380
Mean + 2 Std. Dev.	3,350,815	677,243	421,657	1,268,967	293,046	1,342,131	5,031

Table IV.D-4. Outer Coast, No 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	527,490	147,049	58,065	164,016	0	158,360	0
95th	1,310,997	324,639	87,098	424,179	0	475,081	0
Maximum	1,522,522	576,885	316,721	588,196	395,901	950,162	15,836
Mean	566,731	215,992	105,574	146,031	13,461	85,515	158
Std. Dev.	392,451	152,182	89,633	138,596	52,853	155,406	1,584
Mean + 2 Std. Dev.	1,351,633	520,356	284,840	423,223	119,167	396,327	3,326

IV.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 for the Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts for Tatoosh Island.

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.

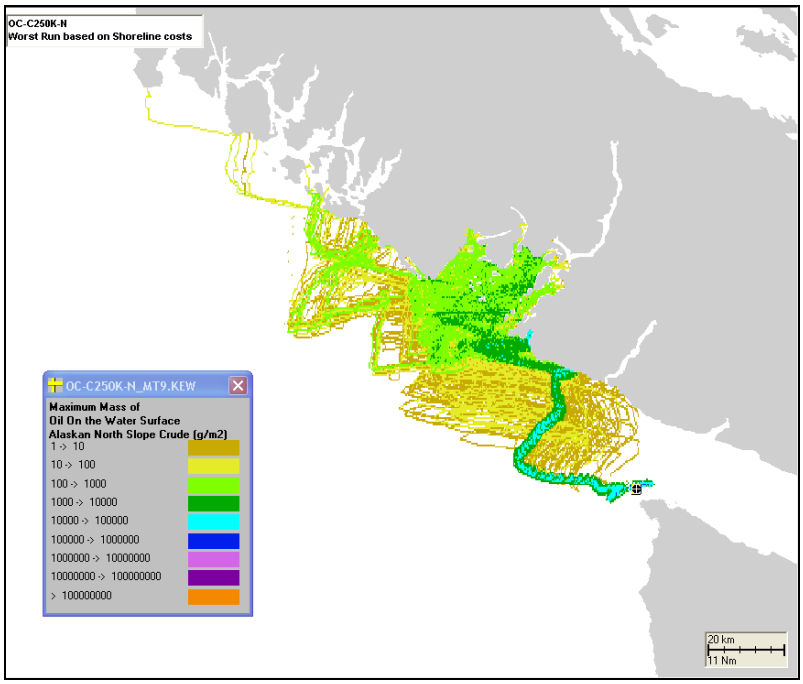


Figure IV.E-1. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

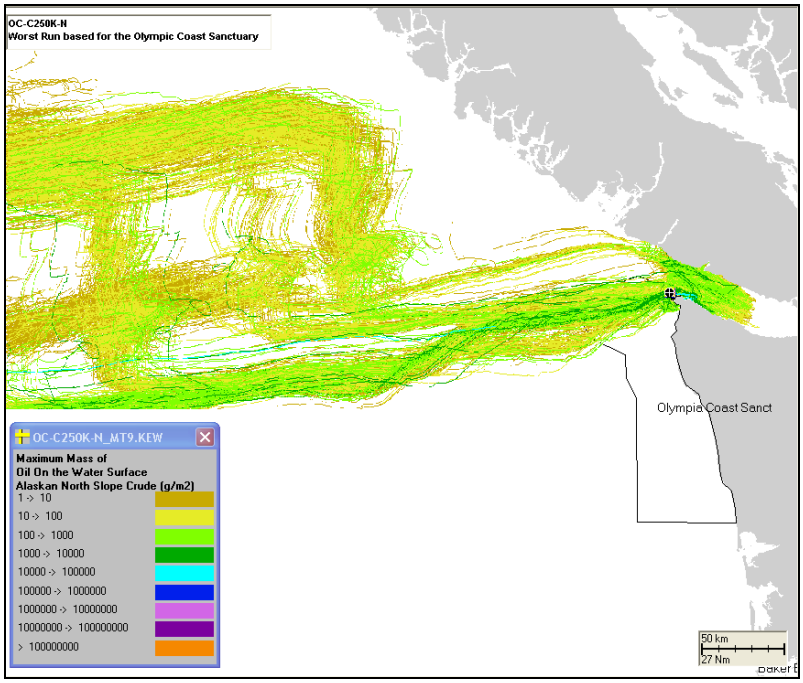


Figure IV.E-2. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary.

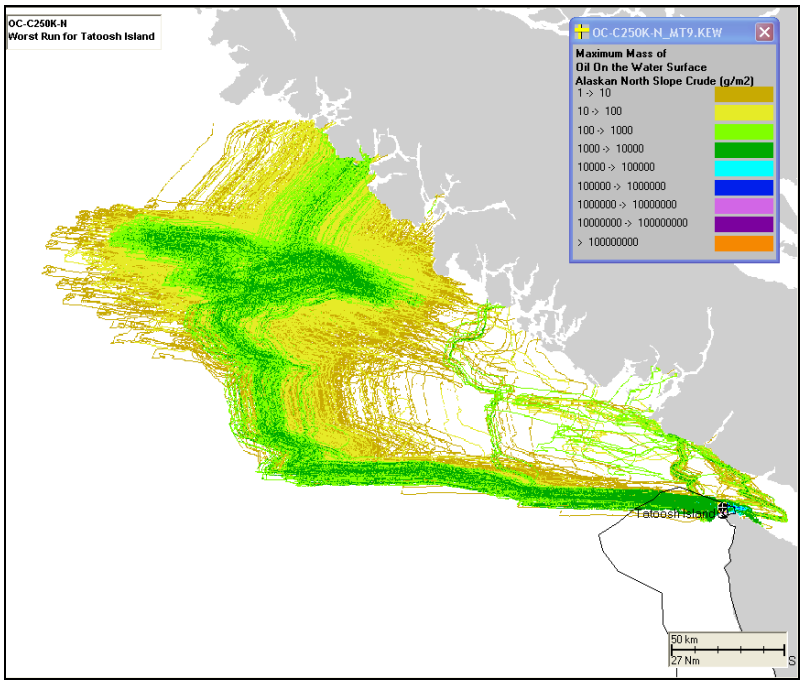


Figure IV.E-3. Outer Coast, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island.

IV.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table IV.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 IV.F-1. Outer Coast, no 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	5.19E-05	-116,604.08	397,125.65	0.6419	0.8012
Seabirds	2.58E-05	22,349.36	100,810.08	0.8731	0.9344
Wading birds	1.33E-05	-2.37	32.63	0.3840	0.6197
Shorebirds	8.48E-04	-155.24	2,039.77	0.3936	0.6274
Raptors[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	2.05E-09	4.25	7.00	0.9003	0.9488
Pinnipeds (seals)	8.75E-09	70.24	128.94	0.3256	0.5706
Other mammals	8.26E-09	24.29	30.80	0.8828	0.9396

[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 IV.F-2. Outer Coast, 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	-	22,349	-	-	-	4	70	24	22,448	22,349	98.77
50th Percentile	7,257	83,938	8	519	-	9	91	44	93,028	92,883	144.23
95th Percentile	974,128	564,703	65	4,149	-	47	254	198	1,539,515	1,539,016	499.16
Mean	281,660	205,770	20	1,301	-	19	132	83	488,986	488,751	234.18
Std Dev (SD)	401,722	210,912	23	1,470	-	17	71	67	612,021	611,866	155.71
Mean - 2SD	-	-	-	-	-	-	-	-	-	-	-
Mean + 2SD	1,085,104	627,593	67	4,241	-	52	275	218	1,713,028	1,712,483	545.59

IV.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table IV.G-1. Outer Coast, no 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	1.85E+02	-820.57	767.44	0.2903	0.5388
Total large pelagic fish	2.42E+02	-1,139.50	1,032.20	0.2799	0.5291
Total demersal fish	1.60E+00	-2.80	7.67	0.2360	0.4858
Total demersal invertebrates	7.03E+00	-36.14	35.52	0.2167	0.4655
Total mollusks[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 fishes and invertebrates (i.e., the regression's intercept) was used to estimate injuries for the additional 88 stochastic runs.
[2] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table IV.G-2. Outer Coast, 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	-	-	0.35	-	-	-	-
50th Percentile	473.70	557.33	8.44	13.12	-	3,243	4,295
95th Percentile	1,978.52	2,530.19	21.52	70.38	-	30,746	35,347
Mean	605.57	742.32	9.11	19.16	-	9,026	10,403
Std Dev (SD)	594.11	766.74	5.75	21.63	-	10,561	11,949
Mean - 2SD	-	-	-	-	-	-	-
Mean + 2SD	1,793.78	2,275.79	20.61	62.41	-	30,149	34,301

IV.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 IV.H-1. Outer Coast, no 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	-	473.7	1,978.5	605.6	-	1,793.8
Large pelagic fish	-	557.3	2,530.2	742.3	-	2,275.8
Demersal fish	0.3	8.4	21.5	9.1	-	20.6
Decapods	-	13.1	70.4	19.2	-	62.4
Molluscs	-	3,243	30,746	9,026	-	30,149
Birds:						
Waterfowl (# * kg each)	-	8,091	1,086,153	314,051	-	1,209,891
Seabirds (# * kg each)	12,516	47,005	316,234	115,231	-	351,452
Waders (# * kg each)	-	5	36	11	-	37
Shorebirds (# * kg each)	-	291	2,323	729	-	2,375
Raptors (# * kg each)	-	-	-	-	-	-
Other wildlife:						
Sea otters, other mammals	13.6	24.6	110.7	46.5	-	122.0
Pinnipeds	39.3	51.0	142.3	74.1	-	154.2
Cetaceans	2.4	5.1	26.5	10.5	-	29.3
Totals:						
Subtotal fish and invertebrates	-	4,295	35,347	10,403	-	34,301
Subtotal birds	12,516	55,392	1,404,746	430,022	-	1,563,756
Subtotal other wildlife	55	81	280	131	-	306
Total all species	12,571	59,768	1,440,372	440,556	-	1,598,363

Table IV.H-2. Outer Coast, no 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)	78.0	299.2	3,242.1	1,083.2	1,260.3	-	3,603.9
Saltmarsh Area (acres)	192.8	739.2	8,011.2	2,676.7	3,114.2	-	8,905.1
Saltmarsh Cost (millions of 2004$)	36.1	138..5	1,501	501.5	583.5	-	1,669
Eelgrass Area (m2)	48.7	186.9	2,026.0	676.9	787.6	-	2,252.1
Eelgrass Area (acres)	120.5	461.9	5,006.2	1,672.6	1,946.1	-	5,564.8
Eelgrass Cost (millions of 2004$)	14.4	55.1	597.7	199.7	232.3	-	664.4

IV.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table IV.I-1. Outer Coast, no 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.)	22.69	23.64	23.64	23.40	21.91	24.89
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	238	248	248	246	230	261

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 V: Results of Alternative Response Scenarios for Outer Coast at Duntz Rock – 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

V.A. Introduction 1
V.B. Oil Fate Over Time 3
V.C. Estimated Biological Impacts: Wildlife 43
V.D. Estimated Biological Impacts: Fish and Invertebrates 47
V.E. Estimated NRDA Costs: Habitat Restoration Costs 49
V.F. Estimated NRDA Costs: Washington Compensation schedule 58

List of Figures

Figure V.A-1 Sensitive sites for location: Outer Coast at Duntz Rock 2
Figure V.B-1 Outer Coast at Duntz Rock - 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 V.B-2 Outer Coast at Duntz Rock - 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 V.B-3 Outer Coast at Duntz Rock - 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 V.B-4 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 7
Figure V.B-5 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 8
Figure V.B-6 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 9
Figure V.B-7 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary..... 10
Figure V.B-8 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Tatoosh Island. 11
Figure V.B-9 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Tatoosh Island. 12
Figure V.B-10 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Tatoosh Island. 13
Figure V.B-11 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Tatoosh Island 14

List of Tables

Table V.B-1 Outer Coast at Duntz Rock - 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). 15
Table V.B-2 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 17
Table V.B-3 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 19
Table V.B-4 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 21
Table V.B-5 Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 23
Table V.B-6 Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 25
Table V.B-7 Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 27
Table V.B-8 Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 29
Table V.B-9 Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh Island. 31
Table V.B-10 Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh Island. 33
Table V.B-11 Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh Island. 35
Table V.B-12 Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh Island. 37
Table V.B-13 Outer Coast at Duntz Rock - 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. 39

Table V.B-14 Outer Coast at Duntz Rock - 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. 40
Table V.B-15 Outer Coast at Duntz Rock - 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. 41
Table V.B-16 Outer Coast at Duntz Rock - 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. 42
Table V.C-1 Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost). 43
Table V.C-2 Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost)..... 44
Table V.C-3 Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost)..... 45
Table V.C-4 Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost)..... 46
Table V.D-1. Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table V.D-2. Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg)..... 47
Table V.D-3. Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg)..... 48
Table V.D-4. Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg)..... 48
Table V.E-1. Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 50
Table V.E-2. Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 51
Table V.E-3. Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration..... 52
Table V.E-4. Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 53
Table V.E-5. Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration..... 54
Table V.E-6. Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 55

Table V.E-7. Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 56
Table V.E-8. Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 57
Table V.F-1. Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table V.F-2. Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table V.F-3. Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table V.F-4. Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59

V.A. INTRODUCTION

The results of the alternate response scenarios for the Outer Coast at Duntz Rock – 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at the Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts at Tatoosh Island (including Tatoosh Island proper and nearby Cape Flattery shorelines).

Locations of the sensitive sites are shown in Figure V.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.

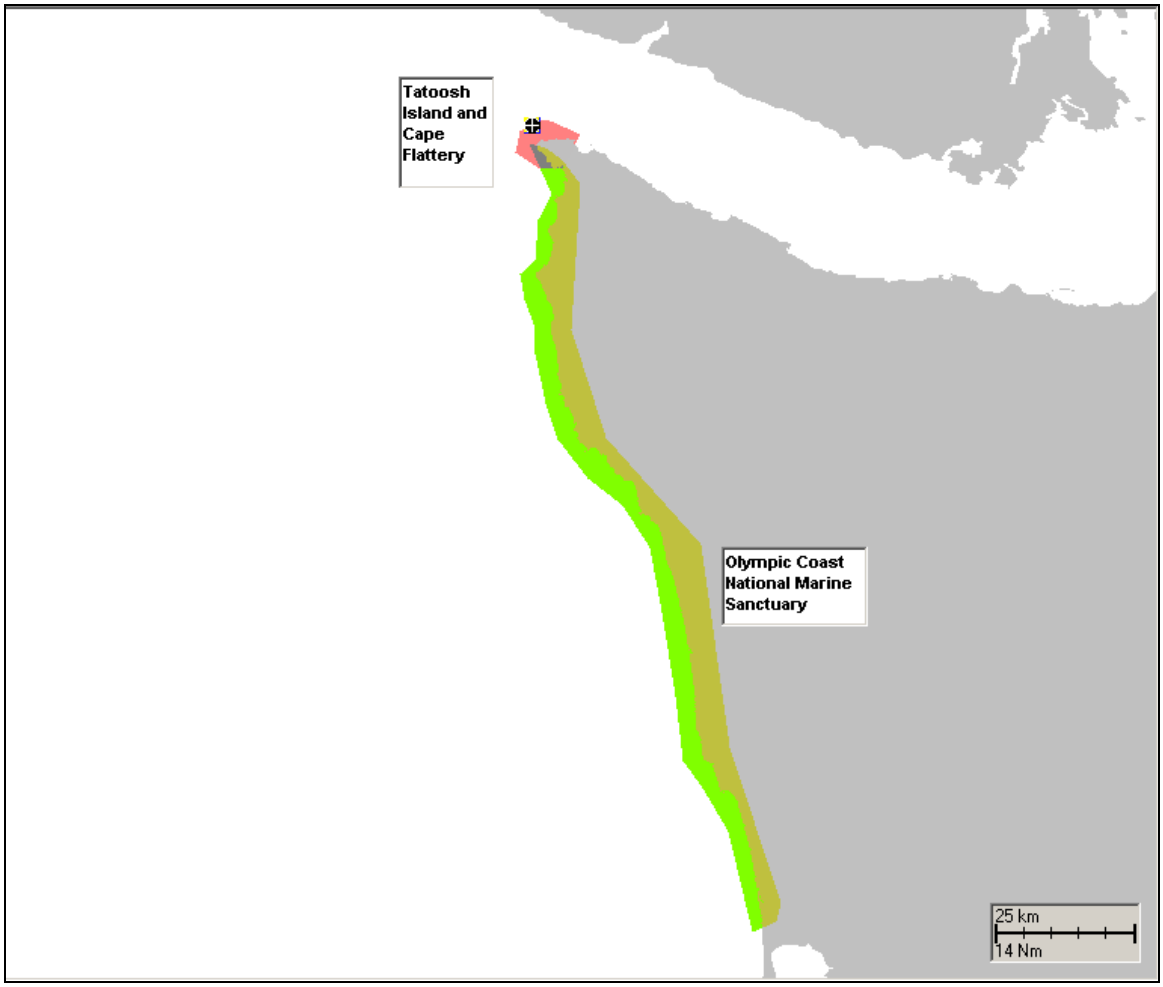
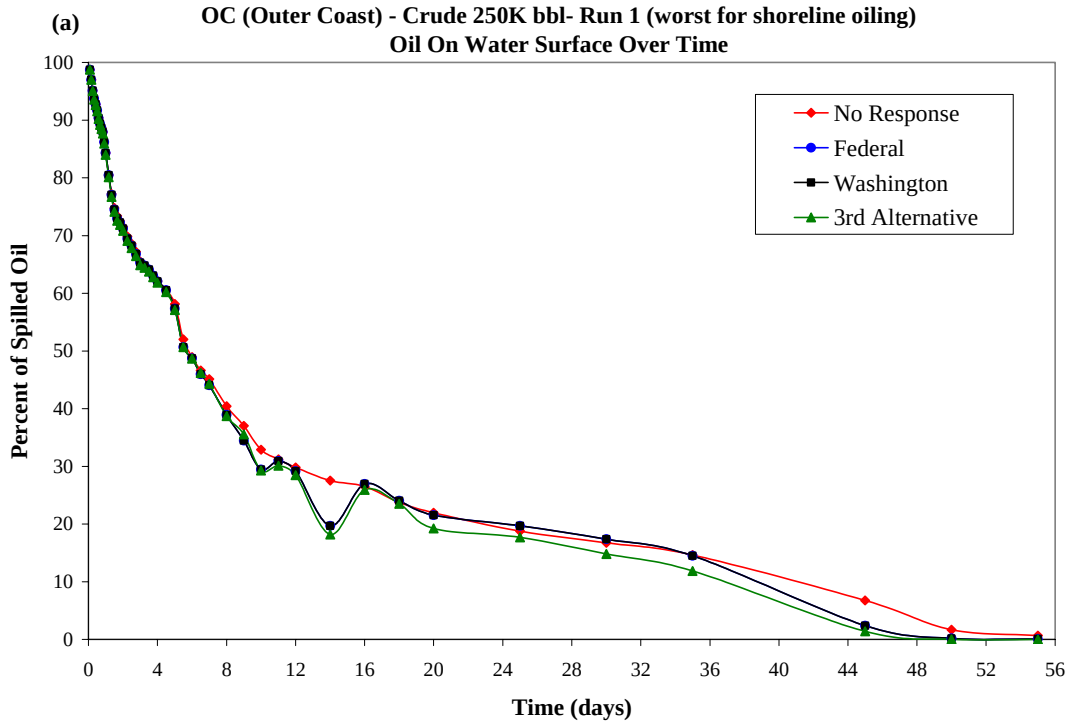


Figure V.A-1 Sensitive sites for location: Outer Coast at Duntz Rock

V.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables V.B-1 to V.B-12 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 V.B-1 to V.B-11 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 V.B-13 to V.B-16 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 Etkin 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.



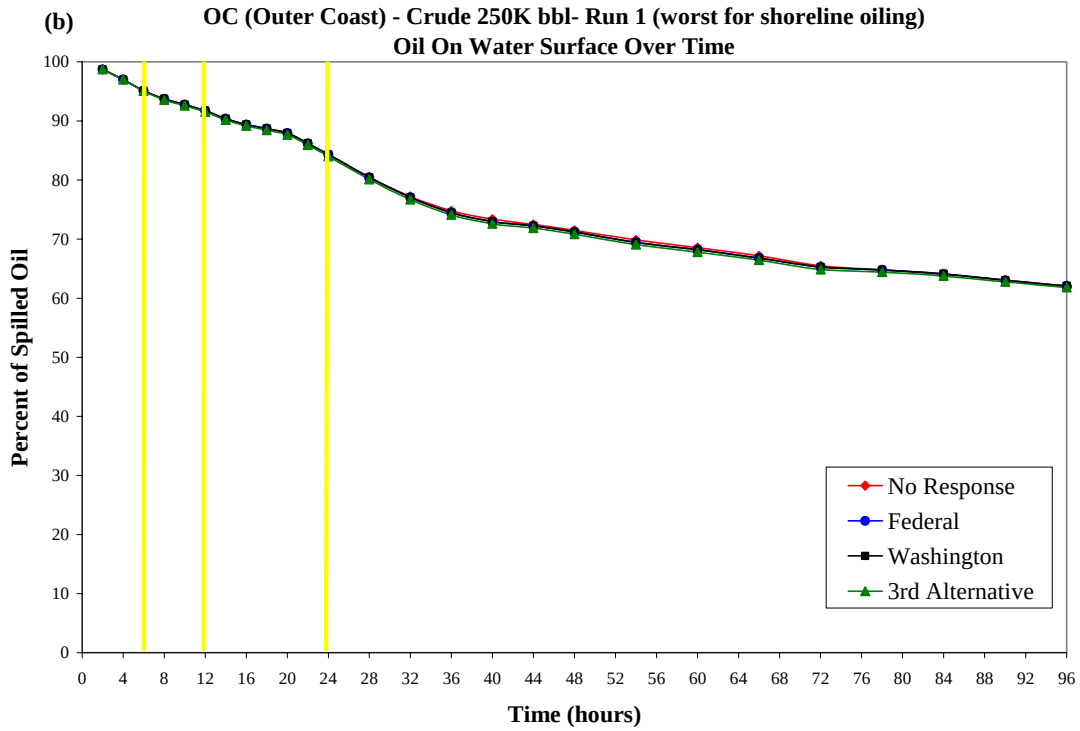


Figure V.B-1 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a.

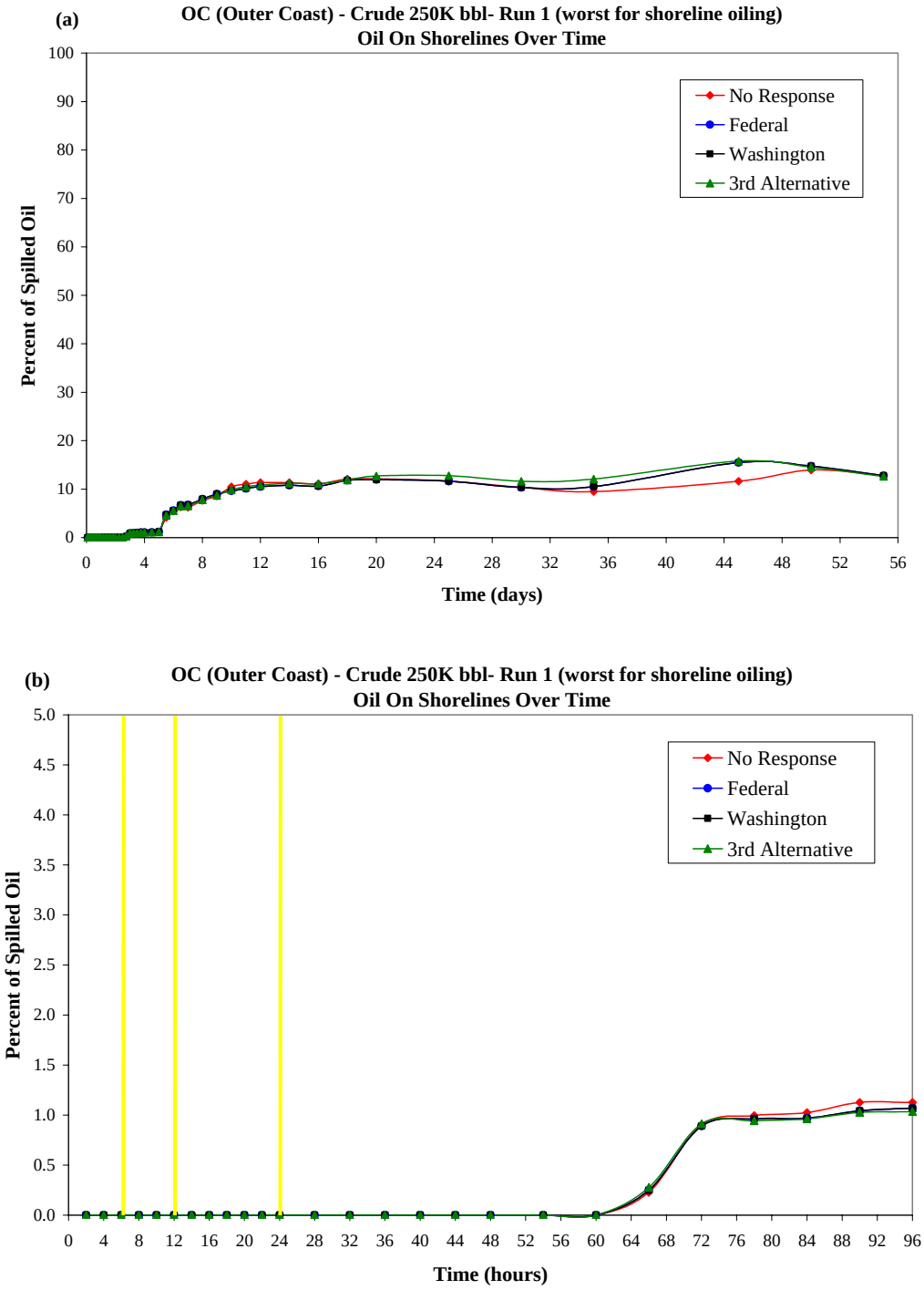


Figure V.B-2 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

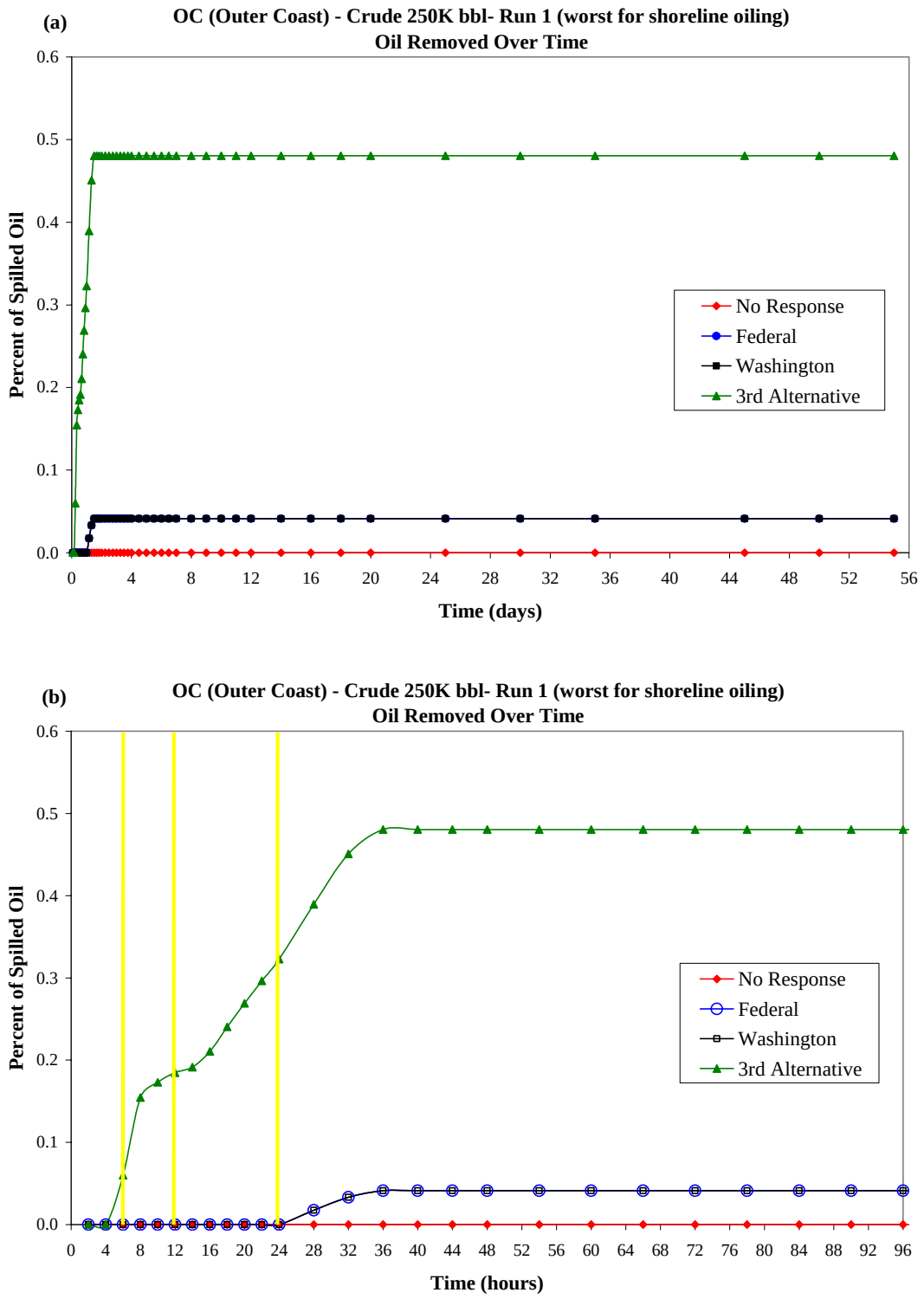


Figure V.B-3 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

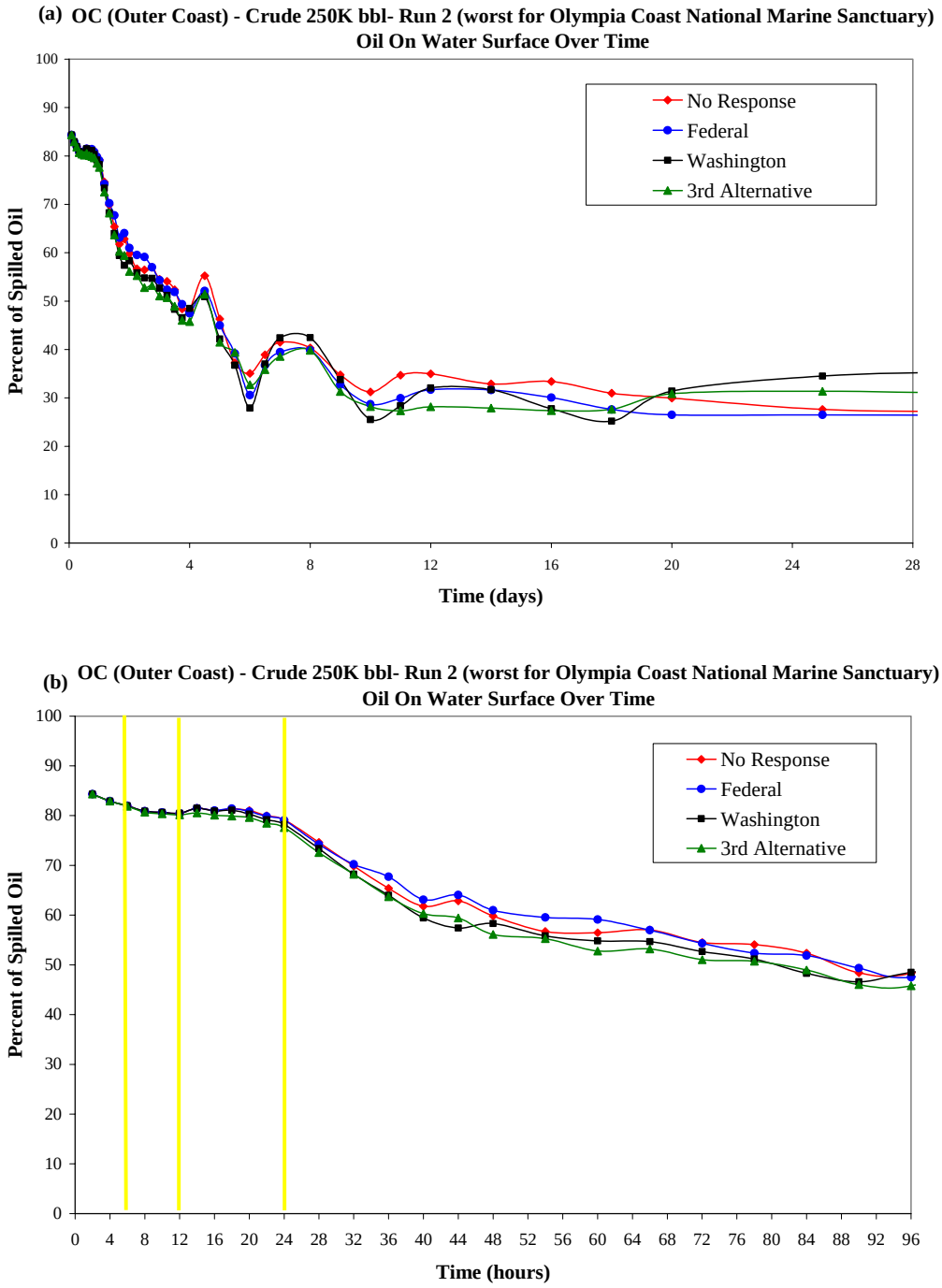


Figure V.B-4 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

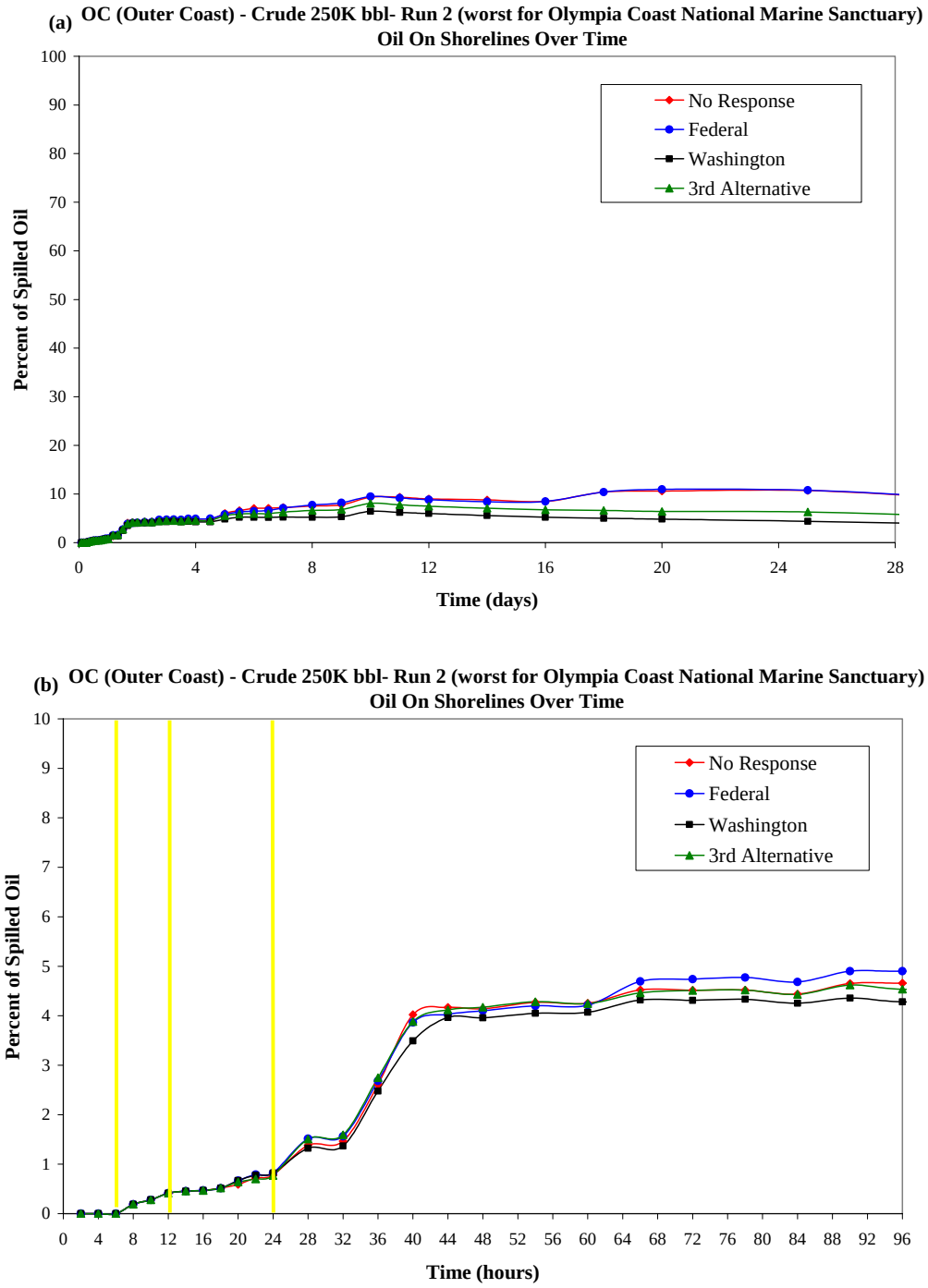


Figure V.B-5 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

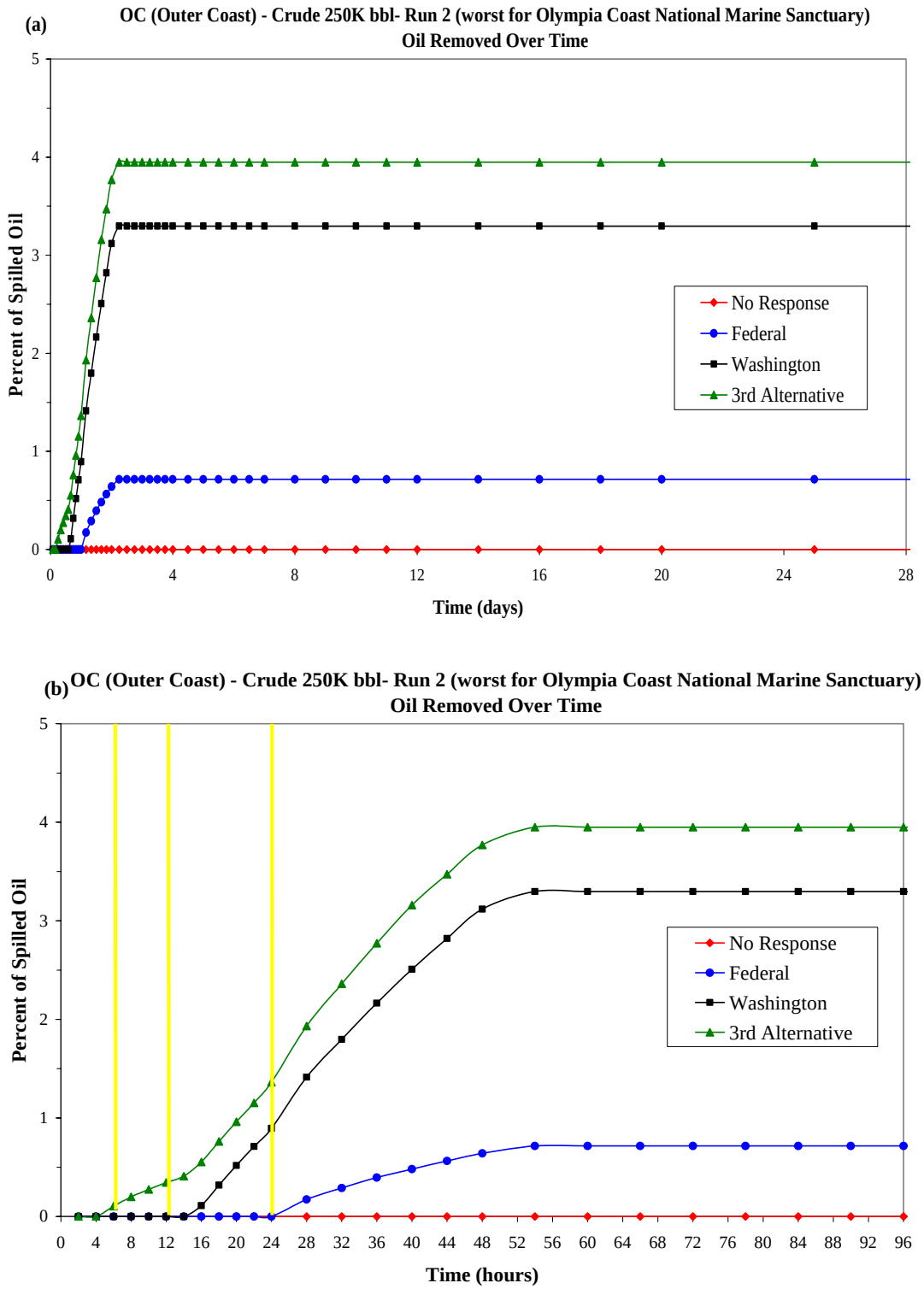
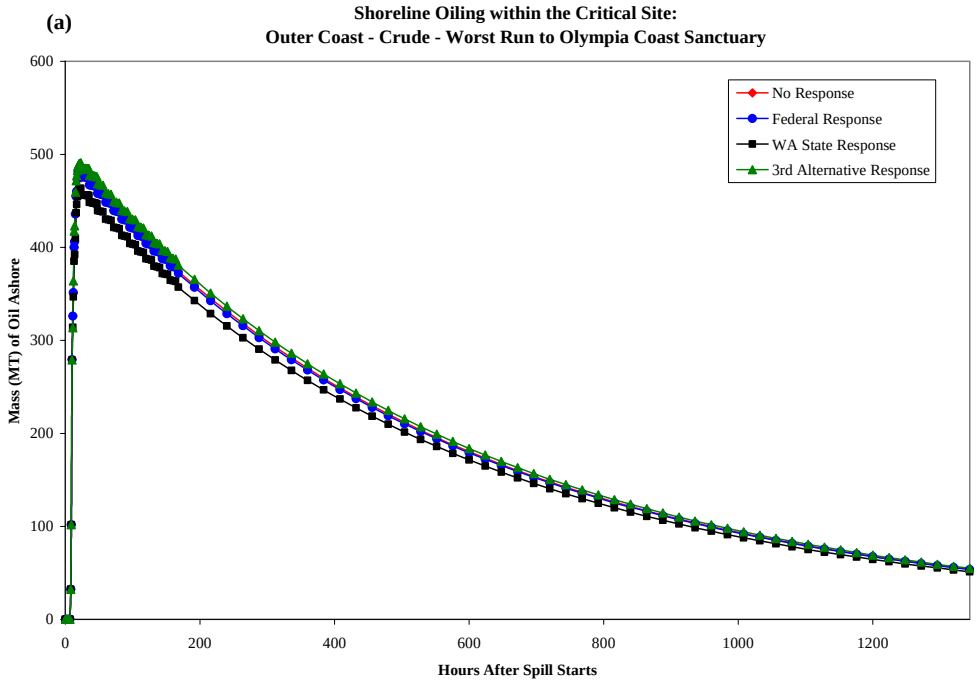


Figure V.B-6 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a.



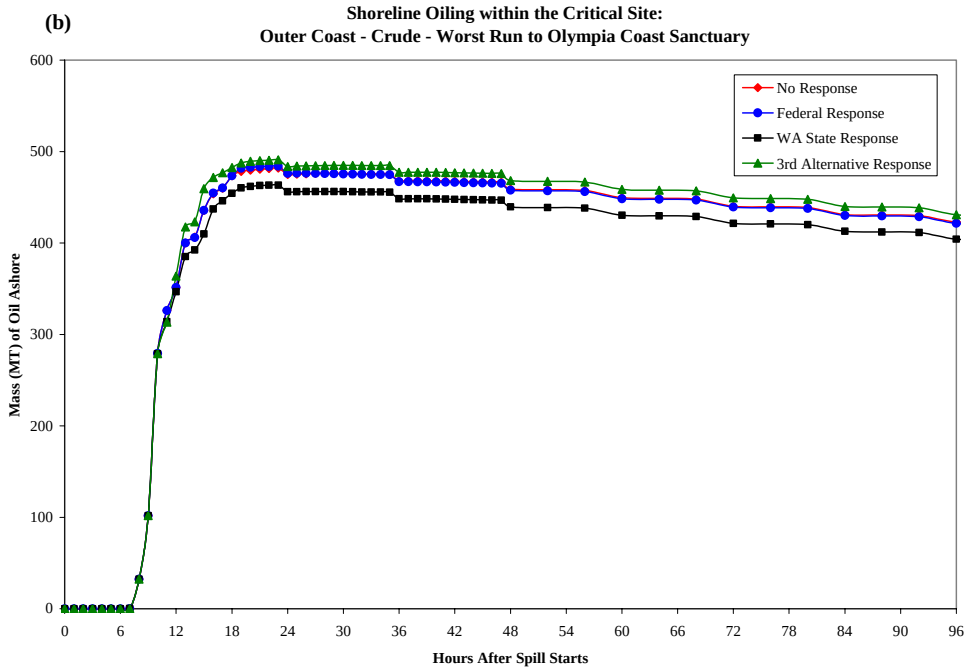
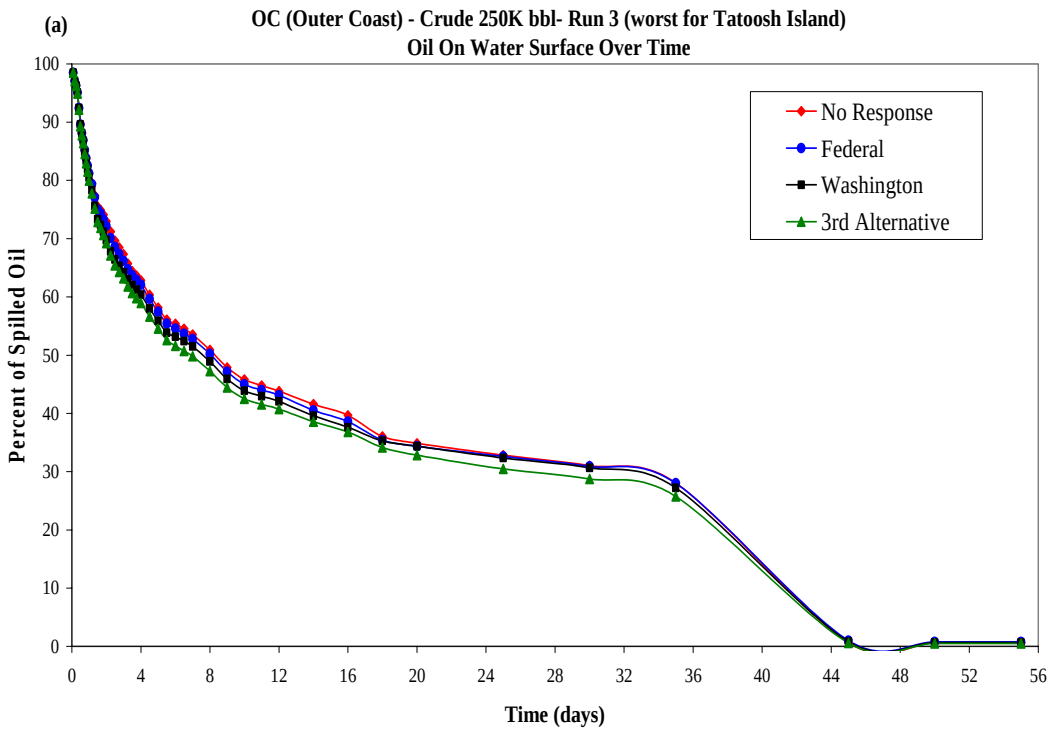


Figure V.B-7 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



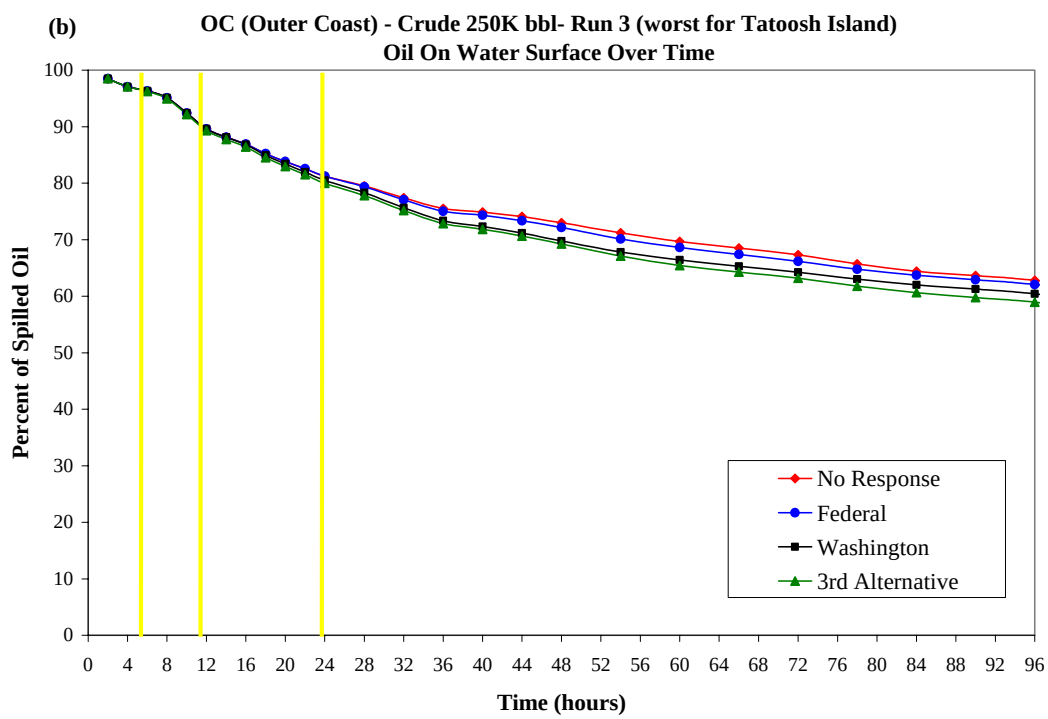


Figure V.B-8 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Tatoosh Island. Part b of this figure is a subset of Part a.

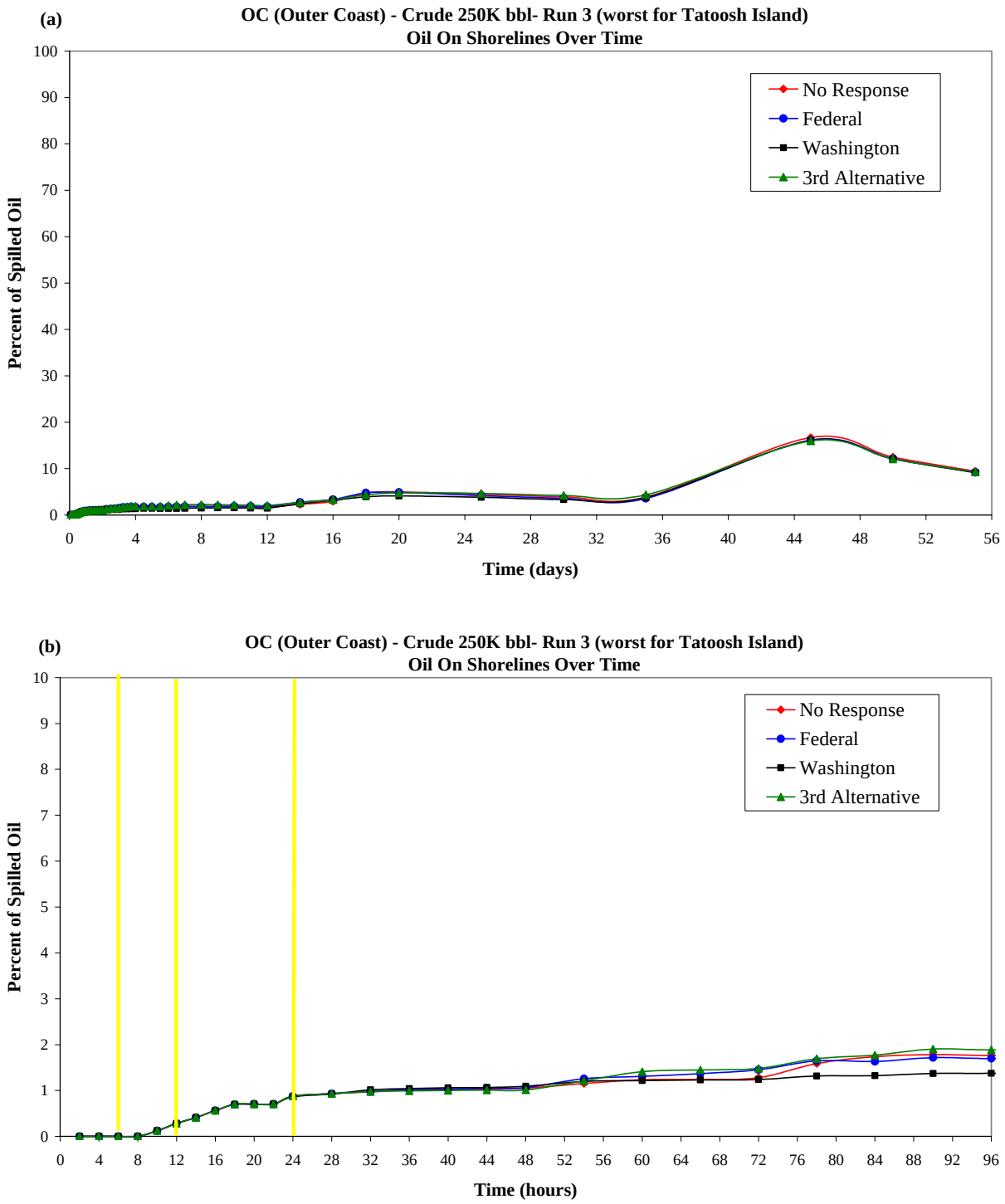
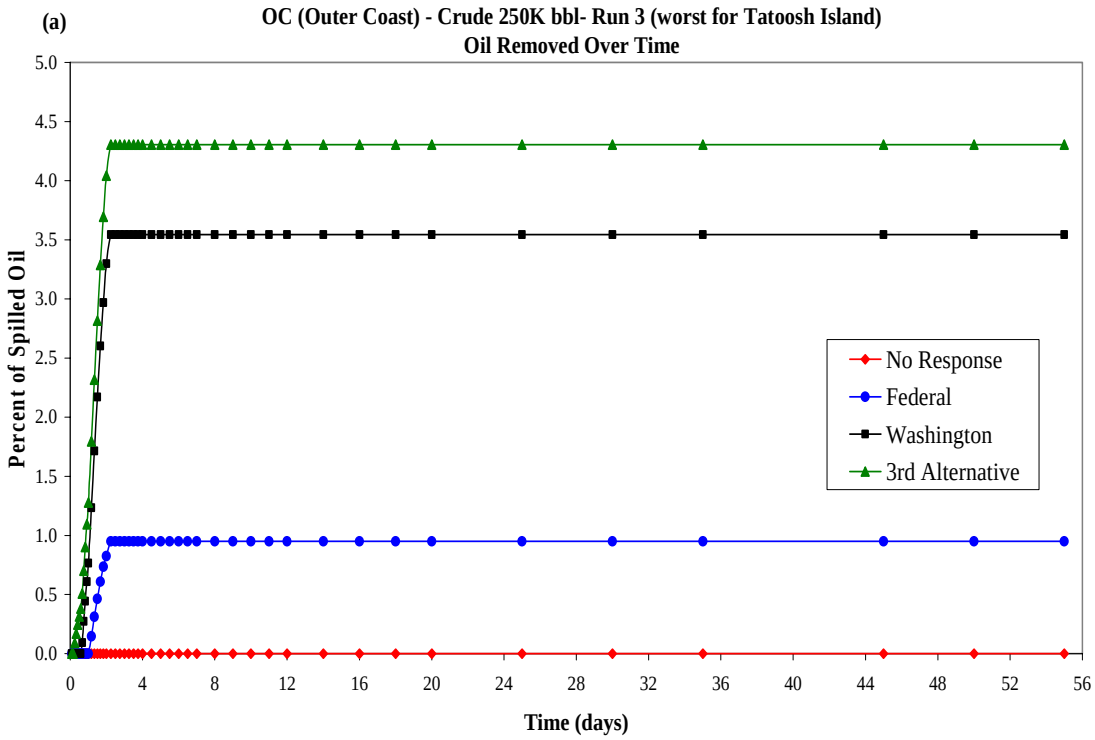


Figure V.B-9 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Tatoosh Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



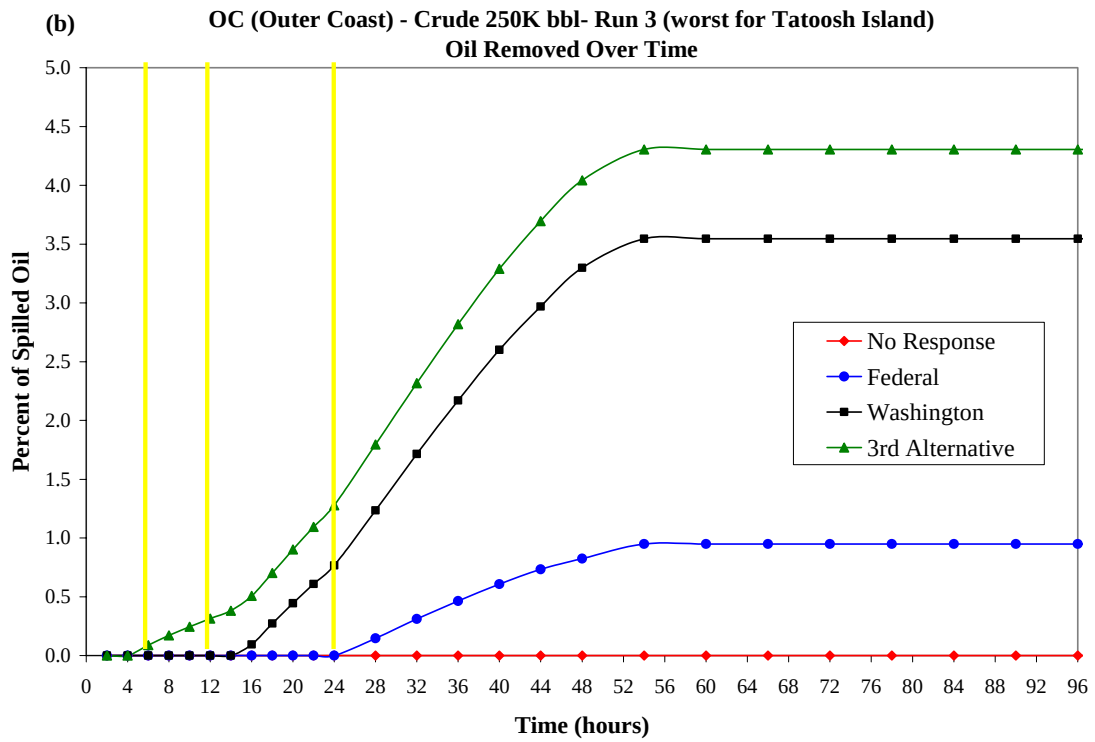
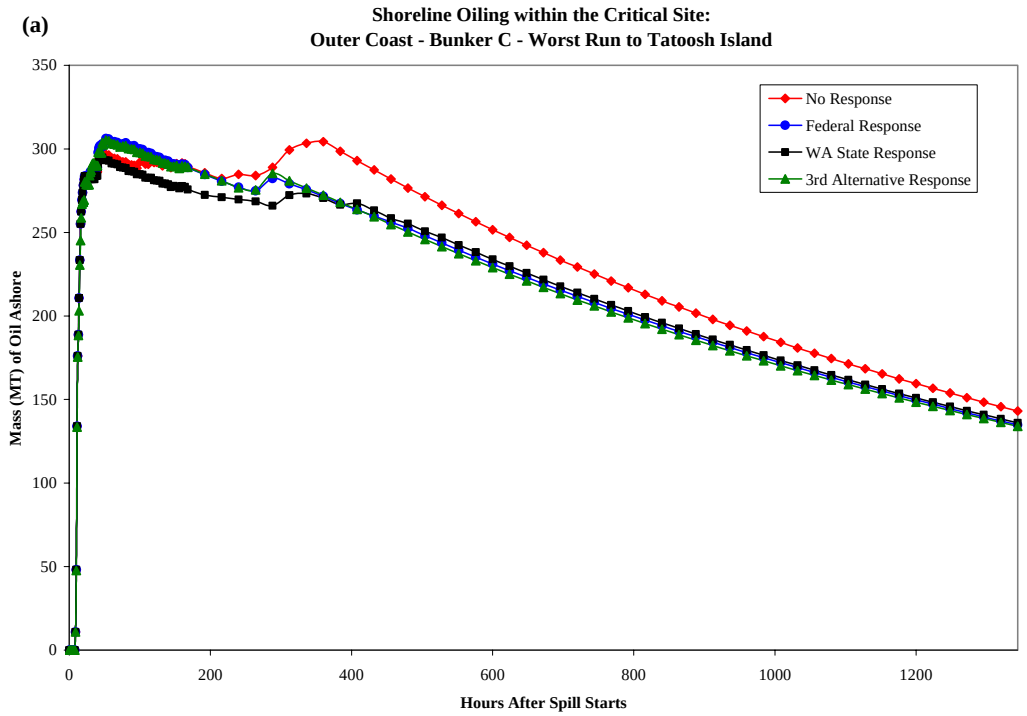


Figure V.B-10 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Tatoosh Island. Part b of this figure is a subset of Part a.



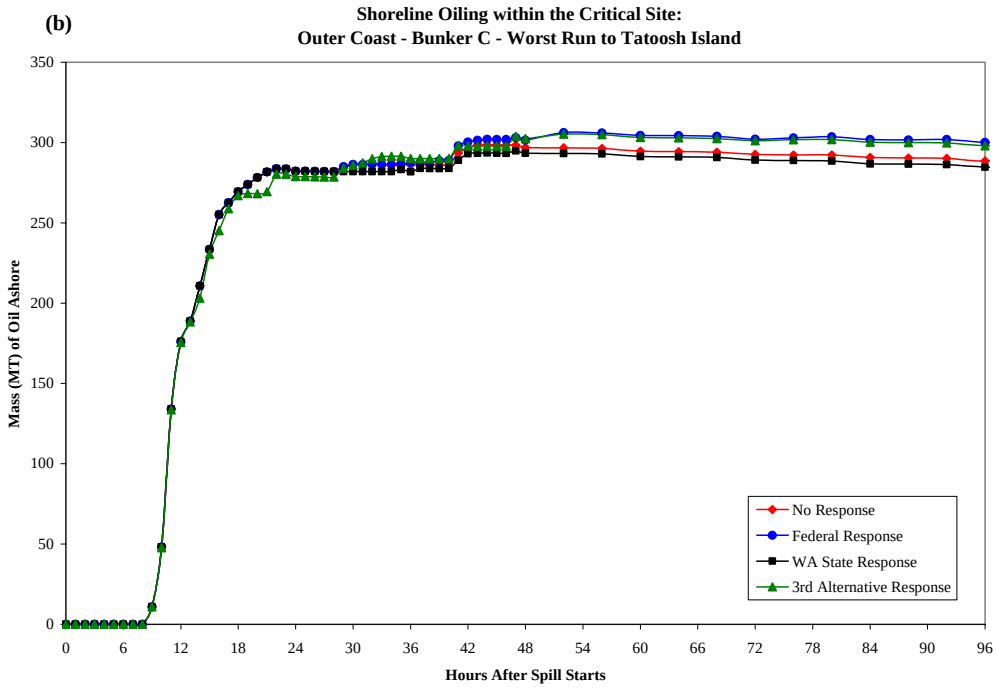


Figure V.B-11 Outer Coast at Duntz Rock - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Tatoosh Island (includes Tatoosh Island and Cape Flattery shorelines).

Table V.B-1 Outer Coast at Duntz Rock - 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	98.74	1.18	0.00	0.00	0.00	0.08	0.00	0.00	98.74
4	0.17	97.00	2.83	0.00	0.00	0.00	0.16	0.00	0.00	97.00
6	0.25	95.11	4.64	0.00	0.00	0.00	0.24	0.00	0.00	95.11
8	0.33	93.72	5.96	0.00	0.00	0.00	0.32	0.00	0.00	93.72
10	0.42	92.77	6.83	0.00	0.00	0.00	0.40	0.00	0.00	92.77
12	0.50	91.72	7.81	0.00	0.00	0.00	0.48	0.00	0.00	91.72
14	0.58	90.38	9.07	0.00	0.00	0.00	0.55	0.00	0.00	90.38
16	0.67	89.37	10.00	0.00	0.00	0.00	0.63	0.00	0.00	89.37
18	0.75	88.67	10.63	0.00	0.00	0.00	0.70	0.00	0.00	88.67
20	0.83	87.94	11.29	0.00	0.00	0.00	0.77	0.00	0.00	87.94
22	0.92	86.22	12.94	0.00	0.00	0.00	0.85	0.00	0.00	86.22
24	1.00	84.31	14.77	0.00	0.00	0.00	0.92	0.00	0.00	84.31
28	1.17	80.50	18.43	0.02	0.00	0.00	1.05	0.00	0.00	80.50
32	1.33	77.20	21.57	0.05	0.00	0.00	1.18	0.00	0.00	77.20
36	1.50	74.79	23.80	0.10	0.00	0.00	1.31	0.00	0.00	74.79
40	1.67	73.37	25.09	0.11	0.00	0.00	1.43	0.00	0.00	73.37
44	1.83	72.50	25.83	0.12	0.00	0.00	1.56	0.00	0.00	72.50
48	2.00	71.48	26.71	0.14	0.00	0.00	1.68	0.00	0.00	71.48
54	2.25	69.85	28.08	0.21	0.00	0.00	1.85	0.00	0.00	69.85
60	2.50	68.56	29.18	0.23	0.00	0.00	2.03	0.00	0.00	68.56
66	2.75	67.17	30.23	0.18	0.00	0.23	2.20	0.00	0.00	67.17
72	3.00	65.49	31.15	0.10	0.00	0.90	2.36	0.00	0.00	65.49
78	3.25	64.78	31.64	0.06	0.00	1.00	2.53	0.00	0.00	64.78
84	3.50	64.02	32.19	0.07	0.00	1.02	2.69	0.00	0.00	64.02

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
90	3.75	63.02	32.93	0.08	0.00	1.13	2.85	0.00	0.00	63.02
96	4.00	62.10	33.67	0.09	0.00	1.13	3.01	0.00	0.00	62.10
108	4.50	60.53	34.90	0.12	0.00	1.13	3.33	0.00	0.00	60.53
120	5.00	58.13	36.77	0.27	0.00	1.19	3.63	0.00	0.00	58.13
132	5.50	52.00	39.64	0.31	0.00	4.12	3.92	0.00	0.00	52.00
144	6.00	48.93	41.07	0.31	0.00	5.48	4.20	0.00	0.00	48.93
156	6.50	46.62	42.21	0.39	0.00	6.30	4.47	0.00	0.00	46.62
168	7.00	45.10	43.35	0.55	0.01	6.24	4.74	0.00	0.00	45.10
192	8.00	40.43	45.77	0.87	0.04	7.64	5.25	0.00	0.00	40.43
216	9.00	37.01	47.55	1.03	0.08	8.59	5.73	0.00	0.00	37.01
240	10.00	32.88	48.86	1.47	0.13	10.46	6.20	0.00	0.00	32.88
264	11.00	31.22	49.39	1.52	0.18	11.04	6.65	0.00	0.00	31.22
288	12.00	29.79	49.73	1.78	0.25	11.36	7.10	0.00	0.00	29.79
336	14.00	27.54	50.16	2.51	0.45	11.36	7.96	0.00	0.00	27.54
384	16.00	26.50	50.34	2.60	0.65	11.11	8.80	0.00	0.00	26.50
432	18.00	23.76	50.67	3.03	0.86	12.07	9.61	0.00	0.00	23.76
480	20.00	21.96	50.87	3.43	1.23	12.12	10.40	0.00	0.00	21.96
600	25.00	18.76	51.19	4.27	1.87	11.66	12.25	0.00	0.00	18.76
720	30.00	16.73	51.32	4.59	3.05	10.35	13.95	0.00	0.00	16.73
840	35.00	14.64	51.50	5.02	3.83	9.51	15.50	0.00	0.00	14.64
1080	45.00	6.76	52.41	5.57	5.41	11.63	18.23	0.00	0.00	6.76
1200	50.00	1.67	53.11	5.35	6.54	13.94	19.39	0.00	0.00	1.67
1320	55.00	0.66	53.27	5.31	7.51	12.83	20.42	0.00	0.00	0.66
Maximum	56.00	99.39	53.30	5.87	7.76	13.94	20.61	0.00	0.00	99.39

Table V.B-2 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	98.74	1.18	0.00	0.00	0.00	0.08	0.00	0.00	98.74
4	0.17	97.00	2.83	0.00	0.00	0.00	0.16	0.00	0.00	97.00
6	0.25	95.11	4.64	0.00	0.00	0.00	0.24	0.00	0.00	95.11
8	0.33	93.72	5.96	0.00	0.00	0.00	0.32	0.00	0.00	93.72
10	0.42	92.77	6.83	0.00	0.00	0.00	0.40	0.00	0.00	92.77
12	0.50	91.72	7.81	0.00	0.00	0.00	0.48	0.00	0.00	91.72
14	0.58	90.38	9.07	0.00	0.00	0.00	0.55	0.00	0.00	90.38
16	0.67	89.37	10.00	0.00	0.00	0.00	0.63	0.00	0.00	89.37
18	0.75	88.67	10.63	0.00	0.00	0.00	0.70	0.00	0.00	88.67
20	0.83	87.94	11.29	0.00	0.00	0.00	0.77	0.00	0.00	87.94
22	0.92	86.22	12.94	0.00	0.00	0.00	0.85	0.00	0.00	86.22
24	1.00	84.30	14.77	0.01	0.00	0.00	0.92	0.00	0.00	84.30
28	1.17	80.46	18.42	0.04	0.00	0.00	1.05	0.02	0.00	80.46
32	1.33	77.07	21.56	0.14	0.00	0.00	1.18	0.03	0.00	77.07
36	1.50	74.48	23.80	0.36	0.00	0.00	1.31	0.04	0.00	74.48
40	1.67	72.97	25.08	0.48	0.00	0.00	1.43	0.04	0.00	72.97
44	1.83	72.26	25.81	0.33	0.00	0.00	1.55	0.04	0.00	72.26
48	2.00	71.22	26.68	0.38	0.00	0.00	1.67	0.04	0.00	71.22
54	2.25	69.46	28.03	0.62	0.00	0.00	1.85	0.04	0.00	69.46
60	2.50	68.22	29.10	0.62	0.00	0.00	2.03	0.04	0.00	68.22
66	2.75	66.78	30.13	0.60	0.00	0.25	2.20	0.04	0.00	66.78
72	3.00	65.29	31.02	0.40	0.00	0.89	2.36	0.04	0.00	65.29
78	3.25	64.78	31.48	0.20	0.00	0.96	2.53	0.04	0.00	64.78
84	3.50	64.11	32.00	0.19	0.00	0.97	2.69	0.04	0.00	64.11
90	3.75	63.05	32.69	0.32	0.00	1.04	2.85	0.04	0.00	63.05

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	62.06	33.43	0.39	0.00	1.07	3.01	0.04	0.00	62.06
108	4.50	60.51	34.63	0.39	0.00	1.10	3.33	0.04	0.00	60.51
120	5.00	57.35	36.43	1.35	0.00	1.19	3.63	0.04	0.00	57.35
132	5.50	50.65	39.53	1.11	0.00	4.74	3.93	0.04	0.00	50.65
144	6.00	48.73	40.74	0.68	0.00	5.60	4.21	0.04	0.00	48.73
156	6.50	45.97	41.96	0.84	0.00	6.70	4.48	0.04	0.00	45.97
168	7.00	44.05	43.12	1.27	0.01	6.76	4.75	0.04	0.00	44.05
192	8.00	38.91	45.64	2.16	0.04	7.95	5.26	0.04	0.00	38.91
216	9.00	34.47	47.90	2.77	0.08	9.00	5.74	0.04	0.00	34.47
240	10.00	29.45	48.95	5.60	0.13	9.63	6.21	0.04	0.00	29.45
264	11.00	30.94	49.26	2.80	0.18	10.13	6.66	0.04	0.00	30.94
288	12.00	29.17	49.44	3.49	0.24	10.51	7.10	0.04	0.00	29.17
336	14.00	19.69	49.66	11.43	0.43	10.77	7.97	0.04	0.00	19.69
384	16.00	26.93	49.79	3.21	0.61	10.60	8.82	0.04	0.00	26.93
432	18.00	24.04	50.15	3.53	0.79	11.80	9.64	0.04	0.00	24.04
480	20.00	21.54	50.34	4.58	1.13	11.94	10.44	0.04	0.00	21.54
600	25.00	19.68	50.69	3.93	1.71	11.63	12.32	0.04	0.00	19.68
720	30.00	17.36	50.81	4.64	2.77	10.33	14.05	0.04	0.00	17.36
840	35.00	14.49	51.19	4.67	3.48	10.50	15.63	0.04	0.00	14.49
1080	45.00	2.39	52.89	5.79	5.03	15.47	18.39	0.04	0.00	2.39
1200	50.00	0.19	53.23	5.95	6.31	14.73	19.55	0.04	0.00	0.19
1320	55.00	0.05	53.26	5.87	7.41	12.79	20.57	0.04	0.00	0.05
Maximum	56.00	99.39	53.27	11.43	7.70	15.76	20.76	0.04	0.00	99.39

Table V.B-3 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	98.74	1.18	0.00	0.00	0.00	0.08	0.00	0.00	98.74
4	0.17	97.00	2.83	0.00	0.00	0.00	0.16	0.00	0.00	97.00
6	0.25	95.11	4.64	0.00	0.00	0.00	0.24	0.00	0.00	95.11
8	0.33	93.72	5.96	0.00	0.00	0.00	0.32	0.00	0.00	93.72
10	0.42	92.77	6.83	0.00	0.00	0.00	0.40	0.00	0.00	92.77
12	0.50	91.72	7.81	0.00	0.00	0.00	0.48	0.00	0.00	91.72
14	0.58	90.38	9.07	0.00	0.00	0.00	0.55	0.00	0.00	90.38
16	0.67	89.37	10.00	0.00	0.00	0.00	0.63	0.00	0.00	89.37
18	0.75	88.67	10.63	0.00	0.00	0.00	0.70	0.00	0.00	88.67
20	0.83	87.94	11.29	0.00	0.00	0.00	0.77	0.00	0.00	87.94
22	0.92	86.22	12.94	0.00	0.00	0.00	0.85	0.00	0.00	86.22
24	1.00	84.30	14.77	0.01	0.00	0.00	0.92	0.00	0.00	84.30
28	1.17	80.46	18.42	0.04	0.00	0.00	1.05	0.02	0.00	80.46
32	1.33	77.07	21.56	0.14	0.00	0.00	1.18	0.03	0.00	77.07
36	1.50	74.48	23.80	0.36	0.00	0.00	1.31	0.04	0.00	74.48
40	1.67	72.97	25.08	0.48	0.00	0.00	1.43	0.04	0.00	72.97
44	1.83	72.26	25.81	0.33	0.00	0.00	1.55	0.04	0.00	72.26
48	2.00	71.22	26.68	0.38	0.00	0.00	1.67	0.04	0.00	71.22
54	2.25	69.46	28.03	0.62	0.00	0.00	1.85	0.04	0.00	69.46
60	2.50	68.22	29.10	0.62	0.00	0.00	2.03	0.04	0.00	68.22
66	2.75	66.78	30.13	0.60	0.00	0.25	2.20	0.04	0.00	66.78
72	3.00	65.29	31.02	0.40	0.00	0.89	2.36	0.04	0.00	65.29
78	3.25	64.78	31.48	0.20	0.00	0.96	2.53	0.04	0.00	64.78
84	3.50	64.11	32.00	0.19	0.00	0.97	2.69	0.04	0.00	64.11

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
90	3.75	63.05	32.69	0.32	0.00	1.04	2.85	0.04	0.00	63.05
96	4.00	62.06	33.43	0.39	0.00	1.07	3.01	0.04	0.00	62.06
108	4.50	60.51	34.63	0.39	0.00	1.10	3.33	0.04	0.00	60.51
120	5.00	57.35	36.43	1.35	0.00	1.19	3.63	0.04	0.00	57.35
132	5.50	50.65	39.53	1.11	0.00	4.74	3.93	0.04	0.00	50.65
144	6.00	48.73	40.74	0.68	0.00	5.60	4.21	0.04	0.00	48.73
156	6.50	45.97	41.96	0.84	0.00	6.70	4.48	0.04	0.00	45.97
168	7.00	44.05	43.12	1.27	0.01	6.76	4.75	0.04	0.00	44.05
192	8.00	38.91	45.64	2.16	0.04	7.95	5.26	0.04	0.00	38.91
216	9.00	34.47	47.90	2.77	0.08	9.00	5.74	0.04	0.00	34.47
240	10.00	29.45	48.95	5.60	0.13	9.63	6.21	0.04	0.00	29.45
264	11.00	30.94	49.26	2.80	0.18	10.13	6.66	0.04	0.00	30.94
288	12.00	29.17	49.44	3.49	0.24	10.51	7.10	0.04	0.00	29.17
336	14.00	19.69	49.66	11.43	0.43	10.77	7.97	0.04	0.00	19.69
384	16.00	26.93	49.79	3.21	0.61	10.60	8.82	0.04	0.00	26.93
432	18.00	24.04	50.15	3.53	0.79	11.80	9.64	0.04	0.00	24.04
480	20.00	21.54	50.34	4.58	1.13	11.94	10.44	0.04	0.00	21.54
600	25.00	19.68	50.69	3.93	1.71	11.63	12.32	0.04	0.00	19.68
720	30.00	17.36	50.81	4.64	2.77	10.33	14.05	0.04	0.00	17.36
840	35.00	14.49	51.19	4.67	3.48	10.50	15.63	0.04	0.00	14.49
1080	45.00	2.39	52.89	5.79	5.03	15.47	18.39	0.04	0.00	2.39
1200	50.00	0.19	53.23	5.95	6.31	14.73	19.55	0.04	0.00	0.19
1320	55.00	0.05	53.26	5.87	7.41	12.79	20.57	0.04	0.00	0.05
Maximum	56.00	99.39	53.27	11.43	7.70	15.76	20.76	0.04	0.00	99.39

Table V.B-4 Outer Coast at Duntz Rock - 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). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	98.74	1.18	0.00	0.00	0.00	0.08	0.00	0.00	98.74
4	0.17	97.00	2.83	0.00	0.00	0.00	0.16	0.00	0.00	97.00
6	0.25	95.05	4.64	0.00	0.00	0.00	0.24	0.06	0.00	95.05
8	0.33	93.56	5.96	0.00	0.00	0.00	0.32	0.15	0.00	93.56
10	0.42	92.59	6.83	0.00	0.00	0.00	0.40	0.17	0.00	92.59
12	0.50	91.53	7.81	0.00	0.00	0.00	0.48	0.18	0.00	91.53
14	0.58	90.19	9.07	0.00	0.00	0.00	0.55	0.19	0.00	90.19
16	0.67	89.17	10.00	0.00	0.00	0.00	0.63	0.21	0.00	89.17
18	0.75	88.44	10.62	0.00	0.00	0.00	0.70	0.24	0.00	88.44
20	0.83	87.67	11.29	0.00	0.00	0.00	0.77	0.27	0.00	87.67
22	0.92	85.93	12.93	0.00	0.00	0.00	0.85	0.30	0.00	85.93
24	1.00	83.99	14.76	0.01	0.00	0.00	0.92	0.32	0.00	83.99
28	1.17	80.11	18.41	0.04	0.00	0.00	1.05	0.39	0.00	80.11
32	1.33	76.70	21.53	0.14	0.00	0.00	1.18	0.45	0.00	76.70
36	1.50	74.12	23.75	0.34	0.00	0.00	1.31	0.48	0.00	74.12
40	1.67	72.58	25.03	0.48	0.00	0.00	1.43	0.48	0.00	72.58
44	1.83	71.85	25.76	0.35	0.00	0.00	1.55	0.48	0.00	71.85
48	2.00	70.82	26.62	0.40	0.00	0.00	1.67	0.48	0.00	70.82
54	2.25	69.06	27.97	0.64	0.00	0.00	1.85	0.48	0.00	69.06
60	2.50	67.80	29.05	0.65	0.00	0.00	2.02	0.48	0.00	67.80
66	2.75	66.44	30.09	0.53	0.00	0.28	2.19	0.48	0.00	66.44
72	3.00	64.86	30.98	0.41	0.00	0.91	2.35	0.48	0.00	64.86
78	3.25	64.43	31.41	0.22	0.00	0.94	2.52	0.48	0.00	64.43
84	3.50	63.75	31.94	0.19	0.00	0.96	2.68	0.48	0.00	63.75

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
90	3.75	62.75	32.62	0.28	0.00	1.03	2.84	0.48	0.00	62.75
96	4.00	61.81	33.34	0.33	0.00	1.03	3.00	0.48	0.00	61.81
108	4.50	60.20	34.53	0.40	0.00	1.07	3.32	0.48	0.00	60.20
120	5.00	57.10	36.33	1.33	0.00	1.15	3.62	0.48	0.00	57.10
132	5.50	50.65	39.36	1.03	0.00	4.57	3.91	0.48	0.00	50.65
144	6.00	48.65	40.60	0.53	0.00	5.55	4.19	0.48	0.00	48.65
156	6.50	46.19	41.75	0.65	0.00	6.47	4.46	0.48	0.00	46.19
168	7.00	44.31	42.88	1.08	0.01	6.50	4.73	0.48	0.00	44.31
192	8.00	38.71	45.42	2.36	0.03	7.76	5.24	0.48	0.00	38.71
216	9.00	35.55	47.58	1.90	0.07	8.70	5.72	0.48	0.00	35.55
240	10.00	29.27	48.77	5.32	0.13	9.84	6.18	0.48	0.00	29.27
264	11.00	30.14	49.16	2.91	0.18	10.51	6.63	0.48	0.00	30.14
288	12.00	28.48	49.34	3.55	0.24	10.84	7.07	0.48	0.00	28.48
336	14.00	18.19	49.63	12.12	0.44	11.21	7.94	0.48	0.00	18.19
384	16.00	25.93	49.79	3.31	0.63	11.09	8.78	0.48	0.00	25.93
432	18.00	23.50	50.11	3.62	0.82	11.88	9.59	0.48	0.00	23.50
480	20.00	19.23	50.44	5.58	1.18	12.71	10.38	0.48	0.00	19.23
600	25.00	17.67	50.90	4.14	1.78	12.79	12.23	0.48	0.00	17.67
720	30.00	14.81	51.08	5.15	2.90	11.64	13.94	0.48	0.00	14.81
840	35.00	11.88	51.51	4.92	3.65	12.08	15.49	0.48	0.00	11.88
1080	45.00	1.40	52.94	5.93	5.27	15.79	18.18	0.48	0.00	1.40
1200	50.00	0.04	53.16	5.91	6.57	14.53	19.32	0.48	0.00	0.04
1320	55.00	0.00	53.17	5.75	7.67	12.61	20.32	0.48	0.00	0.00
Maximum	56.00	99.39	53.17	12.12	7.95	15.95	20.51	0.48	0.00	99.39

Table V.B-5 Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	84.33	4.17	11.42	0.00	0.00	0.08	0.00	0.00	84.33
4	0.17	82.92	7.09	9.83	0.00	0.00	0.16	0.00	0.00	82.92
6	0.25	81.96	9.57	8.23	0.00	0.00	0.23	0.00	0.00	81.96
8	0.33	80.89	11.55	7.07	0.00	0.19	0.31	0.00	0.00	80.89
10	0.42	80.65	13.01	5.68	0.00	0.28	0.38	0.00	0.00	80.65
12	0.50	80.48	13.98	4.67	0.00	0.41	0.45	0.00	0.00	80.48
14	0.58	81.47	14.54	3.01	0.00	0.46	0.52	0.00	0.00	81.47
16	0.67	81.04	15.31	2.59	0.00	0.47	0.59	0.00	0.00	81.04
18	0.75	81.35	15.80	1.67	0.00	0.52	0.66	0.00	0.00	81.35
20	0.83	81.03	16.20	1.44	0.00	0.59	0.73	0.00	0.00	81.03
22	0.92	79.98	16.93	1.57	0.00	0.72	0.80	0.00	0.00	79.98
24	1.00	79.16	17.60	1.59	0.00	0.78	0.87	0.00	0.00	79.16
28	1.17	74.61	19.68	3.33	0.00	1.38	1.00	0.00	0.00	74.61
32	1.33	69.88	21.33	6.18	0.00	1.47	1.13	0.00	0.00	69.88
36	1.50	65.37	23.27	7.49	0.00	2.61	1.26	0.00	0.00	65.37
40	1.67	61.76	25.13	7.70	0.00	4.02	1.39	0.00	0.00	61.76
44	1.83	62.85	26.02	5.46	0.00	4.17	1.51	0.00	0.00	62.85
48	2.00	59.82	26.76	7.65	0.00	4.14	1.63	0.00	0.00	59.82
54	2.25	56.69	27.80	9.43	0.00	4.27	1.81	0.00	0.00	56.69
60	2.50	56.45	28.70	8.61	0.00	4.25	1.98	0.00	0.00	56.45
66	2.75	57.02	29.53	6.76	0.01	4.52	2.15	0.00	0.00	57.02
72	3.00	54.51	30.35	8.29	0.01	4.52	2.32	0.00	0.00	54.51
78	3.25	54.06	31.19	7.73	0.01	4.52	2.49	0.00	0.00	54.06
84	3.50	52.36	32.05	8.47	0.02	4.44	2.66	0.00	0.00	52.36
90	3.75	48.42	33.08	11.00	0.02	4.65	2.82	0.00	0.00	48.42
96	4.00	48.29	34.13	9.91	0.03	4.66	2.98	0.00	0.00	48.29

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	55.23	34.99	1.79	0.04	4.66	3.29	0.00	0.00	55.23
120	5.00	46.31	37.16	6.88	0.05	6.00	3.60	0.00	0.00	46.31
132	5.50	37.24	39.62	12.61	0.08	6.57	3.89	0.00	0.00	37.24
144	6.00	35.06	41.45	12.18	0.10	7.04	4.17	0.00	0.00	35.06
156	6.50	38.92	41.61	7.82	0.12	7.08	4.44	0.00	0.00	38.92
168	7.00	41.50	41.73	4.71	0.14	7.20	4.71	0.00	0.00	41.50
192	8.00	40.32	41.97	4.73	0.20	7.53	5.25	0.00	0.00	40.32
216	9.00	34.75	42.21	9.20	0.29	7.77	5.78	0.00	0.00	34.75
240	10.00	30.84	42.72	9.96	0.42	9.36	6.30	0.00	0.41	31.24
264	11.00	32.08	42.92	5.70	0.55	9.33	6.79	0.00	2.62	34.70
288	12.00	31.71	42.93	5.17	0.67	8.98	7.26	0.00	3.26	34.97
336	14.00	24.13	43.05	6.23	0.93	8.79	8.12	0.00	8.75	32.87
384	16.00	15.12	43.13	5.00	1.22	8.46	8.79	0.00	18.26	33.39
432	18.00	11.41	43.66	4.06	1.57	10.39	9.35	0.00	19.56	30.96
480	20.00	10.40	43.86	3.89	1.83	10.60	9.88	0.00	19.56	29.95
600	25.00	7.98	44.25	3.57	2.74	10.71	11.10	0.00	19.65	27.62
720	30.00	3.86	44.28	3.65	3.61	9.21	12.10	0.00	23.29	27.15
840	35.00	0.81	44.29	3.52	4.33	8.01	12.84	0.00	26.20	27.01
1080	45.00	0.16	44.31	3.08	5.38	6.25	13.97	0.00	26.85	27.01
1200	50.00	0.00	44.31	2.53	5.90	5.60	14.41	0.00	27.25	27.25
1310	54.58	0.00	44.31	2.39	6.18	5.09	14.77	0.00	27.26	27.26
Maximum	56.00	86.40	44.31	12.61	6.21	11.08	14.92	0.00	27.26	86.40

Table V.B-6 Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	84.33	4.17	11.42	0.00	0.00	0.08	0.00	0.00	84.33
4	0.17	82.92	7.09	9.83	0.00	0.00	0.16	0.00	0.00	82.92
6	0.25	81.96	9.57	8.23	0.00	0.00	0.23	0.00	0.00	81.96
8	0.33	80.89	11.55	7.07	0.00	0.19	0.31	0.00	0.00	80.89
10	0.42	80.65	13.01	5.68	0.00	0.28	0.38	0.00	0.00	80.65
12	0.50	80.48	13.98	4.67	0.00	0.41	0.45	0.00	0.00	80.48
14	0.58	81.47	14.54	3.01	0.00	0.46	0.52	0.00	0.00	81.47
16	0.67	81.04	15.31	2.59	0.00	0.47	0.59	0.00	0.00	81.04
18	0.75	81.42	15.80	1.60	0.00	0.52	0.66	0.00	0.00	81.42
20	0.83	80.82	16.27	1.50	0.00	0.67	0.73	0.00	0.00	80.82
22	0.92	79.85	17.00	1.56	0.00	0.79	0.80	0.00	0.00	79.85
24	1.00	79.08	17.64	1.59	0.00	0.82	0.87	0.00	0.00	79.08
28	1.17	74.22	19.79	3.30	0.00	1.52	1.00	0.17	0.00	74.22
32	1.33	70.22	21.41	5.38	0.00	1.57	1.13	0.29	0.00	70.22
36	1.50	67.72	23.32	4.62	0.00	2.69	1.26	0.40	0.00	67.72
40	1.67	63.10	25.00	6.17	0.00	3.87	1.38	0.48	0.00	63.10
44	1.83	64.04	25.90	3.97	0.00	4.03	1.50	0.56	0.00	64.04
48	2.00	60.98	26.71	5.94	0.00	4.10	1.62	0.64	0.00	60.98
54	2.25	59.54	27.72	6.02	0.00	4.20	1.80	0.72	0.00	59.54
60	2.50	59.13	28.64	5.32	0.00	4.21	1.97	0.72	0.00	59.13
66	2.75	57.00	29.63	5.81	0.01	4.69	2.15	0.72	0.00	57.00
72	3.00	54.32	30.49	7.41	0.01	4.74	2.31	0.72	0.00	54.32
78	3.25	52.35	31.34	8.33	0.01	4.77	2.48	0.72	0.00	52.35
84	3.50	51.89	32.20	7.85	0.02	4.68	2.64	0.72	0.00	51.89
90	3.75	49.35	33.20	9.01	0.03	4.90	2.80	0.72	0.00	49.35
96	4.00	47.49	34.26	9.65	0.03	4.90	2.96	0.72	0.00	47.49

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	52.11	35.14	3.78	0.04	4.95	3.27	0.72	0.00	52.11
120	5.00	45.00	37.07	7.77	0.06	5.81	3.57	0.72	0.00	45.00
132	5.50	39.18	39.47	10.40	0.08	6.29	3.86	0.72	0.00	39.18
144	6.00	30.59	41.13	16.85	0.11	6.47	4.14	0.72	0.00	30.59
156	6.50	36.73	41.33	10.06	0.13	6.62	4.41	0.72	0.00	36.73
168	7.00	39.46	41.56	6.35	0.15	7.10	4.68	0.72	0.00	39.46
192	8.00	39.86	41.86	4.40	0.20	7.75	5.21	0.72	0.00	39.86
216	9.00	32.76	42.15	10.17	0.29	8.18	5.73	0.72	0.00	32.76
240	10.00	28.19	42.61	11.83	0.42	9.49	6.25	0.72	0.50	28.69
264	11.00	26.61	42.75	10.18	0.55	9.16	6.73	0.72	3.30	29.91
288	12.00	28.25	42.76	8.13	0.67	8.83	7.19	0.72	3.45	31.70
336	14.00	26.30	42.83	7.43	0.92	8.42	8.08	0.72	5.30	31.61
384	16.00	16.93	42.99	7.71	1.20	8.46	8.85	0.72	13.14	30.08
432	18.00	13.73	43.51	6.72	1.53	10.40	9.50	0.72	13.90	27.63
480	20.00	12.60	43.77	6.14	1.78	10.97	10.13	0.72	13.90	26.50
600	25.00	10.67	44.09	3.70	2.66	10.77	11.56	0.72	15.83	26.50
720	30.00	1.11	44.11	3.41	3.51	9.30	12.58	0.72	25.27	26.38
840	35.00	0.39	44.12	3.28	4.20	8.11	13.24	0.72	25.95	26.34
1080	45.00	0.12	44.14	2.96	5.21	6.34	14.33	0.72	26.18	26.30
1200	50.00	0.05	44.14	2.52	5.72	5.68	14.78	0.72	26.39	26.45
1320	55.00	0.00	44.14	2.33	6.07	5.11	15.18	0.72	26.46	26.46
Maximum	56.00	86.40	44.14	16.85	6.15	11.28	15.25	0.72	26.46	86.40

Table V.B-7 Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	84.33	4.17	11.42	0.00	0.00	0.08	0.00	0.00	84.33
4	0.17	82.92	7.09	9.83	0.00	0.00	0.16	0.00	0.00	82.92
6	0.25	81.96	9.57	8.23	0.00	0.00	0.23	0.00	0.00	81.96
8	0.33	80.89	11.55	7.07	0.00	0.19	0.31	0.00	0.00	80.89
10	0.42	80.65	13.01	5.68	0.00	0.28	0.38	0.00	0.00	80.65
12	0.50	80.48	13.98	4.67	0.00	0.41	0.45	0.00	0.00	80.48
14	0.58	81.47	14.54	3.01	0.00	0.46	0.52	0.00	0.00	81.47
16	0.67	80.93	15.31	2.59	0.00	0.47	0.59	0.11	0.00	80.93
18	0.75	81.10	15.80	1.60	0.00	0.52	0.66	0.32	0.00	81.10
20	0.83	80.30	16.27	1.50	0.00	0.67	0.73	0.52	0.00	80.30
22	0.92	79.17	16.98	1.56	0.00	0.78	0.80	0.71	0.00	79.17
24	1.00	78.25	17.63	1.54	0.00	0.82	0.87	0.89	0.00	78.25
28	1.17	73.36	19.60	3.30	0.00	1.32	1.00	1.41	0.00	73.36
32	1.33	68.23	21.21	6.27	0.00	1.37	1.13	1.80	0.00	68.23
36	1.50	63.98	23.11	7.01	0.00	2.48	1.25	2.16	0.00	63.98
40	1.67	59.42	24.67	8.54	0.00	3.49	1.37	2.51	0.00	59.42
44	1.83	57.39	25.77	8.56	0.00	3.97	1.49	2.82	0.00	57.39
48	2.00	58.33	26.48	6.50	0.00	3.96	1.61	3.12	0.00	58.33
54	2.25	55.83	27.45	7.59	0.00	4.05	1.78	3.30	0.00	55.83
60	2.50	54.80	28.34	7.54	0.00	4.07	1.95	3.30	0.00	54.80
66	2.75	54.68	29.12	6.47	0.01	4.32	2.11	3.30	0.00	54.68
72	3.00	52.69	29.91	7.51	0.01	4.31	2.28	3.30	0.00	52.69
78	3.25	51.16	30.71	8.04	0.01	4.33	2.44	3.30	0.00	51.16
84	3.50	48.29	31.54	10.01	0.02	4.25	2.60	3.30	0.00	48.29
90	3.75	46.58	32.46	10.53	0.02	4.36	2.75	3.30	0.00	46.58

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	48.49	33.41	7.59	0.03	4.28	2.90	3.30	0.00	48.49
108	4.50	50.90	34.21	4.10	0.03	4.26	3.20	3.30	0.00	50.90
120	5.00	42.15	35.95	10.22	0.05	4.83	3.50	3.30	0.00	42.15
132	5.50	36.74	38.24	12.64	0.07	5.23	3.78	3.30	0.00	36.74
144	6.00	27.89	39.88	19.57	0.09	5.22	4.05	3.30	0.00	27.89
156	6.50	37.02	40.01	10.08	0.11	5.18	4.31	3.30	0.00	37.02
168	7.00	42.42	40.10	4.24	0.12	5.23	4.58	3.30	0.00	42.42
192	8.00	42.45	40.26	3.52	0.17	5.21	5.10	3.30	0.00	42.45
216	9.00	33.79	40.45	11.30	0.23	5.32	5.61	3.30	0.00	33.79
240	10.00	25.15	40.83	17.47	0.32	6.44	6.11	3.30	0.38	25.52
264	11.00	25.72	40.99	14.12	0.41	6.20	6.60	3.30	2.65	28.37
288	12.00	29.39	41.00	10.11	0.49	5.97	7.06	3.30	2.68	32.07
336	14.00	28.28	41.02	9.82	0.66	5.56	7.96	3.30	3.40	31.68
384	16.00	18.47	41.04	13.06	0.84	5.21	8.80	3.30	9.28	27.75
432	18.00	15.51	41.08	14.84	1.05	5.01	9.53	3.30	9.67	25.18
480	20.00	21.74	41.11	7.90	1.20	4.84	10.24	3.30	9.67	31.42
600	25.00	18.00	41.18	3.10	1.67	4.38	11.89	3.30	16.50	34.50
720	30.00	0.31	41.19	1.80	2.07	3.81	12.46	3.30	35.07	35.38
840	35.00	0.01	41.19	1.64	2.37	3.36	12.74	3.30	35.40	35.40
1080	45.00	0.00	41.19	1.42	2.80	2.69	13.20	3.30	35.40	35.40
1200	50.00	0.00	41.19	1.27	3.00	2.43	13.40	3.30	35.40	35.41
1320	55.00	0.00	41.19	1.18	3.14	2.21	13.58	3.30	35.41	35.41
Maximum	56.00	86.40	41.19	19.57	3.17	6.44	13.61	3.30	35.41	86.40

Table V.B-8 Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	84.33	4.17	11.42	0.00	0.00	0.08	0.00	0.00	84.33
4	0.17	82.92	7.09	9.83	0.00	0.00	0.16	0.00	0.00	82.92
6	0.25	81.85	9.57	8.23	0.00	0.00	0.23	0.10	0.00	81.85
8	0.33	80.69	11.55	7.07	0.00	0.19	0.31	0.20	0.00	80.69
10	0.42	80.38	13.01	5.68	0.00	0.28	0.38	0.27	0.00	80.38
12	0.50	80.14	13.98	4.67	0.00	0.41	0.45	0.34	0.00	80.14
14	0.58	80.55	14.54	3.52	0.00	0.46	0.52	0.41	0.00	80.55
16	0.67	80.07	15.30	3.01	0.00	0.47	0.59	0.55	0.00	80.07
18	0.75	79.89	15.80	2.37	0.00	0.52	0.66	0.76	0.00	79.89
20	0.83	79.60	16.25	1.82	0.00	0.64	0.73	0.96	0.00	79.60
22	0.92	78.48	16.91	1.95	0.00	0.70	0.80	1.15	0.00	78.48
24	1.00	77.61	17.59	1.80	0.00	0.77	0.87	1.36	0.00	77.61
28	1.17	72.54	19.75	3.27	0.00	1.51	1.00	1.93	0.00	72.54
32	1.33	68.20	21.36	5.36	0.00	1.59	1.12	2.36	0.00	68.20
36	1.50	63.70	23.28	6.26	0.00	2.75	1.25	2.77	0.00	63.70
40	1.67	60.30	24.91	6.39	0.00	3.88	1.37	3.16	0.00	60.30
44	1.83	59.43	25.82	5.67	0.00	4.12	1.48	3.47	0.00	59.43
48	2.00	56.12	26.58	7.76	0.00	4.17	1.60	3.77	0.00	56.12
54	2.25	55.25	27.54	7.21	0.00	4.28	1.77	3.95	0.00	55.25
60	2.50	52.77	28.37	8.73	0.00	4.24	1.93	3.95	0.00	52.77
66	2.75	53.20	29.13	7.15	0.01	4.46	2.10	3.95	0.00	53.20
72	3.00	51.04	29.94	8.29	0.01	4.51	2.26	3.95	0.00	51.04
78	3.25	50.72	30.72	7.66	0.01	4.52	2.42	3.95	0.00	50.72
84	3.50	48.96	31.54	8.52	0.02	4.43	2.58	3.95	0.00	48.96
90	3.75	46.03	32.51	10.14	0.03	4.62	2.73	3.95	0.00	46.03

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	45.79	33.44	9.38	0.03	4.54	2.88	3.95	0.00	45.79
108	4.50	51.45	34.25	2.57	0.04	4.56	3.18	3.95	0.00	51.45
120	5.00	41.53	36.12	9.37	0.06	5.52	3.47	3.95	0.00	41.53
132	5.50	39.38	38.31	8.64	0.08	5.90	3.75	3.95	0.00	39.38
144	6.00	32.70	39.96	13.31	0.10	5.96	4.01	3.95	0.00	32.70
156	6.50	35.86	40.12	9.71	0.13	5.96	4.27	3.95	0.00	35.86
168	7.00	38.55	40.28	6.27	0.14	6.27	4.53	3.95	0.00	38.55
192	8.00	39.84	40.52	3.82	0.19	6.63	5.05	3.95	0.00	39.84
216	9.00	31.35	40.75	11.29	0.27	6.83	5.55	3.95	0.00	31.35
240	10.00	28.01	41.20	12.12	0.40	8.10	6.05	3.95	0.18	28.18
264	11.00	25.00	41.27	12.64	0.51	7.78	6.52	3.95	2.33	27.32
288	12.00	25.57	41.29	11.53	0.62	7.50	6.98	3.95	2.57	28.14
336	14.00	23.92	41.35	11.04	0.85	7.07	7.85	3.95	3.97	27.89
384	16.00	18.68	41.42	10.76	1.09	6.77	8.66	3.95	8.68	27.36
432	18.00	14.78	41.49	9.58	1.38	6.61	9.33	3.95	12.88	27.66
480	20.00	17.98	41.56	5.67	1.58	6.41	9.95	3.95	12.90	30.87
600	25.00	14.44	41.79	2.94	2.25	6.30	11.39	3.95	16.94	31.39
720	30.00	1.05	41.81	2.76	2.83	5.46	12.17	3.95	29.98	31.02
840	35.00	0.03	41.81	2.18	3.28	4.79	12.56	3.95	31.41	31.43
1080	45.00	0.02	41.81	1.90	3.91	3.78	13.21	3.95	31.41	31.43
1200	50.00	0.02	41.81	1.68	4.22	3.40	13.49	3.95	31.42	31.45
1320	55.00	0.00	41.81	1.55	4.43	3.08	13.73	3.95	31.45	31.45
Maximum	56.00	86.40	41.81	17.42	4.47	8.10	13.78	3.95	31.45	86.40

Table V.B-9 Outer Coast at Duntz Rock - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh 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	98.49	1.42	0.00	0.00	0.00	0.08	0.00	0.00	98.49
4	0.17	97.06	2.78	0.00	0.00	0.00	0.16	0.00	0.00	97.06
6	0.25	96.31	3.44	0.00	0.00	0.00	0.24	0.00	0.00	96.31
8	0.33	95.08	4.60	0.00	0.00	0.00	0.32	0.00	0.00	95.08
10	0.42	92.40	7.05	0.02	0.00	0.13	0.40	0.00	0.00	92.40
12	0.50	89.60	9.61	0.03	0.00	0.28	0.48	0.00	0.00	89.60
14	0.58	88.11	10.90	0.02	0.00	0.41	0.55	0.00	0.00	88.11
16	0.67	86.91	11.89	0.02	0.00	0.56	0.62	0.00	0.00	86.91
18	0.75	85.22	13.37	0.02	0.00	0.70	0.70	0.00	0.00	85.22
20	0.83	83.82	14.69	0.02	0.00	0.71	0.77	0.00	0.00	83.82
22	0.92	82.56	15.88	0.02	0.00	0.71	0.84	0.00	0.00	82.56
24	1.00	81.22	16.99	0.01	0.00	0.88	0.91	0.00	0.00	81.22
28	1.17	79.51	18.50	0.01	0.00	0.93	1.04	0.00	0.00	79.51
32	1.33	77.39	20.45	0.01	0.00	0.97	1.17	0.00	0.00	77.39
36	1.50	75.50	22.18	0.01	0.00	1.01	1.30	0.00	0.00	75.50
40	1.67	74.90	22.63	0.01	0.00	1.03	1.43	0.00	0.00	74.90
44	1.83	74.10	23.31	0.01	0.00	1.03	1.55	0.00	0.00	74.10
48	2.00	72.98	24.28	0.01	0.00	1.05	1.68	0.00	0.00	72.98
54	2.25	71.21	25.76	0.03	0.00	1.15	1.86	0.00	0.00	71.21
60	2.50	69.65	27.02	0.05	0.00	1.24	2.04	0.00	0.00	69.65
66	2.75	68.51	27.97	0.07	0.00	1.24	2.22	0.00	0.00	68.51
72	3.00	67.34	28.90	0.09	0.00	1.28	2.39	0.00	0.00	67.34
78	3.25	65.71	30.03	0.10	0.00	1.59	2.56	0.00	0.00	65.71
84	3.50	64.43	31.00	0.10	0.00	1.74	2.73	0.00	0.00	64.43
90	3.75	63.66	31.58	0.08	0.00	1.78	2.89	0.00	0.00	63.66
96	4.00	62.80	32.28	0.10	0.00	1.76	3.05	0.00	0.00	62.80

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
108	4.50	60.38	34.29	0.19	0.00	1.77	3.37	0.00	0.00	60.38
120	5.00	58.18	36.12	0.25	0.00	1.77	3.68	0.00	0.00	58.18
132	5.50	56.11	37.88	0.28	0.01	1.75	3.98	0.00	0.00	56.11
144	6.00	55.37	38.46	0.15	0.01	1.75	4.26	0.00	0.00	55.37
156	6.50	54.51	39.04	0.15	0.01	1.74	4.55	0.00	0.00	54.51
168	7.00	53.55	39.67	0.16	0.01	1.79	4.83	0.00	0.00	53.55
192	8.00	50.89	41.60	0.29	0.02	1.84	5.37	0.00	0.00	50.89
216	9.00	47.88	43.94	0.47	0.03	1.79	5.89	0.00	0.00	47.88
240	10.00	45.84	45.52	0.47	0.04	1.75	6.38	0.00	0.00	45.84
264	11.00	44.78	46.28	0.31	0.05	1.72	6.86	0.00	0.00	44.78
288	12.00	43.84	46.74	0.36	0.06	1.67	7.32	0.00	0.00	43.84
336	14.00	41.59	47.48	0.31	0.08	2.31	8.23	0.00	0.00	41.59
384	16.00	39.67	47.86	0.34	0.11	2.92	9.10	0.00	0.00	39.67
432	18.00	36.05	48.39	0.73	0.15	4.74	9.95	0.00	0.00	36.05
480	20.00	34.87	48.54	0.66	0.20	4.95	10.78	0.00	0.00	34.87
600	25.00	32.82	48.62	0.95	0.38	4.46	12.77	0.00	0.00	32.82
720	30.00	31.03	48.64	1.15	0.60	3.94	14.64	0.00	0.00	31.03
840	35.00	28.07	48.72	2.08	0.87	3.85	16.41	0.00	0.00	28.07
1080	45.00	0.03	52.67	7.74	2.91	16.68	19.38	0.00	0.58	0.61
1200	50.00	0.00	52.68	8.73	4.99	12.46	20.57	0.00	0.58	0.58
1320	55.00	0.00	52.68	9.02	6.72	9.42	21.59	0.00	0.58	0.58
Maximum	56.00	99.26	52.68	9.02	7.07	22.36	21.78	0.00	0.58	99.26

Table V.B-10 Outer Coast at Duntz Rock - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh 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	98.49	1.42	0.00	0.00	0.00	0.08	0.00	0.00	98.49
4	0.17	97.06	2.78	0.00	0.00	0.00	0.16	0.00	0.00	97.06
6	0.25	96.31	3.44	0.00	0.00	0.00	0.24	0.00	0.00	96.31
8	0.33	95.08	4.60	0.00	0.00	0.00	0.32	0.00	0.00	95.08
10	0.42	92.40	7.05	0.02	0.00	0.13	0.40	0.00	0.00	92.40
12	0.50	89.60	9.61	0.03	0.00	0.28	0.48	0.00	0.00	89.60
14	0.58	88.11	10.90	0.02	0.00	0.41	0.55	0.00	0.00	88.11
16	0.67	86.91	11.89	0.02	0.00	0.56	0.62	0.00	0.00	86.91
18	0.75	85.22	13.37	0.02	0.00	0.70	0.70	0.00	0.00	85.22
20	0.83	83.82	14.69	0.02	0.00	0.71	0.77	0.00	0.00	83.82
22	0.92	82.56	15.88	0.02	0.00	0.71	0.84	0.00	0.00	82.56
24	1.00	81.22	16.99	0.01	0.00	0.88	0.91	0.00	0.00	81.22
28	1.17	79.37	18.50	0.01	0.00	0.93	1.04	0.15	0.00	79.37
32	1.33	77.07	20.46	0.01	0.00	0.98	1.17	0.31	0.00	77.07
36	1.50	75.03	22.18	0.01	0.00	1.01	1.30	0.46	0.00	75.03
40	1.67	74.32	22.61	0.01	0.00	1.02	1.43	0.61	0.00	74.32
44	1.83	73.34	23.31	0.01	0.00	1.05	1.55	0.73	0.00	73.34
48	2.00	72.15	24.27	0.01	0.00	1.06	1.67	0.82	0.00	72.15
54	2.25	70.11	25.80	0.02	0.00	1.26	1.85	0.95	0.00	70.11
60	2.50	68.62	27.03	0.06	0.00	1.31	2.03	0.95	0.00	68.62
66	2.75	67.41	28.01	0.06	0.00	1.37	2.20	0.95	0.00	67.41
72	3.00	66.18	28.96	0.08	0.00	1.45	2.37	0.95	0.00	66.18
78	3.25	64.75	30.01	0.10	0.00	1.65	2.54	0.95	0.00	64.75
84	3.50	63.72	30.87	0.12	0.00	1.63	2.71	0.95	0.00	63.72
90	3.75	62.92	31.47	0.08	0.00	1.71	2.87	0.95	0.00	62.92
96	4.00	62.07	32.16	0.10	0.00	1.70	3.03	0.95	0.00	62.07

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
108	4.50	59.65	34.16	0.17	0.00	1.72	3.35	0.95	0.00	59.65
120	5.00	57.46	35.97	0.25	0.00	1.72	3.65	0.95	0.00	57.46
132	5.50	55.39	37.72	0.29	0.00	1.70	3.94	0.95	0.00	55.39
144	6.00	54.56	38.32	0.16	0.01	1.78	4.23	0.95	0.00	54.56
156	6.50	53.70	38.91	0.12	0.01	1.81	4.51	0.95	0.00	53.70
168	7.00	52.78	39.52	0.14	0.01	1.82	4.78	0.95	0.00	52.78
192	8.00	50.24	41.40	0.26	0.01	1.82	5.32	0.95	0.00	50.24
216	9.00	47.17	43.72	0.47	0.02	1.83	5.83	0.95	0.00	47.17
240	10.00	44.99	45.27	0.58	0.03	1.85	6.32	0.95	0.00	44.99
264	11.00	43.99	46.03	0.34	0.04	1.85	6.79	0.95	0.00	43.99
288	12.00	43.12	46.48	0.34	0.05	1.80	7.24	0.95	0.00	43.12
336	14.00	40.51	47.26	0.32	0.08	2.75	8.14	0.95	0.00	40.51
384	16.00	38.62	47.62	0.37	0.10	3.33	9.00	0.95	0.00	38.62
432	18.00	35.44	48.09	0.79	0.15	4.75	9.84	0.95	0.00	35.44
480	20.00	34.37	48.23	0.72	0.20	4.87	10.66	0.95	0.00	34.37
600	25.00	32.62	48.27	0.97	0.39	4.18	12.62	0.95	0.00	32.62
720	30.00	30.91	48.27	1.18	0.63	3.59	14.47	0.95	0.00	30.91
840	35.00	28.01	48.36	2.02	0.90	3.54	16.21	0.95	0.00	28.01
1080	45.00	0.24	52.23	7.64	2.92	16.13	19.13	0.95	0.76	1.00
1200	50.00	0.01	52.26	8.60	4.96	12.15	20.30	0.95	0.77	0.77
1320	55.00	0.00	52.26	8.90	6.66	9.16	21.30	0.95	0.77	0.77
Maximum	56.00	99.26	52.26	8.90	7.01	21.80	21.48	0.95	0.77	99.26

Table V.B-11 Outer Coast at Duntz Rock - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh 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	98.49	1.42	0.00	0.00	0.00	0.08	0.00	0.00	98.49
4	0.17	97.06	2.78	0.00	0.00	0.00	0.16	0.00	0.00	97.06
6	0.25	96.31	3.44	0.00	0.00	0.00	0.24	0.00	0.00	96.31
8	0.33	95.08	4.60	0.00	0.00	0.00	0.32	0.00	0.00	95.08
10	0.42	92.40	7.05	0.02	0.00	0.13	0.40	0.00	0.00	92.40
12	0.50	89.60	9.61	0.03	0.00	0.28	0.48	0.00	0.00	89.60
14	0.58	88.11	10.90	0.02	0.00	0.41	0.55	0.00	0.00	88.11
16	0.67	86.81	11.89	0.02	0.00	0.56	0.62	0.09	0.00	86.81
18	0.75	84.95	13.37	0.02	0.00	0.70	0.70	0.27	0.00	84.95
20	0.83	83.38	14.69	0.02	0.00	0.71	0.77	0.44	0.00	83.38
22	0.92	81.96	15.88	0.02	0.00	0.71	0.84	0.61	0.00	81.96
24	1.00	80.49	16.97	0.01	0.00	0.86	0.90	0.77	0.00	80.49
28	1.17	78.32	18.48	0.01	0.00	0.92	1.04	1.23	0.00	78.32
32	1.33	75.65	20.44	0.01	0.00	1.01	1.17	1.71	0.00	75.65
36	1.50	73.35	22.13	0.02	0.00	1.04	1.29	2.17	0.00	73.35
40	1.67	72.35	22.56	0.01	0.00	1.06	1.42	2.60	0.00	72.35
44	1.83	71.18	23.23	0.01	0.00	1.07	1.54	2.97	0.00	71.18
48	2.00	69.76	24.18	0.02	0.00	1.09	1.66	3.30	0.00	69.76
54	2.25	67.80	25.60	0.03	0.00	1.20	1.83	3.54	0.00	67.80
60	2.50	66.41	26.77	0.05	0.00	1.22	2.00	3.54	0.00	66.41
66	2.75	65.30	27.69	0.06	0.00	1.23	2.17	3.54	0.00	65.30
72	3.00	64.22	28.57	0.09	0.00	1.24	2.33	3.54	0.00	64.22
78	3.25	63.02	29.52	0.10	0.00	1.32	2.50	3.54	0.00	63.02
84	3.50	62.00	30.37	0.11	0.00	1.32	2.66	3.54	0.00	62.00
90	3.75	61.26	30.94	0.08	0.00	1.37	2.82	3.54	0.00	61.26

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	60.41	31.62	0.09	0.00	1.37	2.97	3.54	0.00	60.41
108	4.50	58.01	33.59	0.16	0.00	1.42	3.28	3.54	0.00	58.01
120	5.00	55.90	35.35	0.22	0.00	1.42	3.57	3.54	0.00	55.90
132	5.50	53.88	37.06	0.26	0.00	1.40	3.85	3.54	0.00	53.88
144	6.00	53.18	37.62	0.12	0.00	1.41	4.13	3.54	0.00	53.18
156	6.50	52.38	38.18	0.09	0.00	1.40	4.40	3.54	0.00	52.38
168	7.00	51.50	38.77	0.09	0.00	1.43	4.67	3.54	0.00	51.50
192	8.00	48.91	40.64	0.20	0.01	1.52	5.19	3.54	0.00	48.91
216	9.00	45.90	42.90	0.41	0.01	1.55	5.68	3.54	0.00	45.90
240	10.00	43.89	44.40	0.47	0.02	1.53	6.15	3.54	0.00	43.89
264	11.00	42.93	45.12	0.26	0.02	1.52	6.60	3.54	0.00	42.93
288	12.00	42.08	45.56	0.26	0.03	1.48	7.05	3.54	0.00	42.08
336	14.00	39.59	46.30	0.21	0.04	2.41	7.91	3.54	0.00	39.59
384	16.00	37.61	46.67	0.24	0.05	3.14	8.75	3.54	0.00	37.61
432	18.00	35.29	47.00	0.58	0.08	3.94	9.56	3.54	0.00	35.29
480	20.00	34.34	47.12	0.43	0.11	4.09	10.35	3.54	0.00	34.34
600	25.00	32.36	47.19	0.63	0.22	3.80	12.26	3.54	0.00	32.36
720	30.00	30.67	47.19	0.81	0.36	3.35	14.07	3.54	0.00	30.67
840	35.00	27.22	47.35	1.79	0.54	3.78	15.77	3.54	0.00	27.22
1080	45.00	0.13	51.15	7.39	2.43	16.06	18.63	3.54	0.67	0.80
1200	50.00	0.00	51.17	8.37	4.41	12.06	19.78	3.54	0.67	0.67
1320	55.00	0.00	51.17	8.67	6.07	9.12	20.77	3.54	0.67	0.67
Maximum	56.00	99.26	51.17	8.67	6.41	21.76	20.95	3.54	0.67	99.26

Table V.B-12 Outer Coast at Duntz Rock - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Tatoosh 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	98.49	1.42	0.00	0.00	0.00	0.08	0.00	0.00	98.49
4	0.17	97.06	2.78	0.00	0.00	0.00	0.16	0.00	0.00	97.06
6	0.25	96.22	3.44	0.00	0.00	0.00	0.24	0.09	0.00	96.22
8	0.33	94.91	4.60	0.00	0.00	0.00	0.32	0.17	0.00	94.91
10	0.42	92.16	7.05	0.02	0.00	0.13	0.40	0.25	0.00	92.16
12	0.50	89.29	9.61	0.03	0.00	0.28	0.48	0.32	0.00	89.29
14	0.58	87.73	10.90	0.02	0.00	0.41	0.55	0.38	0.00	87.73
16	0.67	86.41	11.88	0.02	0.00	0.56	0.62	0.51	0.00	86.41
18	0.75	84.53	13.36	0.01	0.00	0.70	0.69	0.70	0.00	84.53
20	0.83	82.95	14.67	0.01	0.00	0.71	0.76	0.90	0.00	82.95
22	0.92	81.50	15.85	0.01	0.00	0.71	0.83	1.09	0.00	81.50
24	1.00	79.97	16.96	0.01	0.00	0.88	0.90	1.28	0.00	79.97
28	1.17	77.79	18.45	0.01	0.00	0.93	1.03	1.80	0.00	77.79
32	1.33	75.17	20.37	0.01	0.00	0.98	1.16	2.32	0.00	75.17
36	1.50	72.86	22.03	0.02	0.00	0.99	1.29	2.82	0.00	72.86
40	1.67	71.83	22.46	0.01	0.00	1.00	1.41	3.29	0.00	71.83
44	1.83	70.64	23.12	0.01	0.00	1.01	1.53	3.69	0.00	70.64
48	2.00	69.25	24.04	0.01	0.00	1.01	1.65	4.04	0.00	69.25
54	2.25	67.12	25.52	0.02	0.00	1.21	1.82	4.31	0.00	67.12
60	2.50	65.43	26.81	0.05	0.00	1.41	1.99	4.31	0.00	65.43
66	2.75	64.29	27.74	0.06	0.00	1.45	2.16	4.31	0.00	64.29
72	3.00	63.19	28.63	0.08	0.00	1.48	2.32	4.31	0.00	63.19
78	3.25	61.77	29.66	0.09	0.00	1.70	2.48	4.31	0.00	61.77
84	3.50	60.65	30.54	0.10	0.00	1.77	2.64	4.31	0.00	60.65
90	3.75	59.76	31.14	0.09	0.00	1.90	2.79	4.31	0.00	59.76

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	58.95	31.81	0.11	0.00	1.88	2.95	4.31	0.00	58.95
108	4.50	56.61	33.72	0.22	0.00	1.89	3.25	4.31	0.00	56.61
120	5.00	54.57	35.46	0.24	0.00	1.89	3.54	4.31	0.00	54.57
132	5.50	52.58	37.13	0.30	0.00	1.87	3.81	4.31	0.00	52.58
144	6.00	51.61	37.75	0.19	0.01	2.05	4.09	4.31	0.00	51.61
156	6.50	50.70	38.34	0.16	0.01	2.13	4.35	4.31	0.00	50.70
168	7.00	49.79	38.93	0.17	0.01	2.18	4.62	4.31	0.00	49.79
192	8.00	47.28	40.73	0.30	0.01	2.24	5.13	4.31	0.00	47.28
216	9.00	44.44	42.91	0.48	0.03	2.21	5.62	4.31	0.00	44.44
240	10.00	42.50	44.35	0.57	0.04	2.16	6.08	4.31	0.00	42.50
264	11.00	41.54	45.05	0.40	0.06	2.11	6.53	4.31	0.00	41.54
288	12.00	40.75	45.46	0.39	0.07	2.05	6.97	4.31	0.00	40.75
336	14.00	38.57	46.12	0.38	0.10	2.70	7.82	4.31	0.00	38.57
384	16.00	36.80	46.46	0.42	0.13	3.25	8.64	4.31	0.00	36.80
432	18.00	34.15	46.84	0.74	0.18	4.34	9.45	4.31	0.00	34.15
480	20.00	32.81	47.03	0.64	0.23	4.76	10.23	4.31	0.00	32.81
600	25.00	30.47	47.15	0.89	0.40	4.67	12.11	4.31	0.00	30.47
720	30.00	28.75	47.18	1.08	0.61	4.20	13.87	4.31	0.00	28.75
840	35.00	25.75	47.31	1.87	0.86	4.37	15.54	4.31	0.00	25.75
1080	45.00	0.08	50.91	7.15	2.76	15.94	18.34	4.31	0.51	0.59
1200	50.00	0.00	50.92	8.04	4.66	12.08	19.48	4.31	0.51	0.51
1320	55.00	0.00	50.92	8.30	6.25	9.26	20.45	4.31	0.51	0.51
Maximum	56.00	99.26	50.92	8.30	6.58	21.43	20.63	4.31	0.51	99.26

Table V.B-13 Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	3,251	46,034	21,583
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	2,127	33,931	16,508
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	6,939	931	3,418
Shoreline length (km) oiled by > 100 g/m^2	3,869	726	2,510
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	5,318,700	463,390	2,189,100
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,620,600	467,160	1,228,800
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	256	26	87

Table V.B-14 Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	4,032	40,633	21,524
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	2,967	27,434	16,603
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	7,482	900	3,446
Shoreline length (km) oiled by > 100 g/m^2	3,050	746	2,361
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	6,389,900	429,080	2,280,800
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,092,300	471,310	1,165,500
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	238	26	86

Table V.B-15 Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	4,032	34,931	22,100
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	2,967	23,518	16,711
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	7,482	558	4,085
Shoreline length (km) oiled by > 100 g/m^2	3,050	394	2,476
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	6,389,900	360,840	2,831,600
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,092,300	197,200	1,253,300
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	238	12	104

Table V.B-16 Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	4,140	36,685	20,242
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	2,854	25,896	16,757
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	6,850	900	3,209
Shoreline length (km) oiled by > 100 g/m^2	3,148	686	2,394
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	5,701,700	545,590	1,964,400
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,148,100	354,050	1,244,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	211	21	87

V.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 V.C-1 Outer Coast at Duntz Rock - 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)	-	77,378	75	4,812	-	9	89	42	82,405	82,265	139
Worst run for the Olympia Coast National Marine Sanctuary	1,645,669	898,618	7	460	-	74	367	305	2,545,500	2,544,755	746
Worst run for Tatoosh Island	740,850	448,708	31	1,973	-	38	215	161	1,191,975	1,191,561	414

Table V.C-2 Outer Coast at Duntz Rock - 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)	37,655	99,053	57	3,636	-	10	96	49	140,555	140,400	155
Worst run for the Olympia Coast National Marine Sanctuary	1,308,244	730,838	8	477	-	61	310	251	2,040,189	2,039,567	622
Worst run for Tatoosh Island	745,836	451,187	31	1,967	-	38	216	161	1,199,436	1,199,021	415

Table V.C-3 Outer Coast at Duntz Rock - 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)	37,655	99,053	57	3,636	-	10	96	49	140,555	140,400	155
Worst run for the Olympia Coast National Marine Sanctuary	1,104,813	629,684	3	179	-	53	276	219	1,735,226	1,734,679	547
Worst run for Tatoosh Island	751,445	453,976	31	1,944	-	39	217	162	1,207,812	1,207,395	417

Table V.C-4 Outer Coast at Duntz Rock - 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)	31,775	96,129	62	3,960	-	10	95	48	132,080	131,926	153
Worst run for the Olympia Coast National Marine Sanctuary	1,228,368	691,120	7	426	-	57	297	238	1,920,514	1,919,921	592
Worst run for Tatoosh Island	753,782	455,138	29	1,874	-	39	217	163	1,211,242	1,210,824	418

V.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 V.D-1. Outer Coast at Duntz Rock - 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)	264	283	6.6	5.2	-	33,652	34,211
Worst run for the Olympia Coast National Marine Sanctuary	1,508	1,914	17	52	-	2,454	5,945
Worst run for Tatoosh Island	846	1,045	12	27	-	21,968	23,897

Table V.D-2. Outer Coast at Duntz Rock - 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)	1,291	1,629	16	44	-	25,006	27,985
Worst run for the Olympia Coast National Marine Sanctuary	2,292	2,941	24	82	-	2,980	8,318

Worst run for Tatoosh Island	823	1,016	11	26	-	21,091	22,968

Table V.D-3. Outer Coast at Duntz Rock - 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)	1,2910	1,629	16	44	-	25,006	27,985
Worst run for the Olympia Coast National Marine Sanctuary	2,794	3,600	29	101	-	1,753	8,276
Worst run for Tatoosh Island	780	959	11	25	-	22,727	24,503

Table V.D-4. Outer Coast at Duntz Rock - 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)	1,417	1,794	17	49	-	25,473	28,750
Worst run for the Olympia Coast National Marine Sanctuary	2,397	3,078	25	86	-	2,395	7,982
Worst run for Tatoosh Island	713	870	11	22	-	21,266	22,882

V.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 V.E-1. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Fish and Invertebrates:			
Small pelagic fish	265	1,508	846
Large pelagic fish	283	1,914	1,045
Demersal fish	6.6	17	12
Decapods	5.2	53	27
Molluscs	33,652	2,454	21,968
Birds:			
Waterfowl (# * kg each)	-	1,834,921	826,048
Seabirds (# * kg each)	43,332	503,226	251,276
Waders (# * kg each)	42	4	17
Shorebirds (# * kg each)	2,695	258	1,105
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	24	171	90
Pinnipeds	50	206	120
Cetaceans	4.8	41	21
Totals:			
Subtotal fish and invertebrates	34,211	5,945	23,897
Subtotal birds	46,069	2,338,409	1,078,446
Subtotal other wildlife	78	418	232
Total all species	80,358	2,344,772	1,102,574

Table V.E-2. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Saltmarsh Area (ha)	273	5,270	2,528
Saltmarsh Area (acres)	675	13,021	6,246
Saltmarsh Cost (millions of 2004$)	126	2,439	1,170
Eelgrass Area (m2)	171	3,293	1,580
Eelgrass Area (acres)	422	8,137	3,903
Eelgrass Cost (millions of 2004$)	50.3	971.4	466

Table V.E-3. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Fish and Invertebrates:			
Small pelagic fish	1,291	2,292	823
Large pelagic fish	1,629	2,941	1,016
Demersal fish	16	24	12
Decapods	44	82	26
Molluscs	25,006	2,980	21,091
Birds:			
Waterfowl (# * kg each)	41,985	1,458,692	831,607
Seabirds (# * kg each)	55,469	409,269	252,665
Waders (# * kg each)	32	4	17
Shorebirds (# * kg each)	2,036	267	1,102
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	27	141	90
Pinnipeds	54	174	121
Cetaceans	5.8	34	22
Totals:			
Subtotal fish and invertebrates	27,985	8,318	22,968
Subtotal birds	99,522	1,868,233	1,085,390
Subtotal other wildlife	87	348	233
Total all species	127,594	1,876,899	1,108,590

Table V.E-4. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Saltmarsh Area (ha)	400	4,250	2,543
Saltmarsh Area (acres)	987	10,502	6,283
Saltmarsh Cost (millions of 2004$)	185	1,968	1,177
Eelgrass Area (m2)	250	2,656	1,589
Eelgrass Area (acres)	617	6,563	3,926
Eelgrass Cost (millions of 2004$)	73.7	784	469

Table V.E-5. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Fish and Invertebrates:			
Small pelagic fish	1,291	2,794	780
Large pelagic fish	1,629	3,600	959
Demersal fish	16	29	11
Decapods	44	101	25
Molluscs	25,006	1,753	22,727
Birds:			
Waterfowl (# * kg each)	41,985	1,231,867	837,861
Seabirds (# * kg each)	55,469	352,623	254,227
Waders (# * kg each)	32	2	17
Shorebirds (# * kg each)	2,036	100	1,089
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	27	122	91
Pinnipeds	54	155	121
Cetaceans	5.8	29	22
Totals:			
Subtotal fish and invertebrates	27,985	8,276	24,503
Subtotal birds	99,522	1,584,592	1,093,193
Subtotal other wildlife	87	306	234
Total all species	127,594	1,593,175	1,117,929

Table V.E-6. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Saltmarsh Area (ha)	400	3,635	2,5606
Saltmarsh Area (acres)	987	8,983	6,325
Saltmarsh Cost (millions of 2004$)	185	1,683	1,185
Eelgrass Area (m2)	250	2,272	1,600
Eelgrass Area (acres)	617	5,613	3,952
Eelgrass Cost (millions of 2004$)	73.7	670	472

Table V.E-7. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Fish and Invertebrates:			
Small pelagic fish	1,417	2,397	713
Large pelagic fish	1,794	3,078	871
Demersal fish	17	25	11
Decapods	49	86	22
Molluscs	25,473	2,395	21,266
Birds:			
Waterfowl (# * kg each)	35,430	1,369,630	840,467
Seabirds (# * kg each)	53,832	387,027	254,877
Waders (# * kg each)	35	4	16
Shorebirds (# * kg each)	2,217	239	1,050
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	27	133	91
Pinnipeds	53	166	122
Cetaceans	5.7	32	22
Totals:			
Subtotal fish and invertebrates	28,750	7,982	22,882
Subtotal birds	91,514	1,756,900	1,096,410
Subtotal other wildlife	86	332	234
Total all species	120,350	1,765,213	1,119,527

Table V.E-8. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Saltmarsh Area (ha)	383	4,008	2,566
Saltmarsh Area (acres)	945	9,905	6,341
Saltmarsh Cost (millions of 2004$)	177	1,856	1,188
Eelgrass Area (m2)	239	2,505	1,604
Eelgrass Area (acres)	591	6,189	3,963
Eelgrass Cost (millions of 2004$)	70.5	739	473

V.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 V.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table V.F-1. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Vulnerability Score ($/gal.)	23.64	23.64	23.64
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	248	248	248

Table V.F-2. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Vulnerability Score ($/gal.)	23.64	23.64	23.64
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	248	248	248

Table V.F-3. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Vulnerability Score ($/gal.)	23.64	23.64	23.64
% Removed by 24 hours	0.00	0.89	0.77
Compensation (millions $)	248	246	246

Table V.F-4. Outer Coast at Duntz Rock - 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 the Olympia Coast National Marine Sanctuary	Worst run for Tatoosh Island
Vulnerability Score ($/gal.)	23.64	23.64	23.64
% Removed by 24 hours	0.32	1.36	1.28
Compensation (millions $)	247	245	245

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 VI: Model Inputs for Strait of Juan de Fuca – Bunker C

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

VI.A. Introduction 5
VI.B. Geographical Data 6
VI.B.1. Maps of the Vicinity of the Modeled Spill Locations 6
VI.B.2. Gridded Habitat Mapping 7
VI.B-3. Gridded Depth Data 8
VI.B-4. Areas Where Response Actions Assumed 9
VI.C. Current Data 11
VI.C.1. Basis of Current Data 11
VI.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 12
VI.D: Oil Properties 15
VI.E: Inputs to the SIMAP Physical Fates Model 18

List of Figures

Figure VI.B.1-1 Map of the vicinity of the potential spill locations..... 6
Figure VI.B.2-1 Habitat grid used for modeling the potential spills. 7
Figure VI.B.2-2 Habitat grid used for modeling the potential spills (closer view). 7
Figure VI.B.3-1 Depth grid used for modeling the potential spills. 8
Figure VI.B.3-2 Depth grid used for modeling the potential spills (closer view). 8
Figure VI.B.4-1 Jurisdictions in the area of the potential spills. 9
Figure VI.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 9
Figure VI.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 10
Figure VI.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 10
Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data..... 11
Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC). 12
Figure VI.C.2-1 Current component data used in modeling representing the maximum flood time for the M_2 component at Victoria, BC. 13
Figure VI.C.2-2 Current component data used in modeling representing the maximum ebb tide for the M_2 component at Victoria, BC. 13
Figure VI.C.2-3 Current component data used in modeling representing the maximum flood tide for the K_1 component at Victoria, BC. 14
Figure VI.C.2-4 Current component data used in modeling representing the maximum ebb tide for the K_1 component at Victoria, BC. 14
Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit. 21
Figure VI.E-2. Wind Station Locations. 25

List of Tables

Table VI.D-1. Oil properties for Bunker C assumed in the modeling. 15
Table VI.D-2. Aromatic concentrations (mg/kg) for Bunker C..... 16
Table VI.E-1. Inputs to the Fates Model for Stochastic Scenarios..... 18
Table VI.E-2. Time, date and location inputs for each of the 100 stochastic runs. 22
Table VI.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 24
Table VI.E-4. Water temperature by month of the year 24
Table VI.E-5. Wind data sources and records used. 25

VI.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.

VI.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.

VI.B.1. Maps of the Vicinity of the Modeled Spill Locations

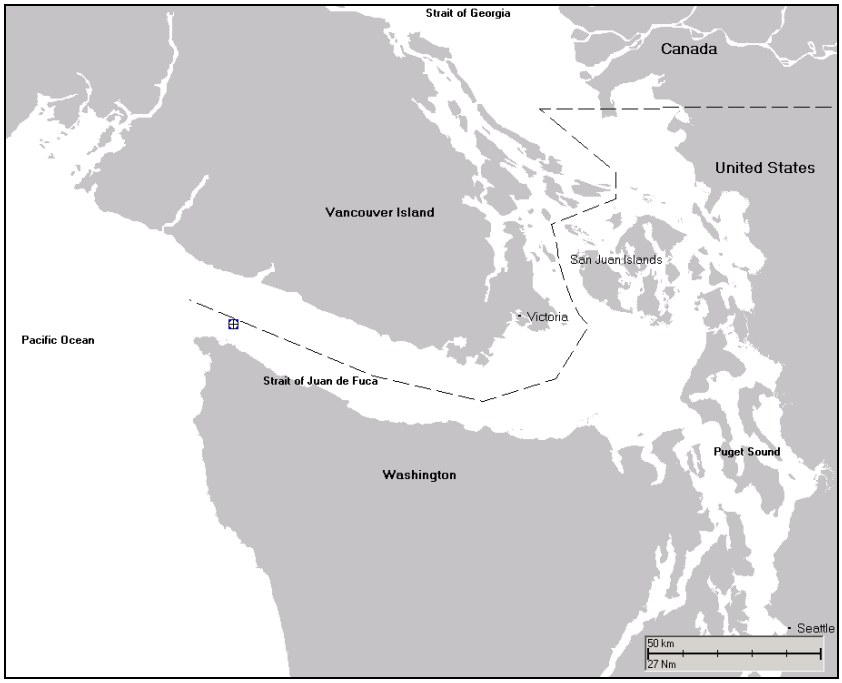


Figure VI.B.1-1 Map of the vicinity of the potential spill locations.

VI.B.2. Gridded Habitat Mapping

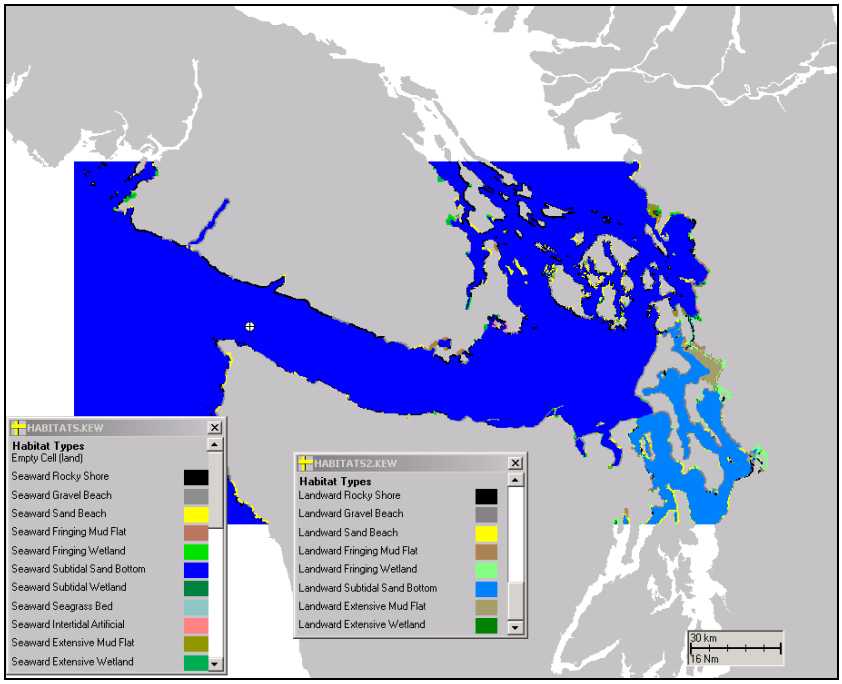


Figure VI.B.2-1 Habitat grid used for modeling the potential spills.

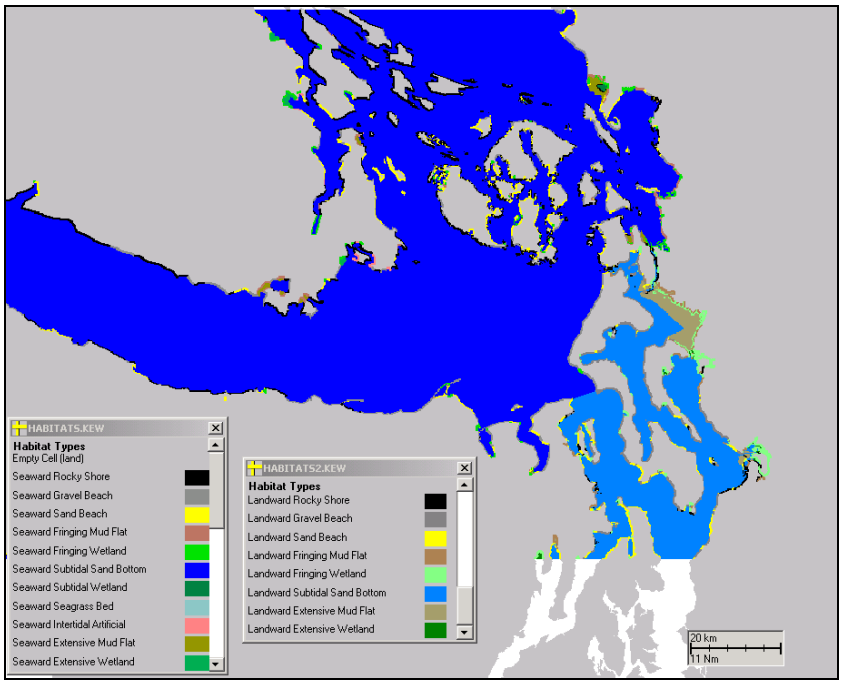


Figure VI.B.2-2 Habitat grid used for modeling the potential spills (closer view).

VI.B-3. Gridded Depth Data

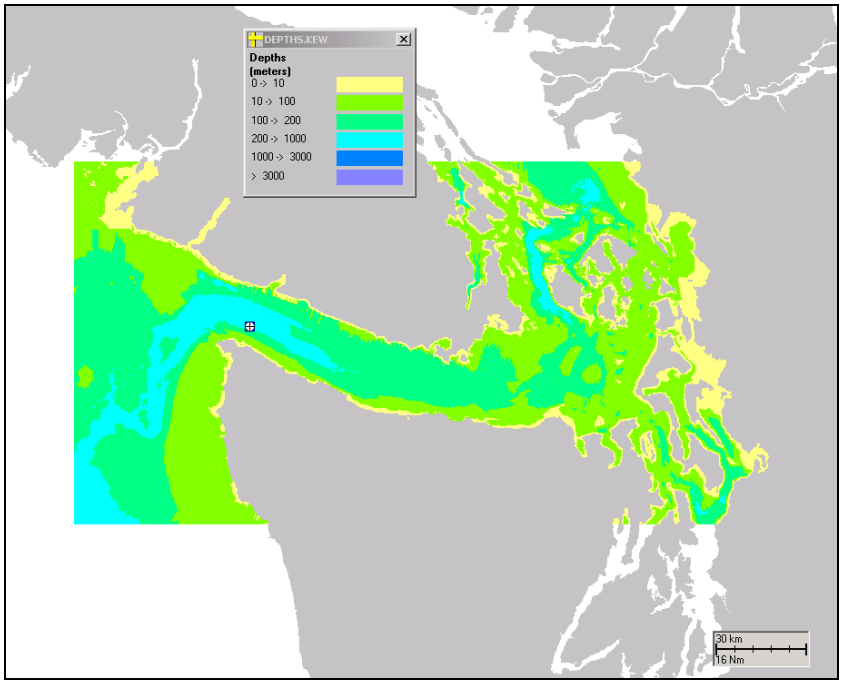


Figure VI.B.3-1 Depth grid used for modeling the potential spills.

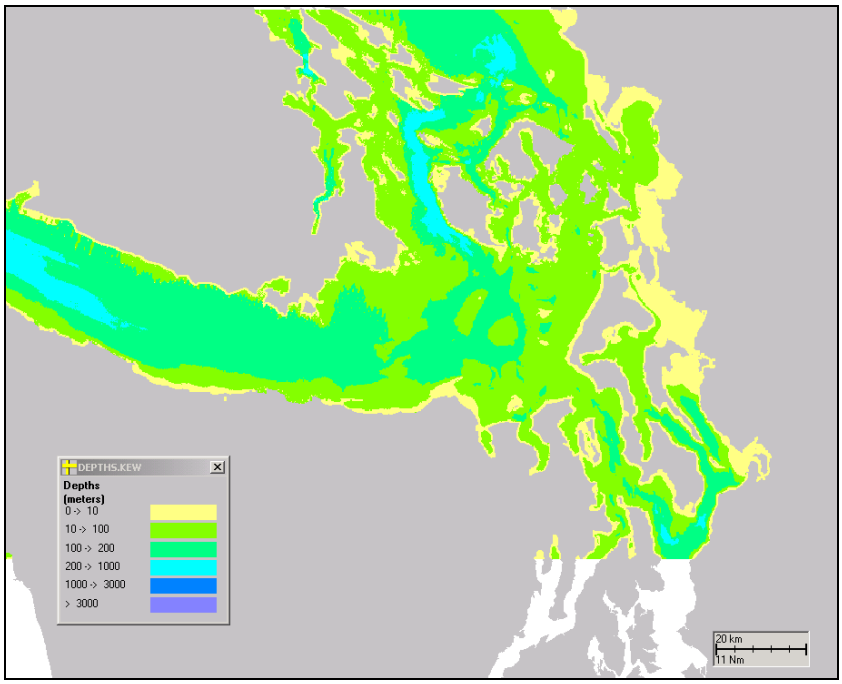


Figure VI.B.3-2 Depth grid used for modeling the potential spills (closer view).

VI.B-4. Areas Where Response Actions Assumed

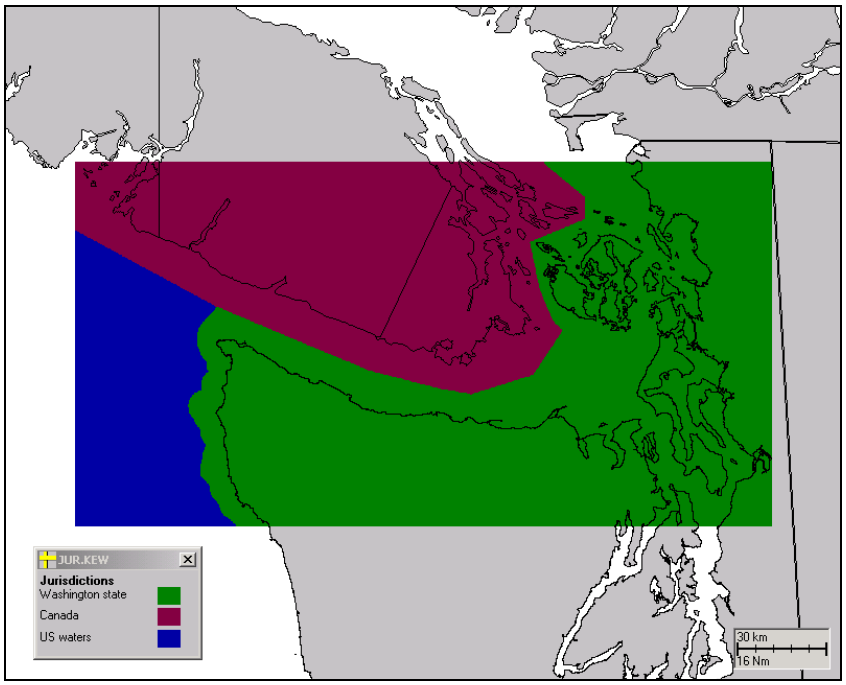


Figure VI.B.4-1 Jurisdictions in the area of the potential spills.

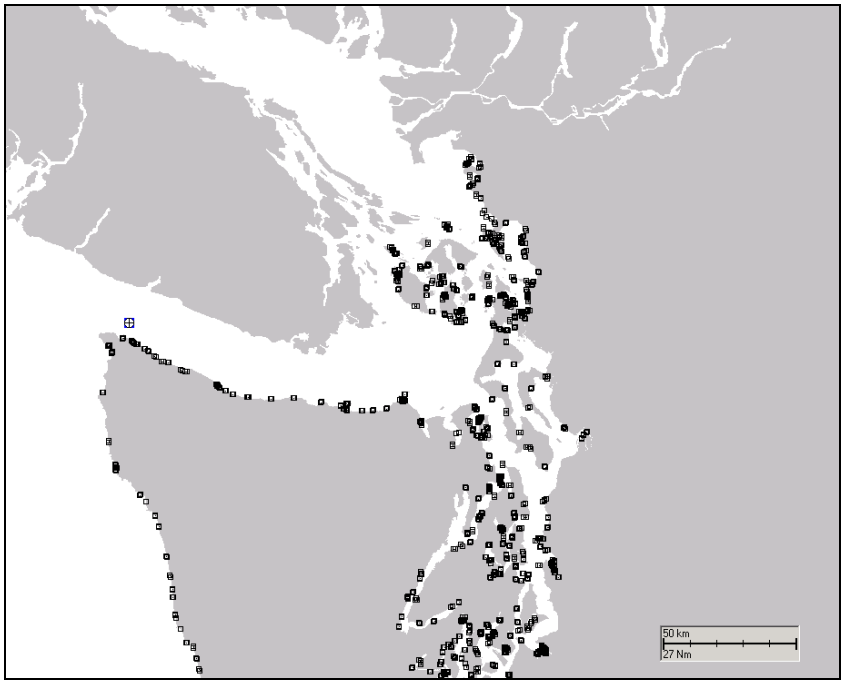


Figure VI.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

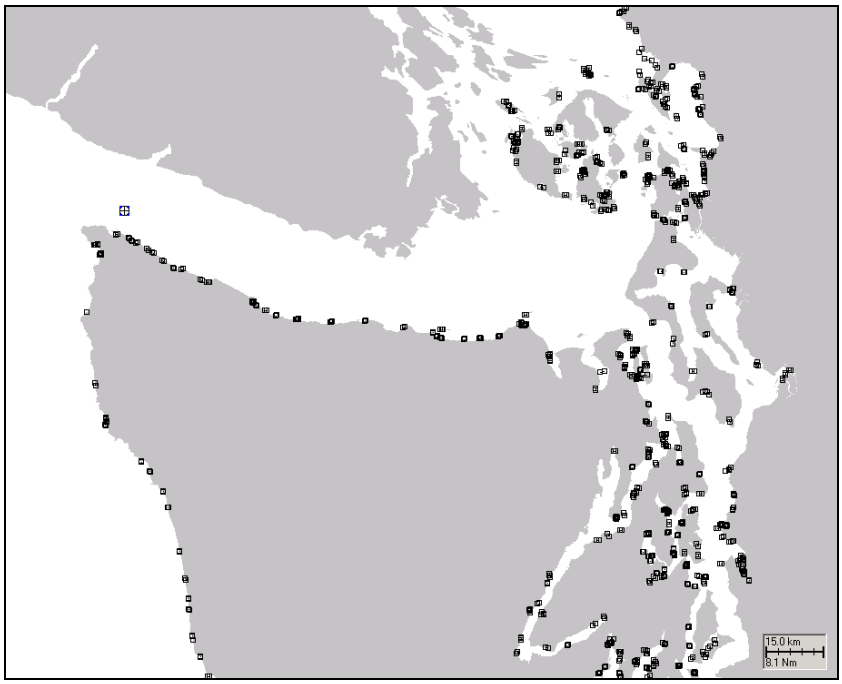


Figure VI.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

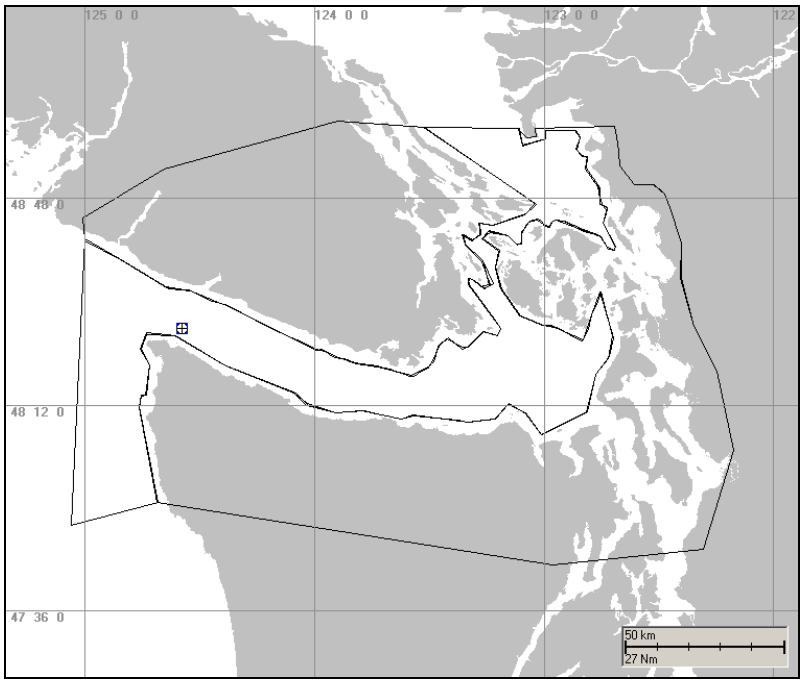


Figure VI.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

VI.C. CURRENT DATA

VI.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).

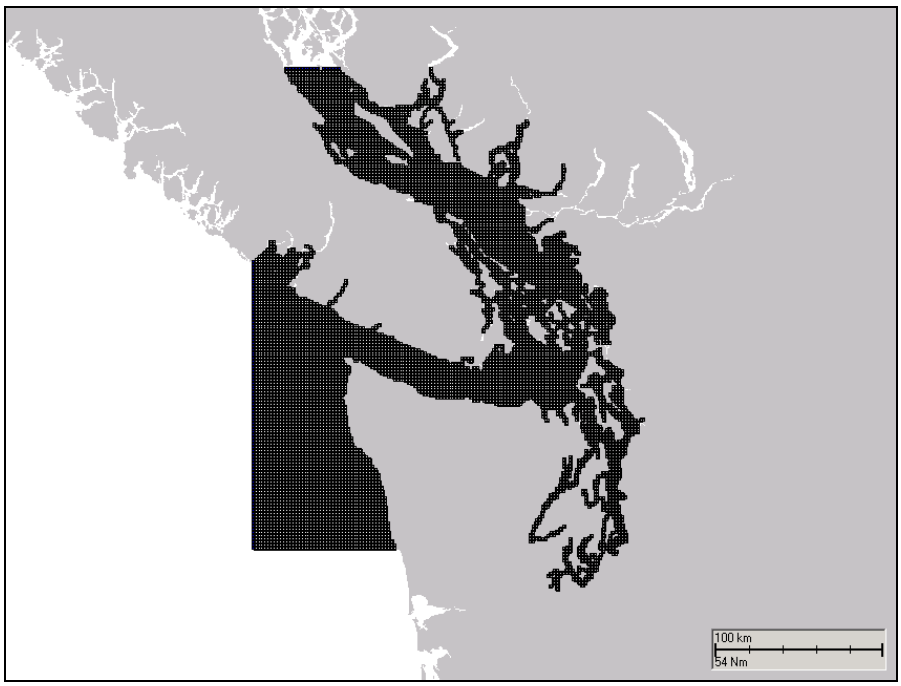


Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data.

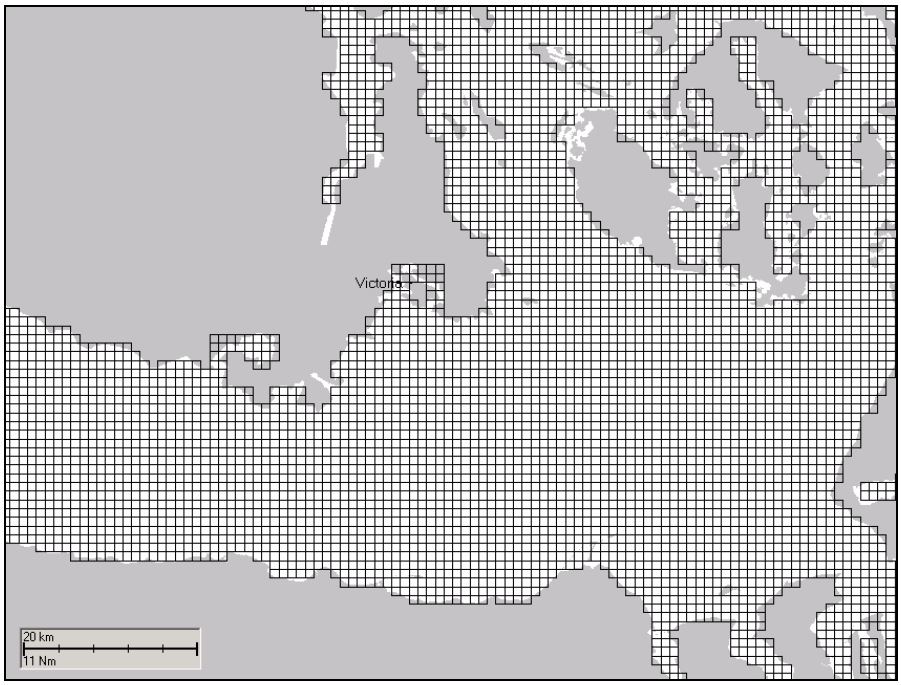


Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

VI.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.

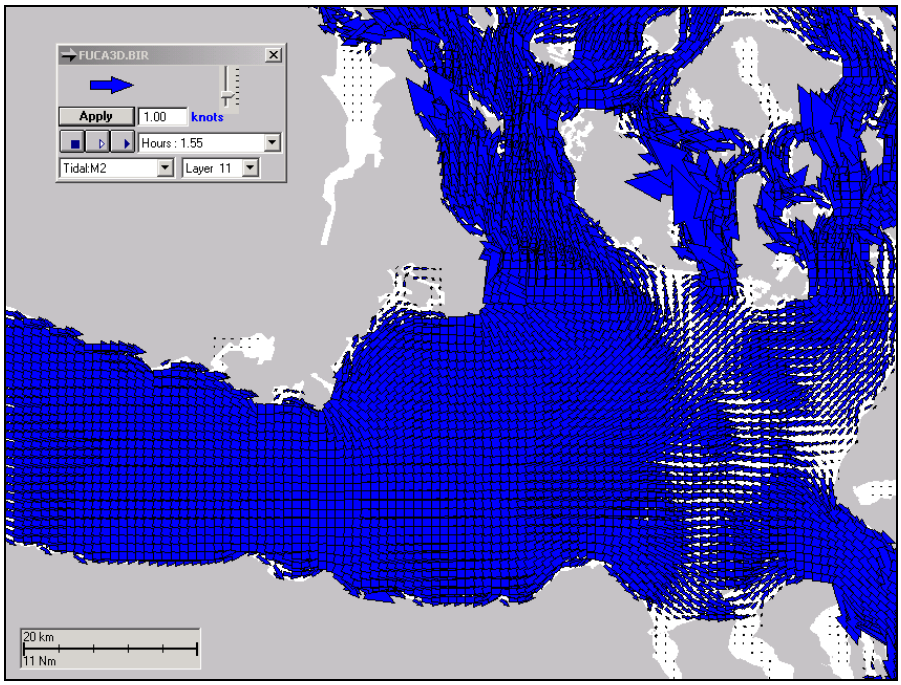


Figure VI.C.2-1 Current component data used in modeling representing the maximum flood time for the M_2 component at Victoria, BC. Vector length indicates speed in the indicated direction.

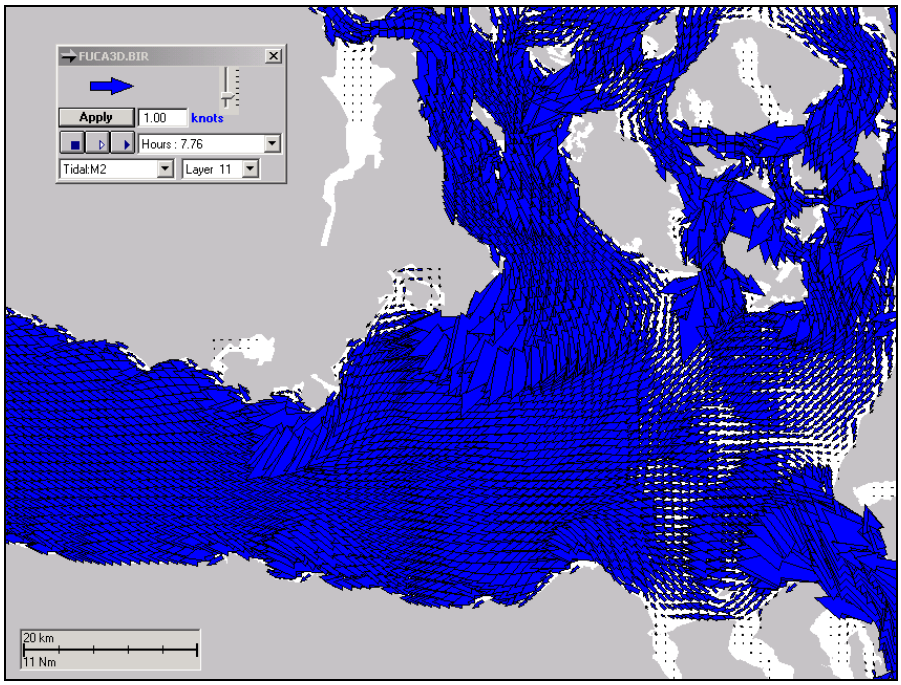


Figure VI.C.2-2 Current component data used in modeling representing the maximum ebb tide for the M_2 component at Victoria, BC. Vector length indicates speed in the indicated direction.

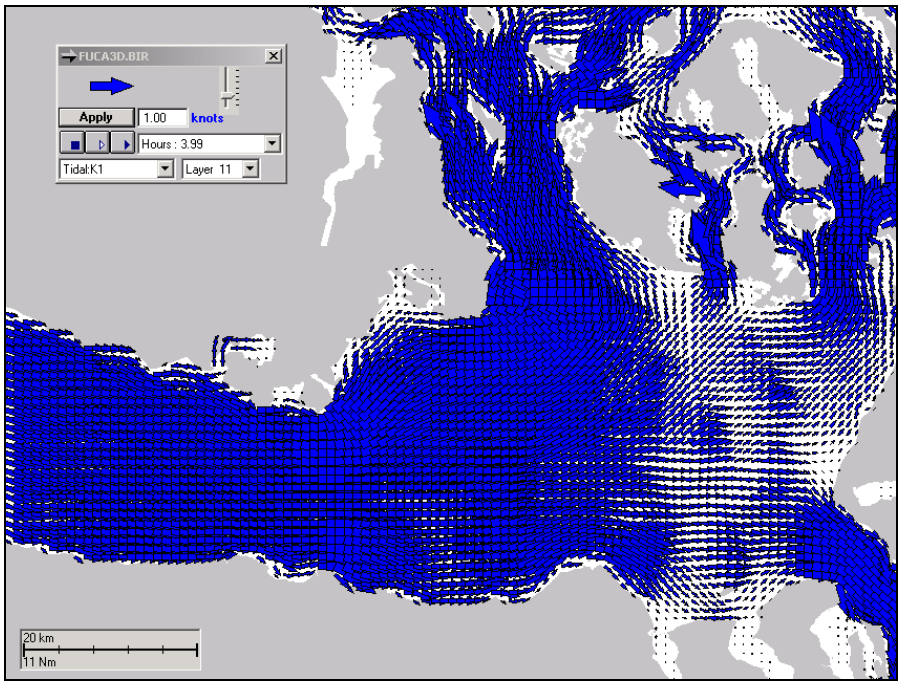


Figure VI.C.2-3 Current component data used in modeling representing the maximum flood tide for the K_1 component at Victoria, BC. Vector length indicates speed in the indicated direction.

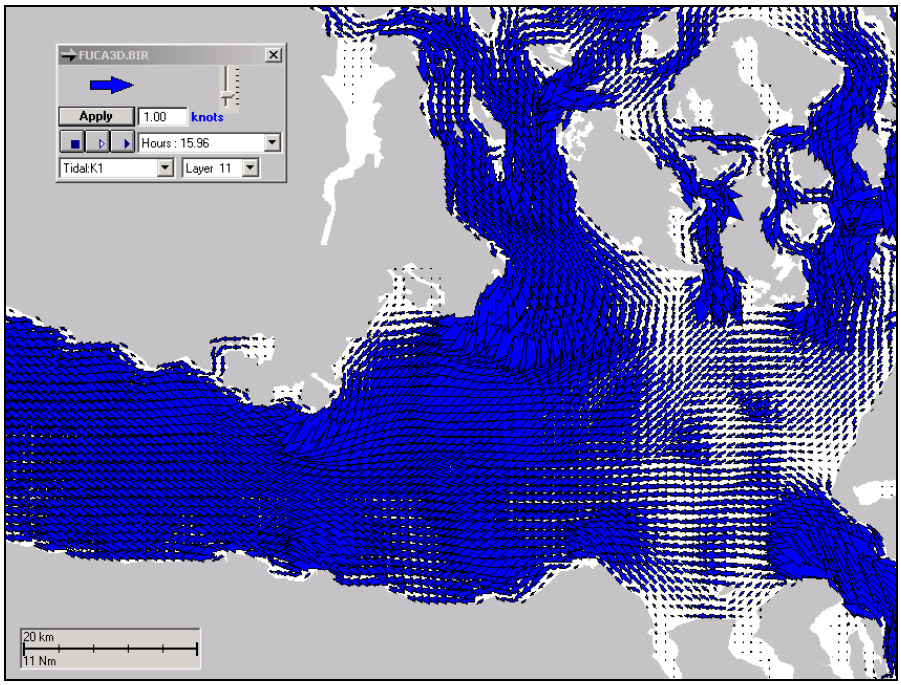


Figure VI.C.2-4 Current component data used in modeling representing the maximum ebb tide for the K_1 component at Victoria, BC. Vector length indicates speed in the indicated direction.

VI.D: OIL PROPERTIES

Table VI.D-1. Oil properties for Bunker C assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.9749	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	3180	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27	Jokuty et al. (1999)
Pour Point (deg. C)	7	Whiticar et al. (1994)
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)	0.00	Ostazeski et al. (1997)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.036093	Ostazeski et al. (1997)
Fraction 2-ring aromatics (included in PAHs above)	0.011987	Ostazeski et al. (1997)
Fraction 3-ring aromatics (included in PAHs above)	0.024106	Ostazeski et al. (1997)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.010000	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.037013	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.088894	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	30	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] – Jokuty 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 VI.D-2. Aromatic concentrations (mg/kg) for Bunker C.

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	752
C1-naphthalenes	3.87	4,100
C2-naphthalenes	4.37	7,135
C3-naphthalenes	5.00	5,509
C4-naphthalenes	5.55	2,746
biphenyls	3.9	74
acenaphthylene	4.07	2
acenaphthene	3.92	219
dibenzofuran	4.31	76
Fluorene	4.18	239
C1-fluorenes	4.97	659
C2-fluorenes	5.20	1,144
C3-fluorenes	5.50	1,077

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table VI.D-2. Aromatic concentrations (mg/kg) for Bunker C (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	346
C1-dibenzothiophene	4.86	1,072
C2-dibenzothiophene	5.50	1,489
C3-dibenzothiophene	5.73	1,176
phenanthrene	4.57	743
anthracene	4.54	88
C1-phenanthrenes/anthracenes	5.14	2,031
C2-phenanthrenes/anthracenes	5.25	2,661
C3-phenanthrenes/anthracenes	6.00	1,825
C4-phenanthrenes/anthracenes	6.51	930
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total $\log(K_{ow}) \leq 5.6$	-	32,162.3

*Estimates of $\log(K_{ow})$ are from Mackay et al. (1992a,b) and Neff and Burns (1996).

VI.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 VI.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	Shipping Lane from Neah Bay to Port Angeles
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Fig. VI.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Fig. VI.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	25,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	56 days

Table VI.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table VI.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 VI.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table VI.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

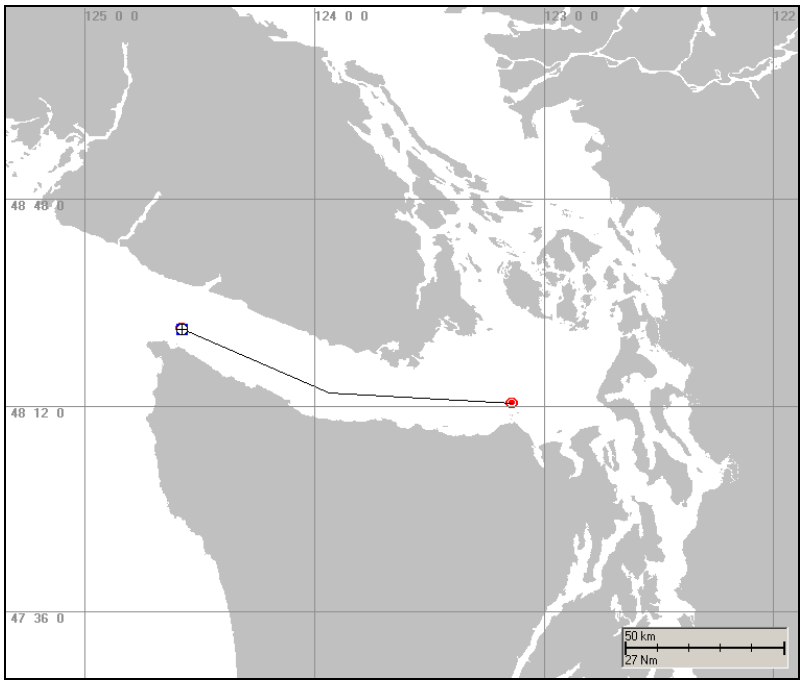


Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit.

Table VI.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	48.213791	123.25175
2	1998	5	16	3	48.353981	124.32769
3	2000	8	16	18	48.235836	123.82753
4	1998	5	31	11	48.303829	124.15526
5	1996	12	29	21	48.366234	124.36981
6	1993	2	13	17	48.226902	123.59418
7	2001	3	14	23	48.37146	124.38778
8	1999	3	9	17	48.230587	123.69041
9	1992	4	23	10	48.269451	124.03706
10	2002	8	18	0	48.355328	124.33232
11	1995	4	22	7	48.222973	123.4916
12	1993	3	17	9	48.225719	123.56332
13	2001	2	9	19	48.221523	123.45371
14	1998	9	7	21	48.268631	124.03423
15	2000	6	23	20	48.216637	123.32606
16	1995	10	12	13	48.227024	123.59737
17	2003	5	10	6	48.381798	124.42332
18	1994	4	16	9	48.230949	123.69993
19	1993	10	14	10	48.220196	123.41904
20	1992	12	26	22	48.251453	123.97518
21	2002	12	9	23	48.212162	123.20924
22	2001	9	20	18	48.401386	124.49068
23	1993	9	16	15	48.239388	123.92026
24	2002	3	17	7	48.406712	124.50898
25	1998	7	1	21	48.376102	124.40374
26	1996	5	24	1	48.235294	123.81342
27	1999	6	5	17	48.321064	124.21452
28	2002	12	30	22	48.222511	123.47953
29	1994	5	27	7	48.226639	123.58734
30	1994	6	15	3	48.237236	123.86407
31	1996	3	30	15	48.231377	123.71107
32	1998	6	10	3	48.349258	124.31145
33	1993	3	14	3	48.290565	124.10966
34	1998	1	9	19	48.346123	124.30067
35	1992	4	27	14	48.211872	123.20163
36	2003	1	18	8	48.273148	124.04977
37	1998	5	29	11	48.397171	124.47619
38	1993	5	21	6	48.235062	123.80727
39	2000	11	29	23	48.280499	124.07505
40	2003	6	3	2	48.230591	123.69053
41	1999	5	8	8	48.396656	124.47442
42	2001	4	6	0	48.228329	123.63148
43	2003	8	17	3	48.21769	123.35358
44	1993	12	13	4	48.422306	124.5626
45	1992	8	8	14	48.332958	124.25541
46	2003	5	16	21	48.348415	124.30856
47	1998	12	17	12	48.223038	123.49325
48	2003	12	13	0	48.40501	124.50314
49	2002	6	11	1	48.224422	123.52939
50	1999	5	20	22	48.209896	123.15006

51	2000	5	4	17	48.211761	123.19877
52	1992	4	29	2	48.333706	124.25797
53	2000	3	10	1	48.233566	123.7683
54	1998	10	24	2	48.225147	123.54839
55	2000	6	26	19	48.290638	124.1099
56	2001	9	18	8	48.209698	123.14481
57	1994	7	29	15	48.255066	123.9876
58	2000	4	24	0	48.231518	123.71472
59	1993	10	14	14	48.224335	123.52715
60	1992	1	12	13	48.231998	123.72729
61	2003	5	3	16	48.214115	123.26027
62	1995	7	13	7	48.227104	123.59943
63	1998	10	26	18	48.414104	124.53441
64	2003	3	29	13	48.23093	123.69936
65	1993	8	7	14	48.215137	123.28696
66	1996	12	18	16	48.22802	123.62341
67	2003	3	11	17	48.239223	123.91602
68	1999	2	24	6	48.279873	124.0729
69	1993	7	2	21	48.227913	123.62064
70	2002	6	14	7	48.222122	123.46939
71	1993	1	23	10	48.39468	124.46761
72	2000	11	26	20	48.212616	123.22112
73	1992	10	4	5	48.257195	123.99493
74	1993	11	10	12	48.239563	123.92487
75	1999	7	3	11	48.283516	124.08543
76	2003	12	28	8	48.413052	124.53078
77	1996	8	27	4	48.399616	124.48459
78	2002	7	23	15	48.218975	123.38712
79	2000	12	16	5	48.228859	123.64531
80	1996	2	3	6	48.330448	124.24679
81	1997	3	27	6	48.378201	124.41096
82	1998	4	9	1	48.216393	123.31976
83	1992	12	29	0	48.254833	123.9868
84	2002	3	8	0	48.226486	123.58332
85	1996	4	24	20	48.313484	124.18845
86	1995	9	22	21	48.2798	124.07265
87	2000	12	1	4	48.228729	123.64191
88	2001	7	2	0	48.325287	124.22903
89	2000	11	30	9	48.278633	124.06863
90	1997	1	1	1	48.279999	124.07333
91	1995	9	7	5	48.401386	124.49068
92	2001	10	24	10	48.232193	123.73241
93	1994	9	13	5	48.238907	123.90778
94	1993	12	25	23	48.210674	123.17033
95	1996	11	6	15	48.27063	124.04111
96	1999	7	24	13	48.23011	123.67803
97	1997	1	5	11	48.22245	123.47797
98	1997	2	20	8	48.225891	123.56776
99	1999	5	6	17	48.251465	123.97522
100	2003	12	11	6	48.412766	124.5298

Table VI.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	S1_S2-COARSE.HAB
Grid W edge	125° 23.40180'W
Grid S edge	47° 48.72180' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^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)	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 VI.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 VI.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 VI.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.

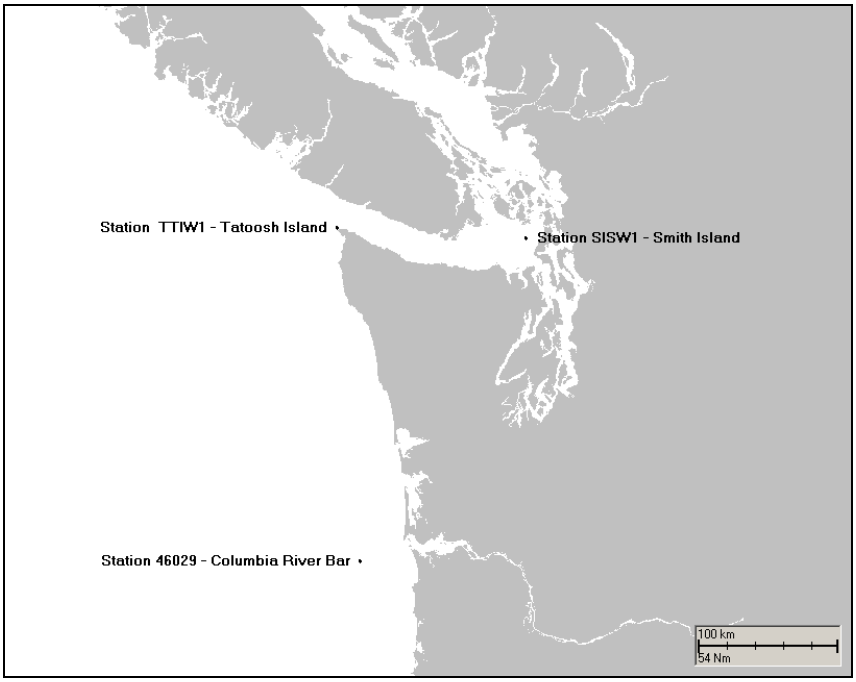


Figure VI.E-2. Wind Station Locations.

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 VII: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – Bunker C

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

VII.A. Introduction 1
VII.B. Maps of Exposure Probability and Time First Exposed 1
VII.C. Statistics for All Model Runs 4
VII.D. Shoreline Areas Exposed by Shore Type 7
VII.E. Exposure for Representative Individual Model Runs. 9
VII.F. Estimated Biological Impacts: Wildlife 11
VII.G. Estimated Biological Impacts: Fish and Invertebrates 14
VII.H. Estimated NRDA Costs: Habitat Restoration Costs 16
VII.I. Estimated NRDA Costs: Washington Compensation schedule 19

List of Figures

Figure VII.B-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen)..... 2
Figure VII.B-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2..... 2
Figure VII.C-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 6
Figure VII.C-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill..... 6
Figure IV.E-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs..... 9
Figure IV.E-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit..... 10
Figure IV.E-3. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island..... 10

List of Tables

Table IV.C-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 5
Table VII.D-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 7
Table VII.D-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 7
Table VII.D-3. Strait of Juan de Fuca – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 8
Table VII.D-4. Strait of Juan de Fuca – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 8
Table VII.F-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose. 12
Table VII.F-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Wildlife injury (as numbers lost). 13
Table VII.G-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column. 15
Table VII.G-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 15
Table VII.H-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 17
Table VII.H-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 18
Table VII.I-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 19

VII.A. INTRODUCTION

The results of the stochastic scenario for the Strait of Juan de Fuca – Bunker C 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).

VII.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)

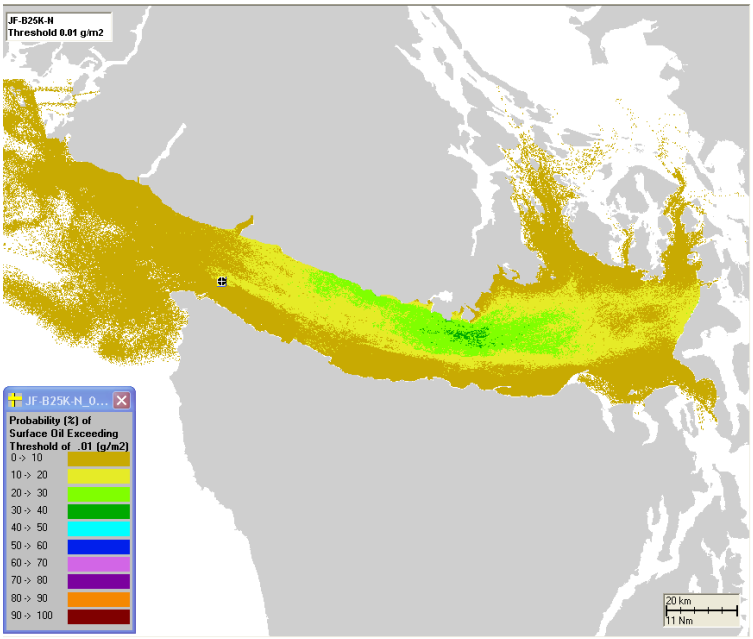


Figure VII.B-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

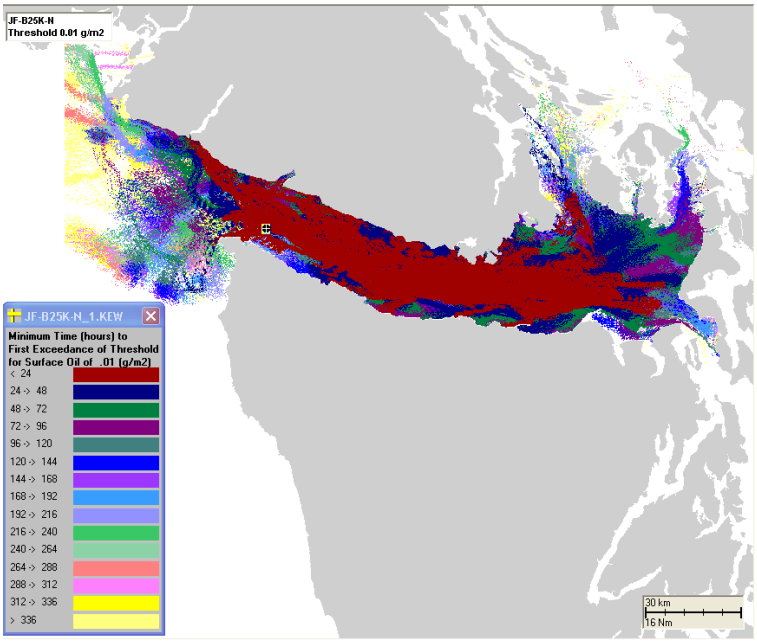


Figure VII.B-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed for the Strait of Juan de Fuca using Bunker C, maximum water column exposure of dissolved aromatic concentration for this scenario never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

VII.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 and 10 g/m^2 (which is sheen) 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 IV.C-1. Strait of Juan de Fuca – Bunker C, 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)	37	21	79	0	32	82	121
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	37	21	79	0	32	82	121
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	3,465	1,806	7,076	0	3,040	7,433	8,804
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	3,465	1,806	7,076	0	3,040	7,433	8,804
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	3,464	1,806	7,076	0	3,040	7,433	8,804
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	3,464	1,806	7,075	0	3,040	7,433	8,803
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	3,358	1,724	6,806	0	2,984	7,213	8,570
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	720	222	1,164	0	740	1,071	1,163
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	0.00E+00	0.00E+00	0.00E+00	100	0.00E+00	0.00E+00	0.00E+00
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 (%)	54.71	9.06	72.84	0	56.36	66.85	69.64
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	33.8335	9.1919	52.2173	0	34.1621	47.1065	51.2884
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	1.40	0.88	3.16	0	1.16	3.23	5.50

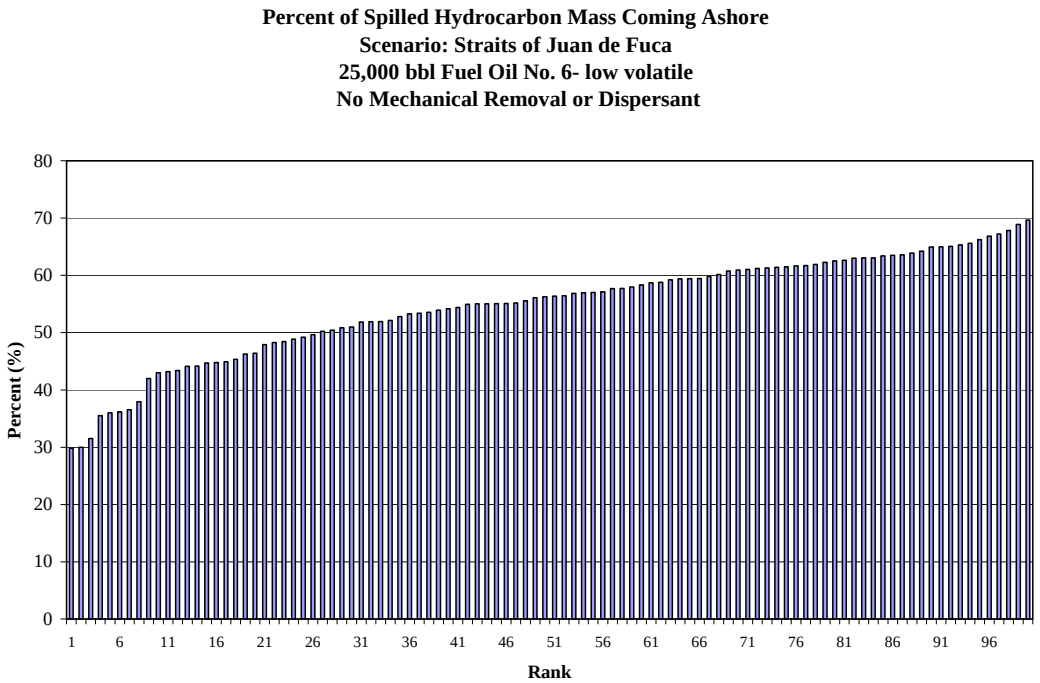


Figure VII.C-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

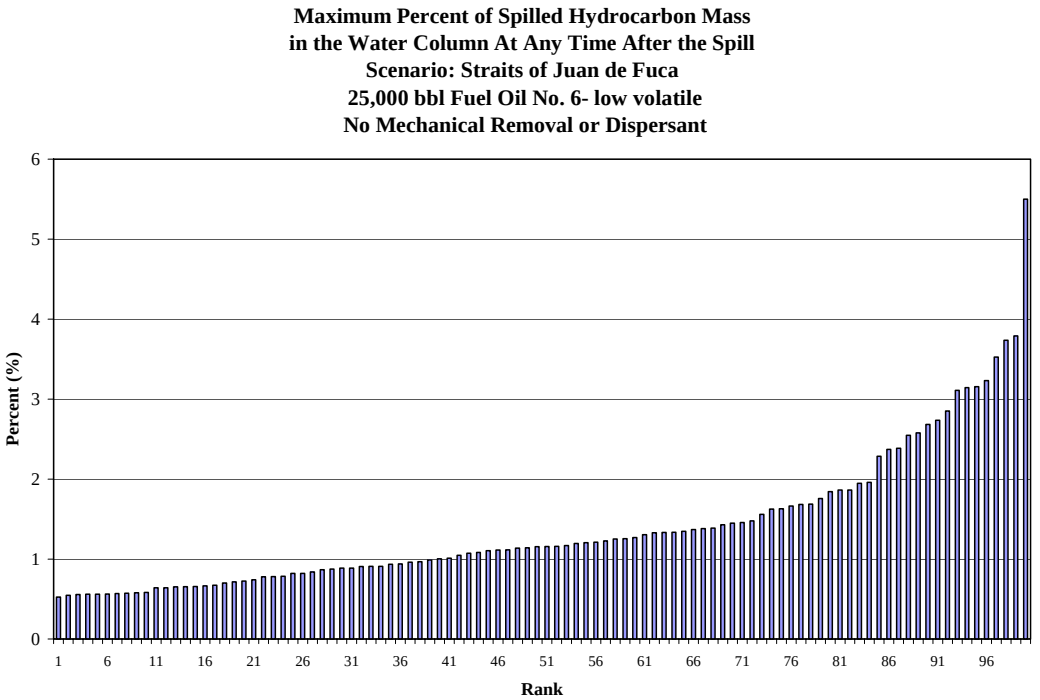


Figure VII.C-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

VII.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 VII.D-1. Strait of Juan de Fuca – Bunker C, 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	355,595	121,661	194,507	0	0	39,427	0
95th	841,113	11,828	198,450	118,282	39,427	473,126	0
Maximum	993,565	216,287	216,849	188,687	512,553	630,835	0
Mean	421,910	95,104	117,335	50,185	65,055	94,231	0
Std. Dev.	214,043	60,975	49,323	41,870	116,256	152,330	0
Mean + 2 Std. Dev.	849,996	217,054	215,981	133,925	297,567	398,891	0

Table VII.D-2. Strait of Juan de Fuca – Bunker C, 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	350,339	187,561	47,313	36,611	0	78,854	0
95th	838,296	11,828	198,450	115,465	39,427	473,126	0
Maximum	987,933	216,287	216,849	183,055	512,553	630,835	0
Mean	419,674	95,065	117,138	49,368	64,661	93,442	0
Std. Dev.	213,213	60,954	49,291	41,431	115,054	152,717	0
Mean + 2 Std. Dev.	846,100	216,973	215,720	132,230	294,769	398,876	0

Table VII.D-3. Strait of Juan de Fuca – Bunker C, 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	319,360	215,723	67,026	36,611	0	0	0
95th	770,895	160,525	69,655	28,162	275,990	236,563	0
Maximum	897,063	215,723	214,221	132,363	512,553	630,835	0
Mean	382,949	94,907	115,351	32,330	54,409	85,951	0
Std. Dev.	197,281	60,842	48,758	29,478	106,737	148,940	0
Mean + 2 Std. Dev.	777,511	216,591	212,867	91,286	267,883	383,831	0

Table VII.D-4. Strait of Juan de Fuca – Bunker C, 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	194,507	114,902	68,340	11,265	0	0	0
95th	298,520	50,129	51,255	0	197,136	0	0
Maximum	469,560	198,263	172,165	36,611	197,136	354,845	0
Mean	196,024	85,213	83,099	1,690	6,703	19,319	0
Std. Dev.	60,878	55,108	38,458	5,647	30,722	56,457	0
Mean + 2 Std. Dev.	317,780	195,429	160,015	12,984	68,147	132,233	0

VII.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

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.

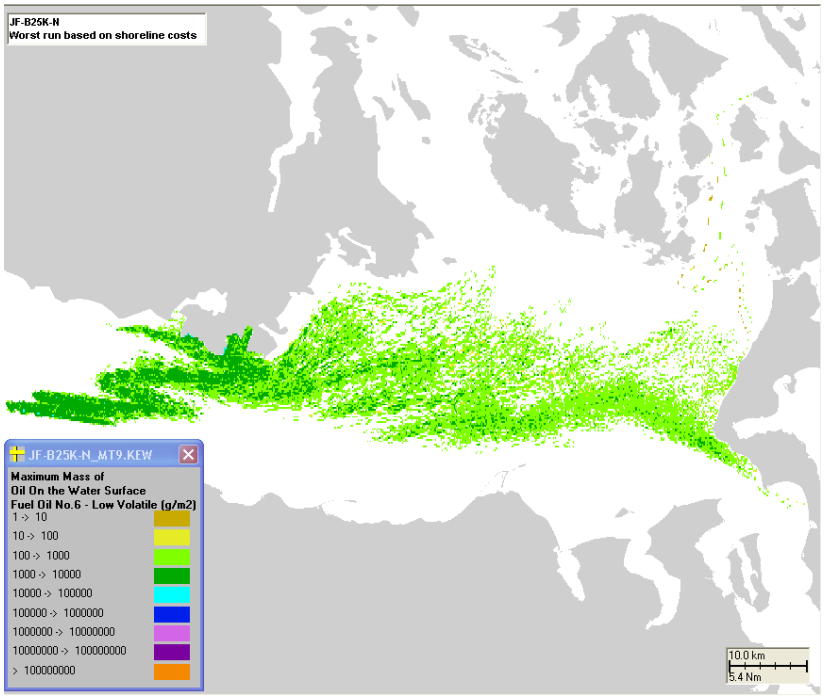


Figure IV.E-1. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

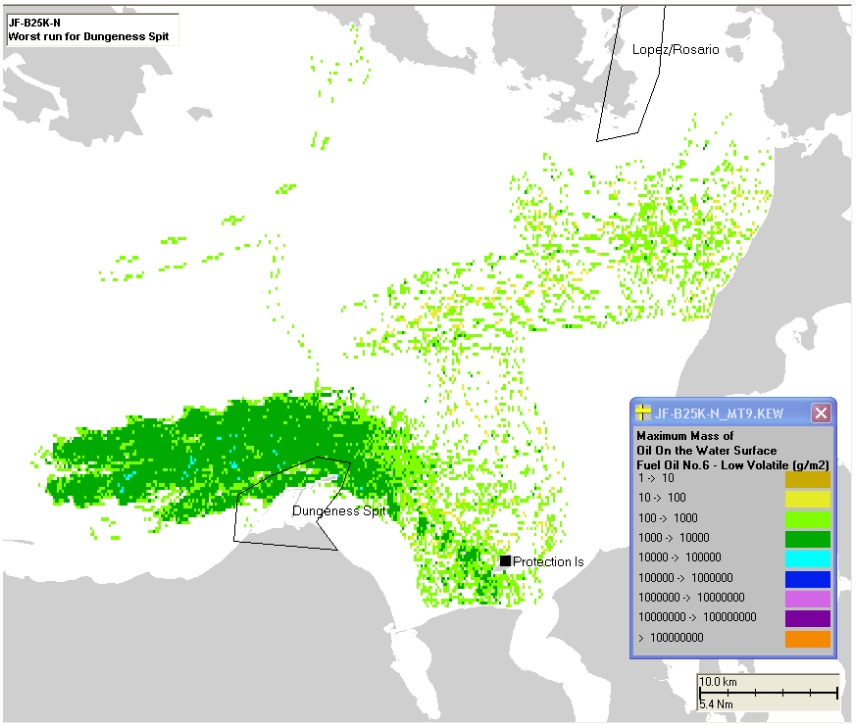


Figure IV.E-2. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit.

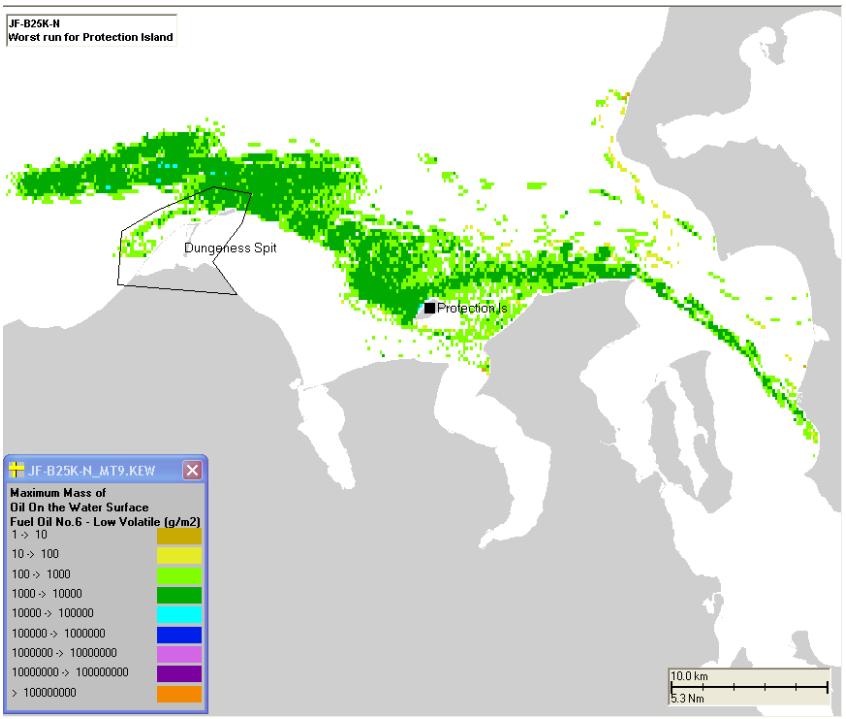


Figure IV.E-3. Strait of Juan de Fuca – Bunker C, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island.

VII.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table VII.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 VII.F-1. Strait of Juan de Fuca – Bunker C, 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	2.36E-06	1,2430.35	10,537.32	0.0043	0.0656
Seabirds	9.80E-06	-171.40	2,333.45	0.6026	0.7763
Wading birds	5.12E-05	3.09	19.91	0.7287	0.8537
Shorebirds	7.50E-05	4.47	29.08	0.7297	0.8542
Raptors	1.09E-06	1.39	2.05	0.1752	0.4186
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	1.16E-08	1.94	1.83	0.7748	0.8802
Pinnipeds (seals)	3.35E-07	49.41	91.12	0.5369	0.7327
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 types of wildlife.

Table VII.F-2. Strait of Juan de Fuca – Bunker C, No 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	9,092	1,925	9	548	0	0	1	-	12,486	12,485	0.96
50th Percentile	14,365	5,152	16	1,038	0	0	2	-	21,019	21,018	1.62
95th Percentile	24,651	11,449	58	3,687	1	0	3	-	39,141	39,138	2.92
Mean	15,746	5,998	21	1,354	1	0	2	-	23,122	23,120	1.80
Std Dev (SD)	4,886	2,991	15	923	1	0	1	-	8,247	8,247	0.62
Mean - 2SD	5,974	16	-	-	-	0	1	-	6,628	6,627	0.57
Mean + 2SD	25,518	11,980	51	3,201	3	0	3	-	39,616	39,613	3.03

VII.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table VII.G-1. Strait of Juan de Fuca – Bunker C, 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	1.07E+00	0.01	2.84	0.1515	0.3892
Total large pelagic fish	9.25E+00	20.14	11.04	0.4663	0.6829
Total demersal fish	1.16E+00	3.09	1.59	0.3970	0.6301
Total demersal invertebrates[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Total mollusks	0.00E+00	22.27	0.00	0.0000	0.0000

[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.
[2] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table VII.G-2. Strait of Juan de Fuca – Bunker C, 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	0.62	25.36	3.74	-	22.27	-	52
50th Percentile	1.26	30.85	4.43	-	22.27	16,997	17,056
95th Percentile	3.40	49.37	6.74	-	22.27	108,804	108,886
Mean	1.52	33.13	4.71	-	22.27	33,955	34,016
Std Dev (SD)	0.95	8.15	1.02	-	0.00	35,399	35,409
Mean - 2SD	-	16.83	2.68	-	22.27	-	42
Mean + 2SD	3.41	49.43	6.75	-	22.27	104,752	104,834

VII.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 VII.H-1. Strait of Juan de Fuca – Bunker C, 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	0.6	1.3	3.4	1.5	-	3.4
Large pelagic fish	25.4	30.8	49.4	33.1	16.8	49.4
Demersal fish	3.7	4.4	6.7	4.7	2.7	6.7
Decapods	-	-	-	-	-	-
Molluscs	22	17,019	108,827	33,977	22	104,774
Birds:						
Waterfowl (# * kg each)	6,417	10,139	17,400	11,114	4,217	18,012
Seabirds (# * kg each)	1,907	5,105	11,344	5,943	16	11,870
Waders (# * kg each)	9	16	58	21	-	50
Shorebirds (# * kg each)	543	1,029	3,653	1,342	-	3,171
Raptors (# * kg each)	0.3	0.4	1.1	0.6	-	2.7
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	0.9	1.6	2.9	1.8	0.6	3.0
Cetaceans	0.0	0.0	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	52	17,056	108,886	34,016	42	104,834
Subtotal birds	8,876	16,290	32,456	18,421	4,233	33,105
Subtotal other wildlife	1	2	3	2	1	3
Total all species	8,929	33,347	141,345	52,439	4,275	137,942

Table VII.H-2. Strait of Juan de Fuca – Bunker C, 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)	20.1	46.6	107.6	55.3	27.6	5.3	110.4
Saltmarsh Area (acres)	49.6	115.2	265.9	136.7	68.1	13.0	272.9
Saltmarsh Cost (millions of 2004$)	9.3	21.6	49.8	25.6	12.7	2.4	51.1
Eelgrass Area (m^2)	12.6	29.1	67.2	34.6	17.2	3.3	69.0
Eelgrass Area (acres)	31.0	72.0	166.2	85.4	42.6	8.1	170.5
Eelgrass Cost (millions of 2004$)	3.7	8.6	19.8	10.2	5.1	0.9	20.4

VII.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table VII.I-1. Strait of Juan de Fuca – Bunker C, 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.)	25.72	26.95	30.64	27.70	24.89	30.52
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	27.0	28.3	32.2	29.1	26.1	32.0

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 VIII: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Bunker C

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

VIII.A. Introduction 1
VIII.B. Oil Fate Over Time 3
VIII.C. Estimated Biological Impacts: Wildlife 43
VIII.D. Estimated Biological Impacts: Fish and Invertebrates 47
VIII.E. Estimated NRDA Costs: Habitat Restoration Costs 50
VIII.F. Estimated NRDA Costs: Washington Compensation schedule 59

List of Figures

Figure XVIII.A-1 Sensitive sites for location: Strait of Juan de Fuca. 2
Figure VIII.B-1 Strait of Juan de Fuca - Bunker C: 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 VIII.B-2 Strait of Juan de Fuca - Bunker C: 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 VIII.B-3 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). 6
Figure VIII.B-4 Strait of Juan de Fuca - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. 7
Figure VIII.B-5 Strait of Juan de Fuca - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit. 8
Figure VIII.B-6 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit. 9
Figure VIII.B-7 Strait of Juan de Fuca - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit. 10
Figure VIII.B-8 Strait of Juan de Fuca - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island..... 11
Figure VIII.B-9 Strait of Juan de Fuca - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. 12
Figure VIII.B-10 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island. 13
Figure VIII.B-11 Strait of Juan de Fuca - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island. 14

List of Tables

Table VIII.B-1 Strait of Juan de Fuca - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 15
Table VIII.B-2 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 17
Table VIII.B-3 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 19
Table VIII.B-4 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost)..... 21
Table VIII.B-5 Strait of Juan de Fuca - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 23
Table VIII.B-6 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 25
Table VIII.B-7 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 27
Table VIII.B-8 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit..... 29
Table VIII.B-9 Strait of Juan de Fuca - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island. 31
Table VIII.B-10 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island..... 33
Table VIII.B-11 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island..... 35
Table VIII.B-12 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island..... 37
Table VIII.B-13 Strait of Juan de Fuca - Bunker C, 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. ... 39
Table VIII.B-14 Strait of Juan de Fuca - Bunker C, 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. 40
Table VIII.B-15 Strait of Juan de Fuca - Bunker C, 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. 41
Table VIII.B-16 Strait of Juan de Fuca - Bunker C, 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. 42
Table VIII.C-1 Strait of Juan de Fuca - Bunker C, no removal: Wildlife injury (as numbers lost). 43
Table VIII.C-2 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table VIII.C-3 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table VIII.C-4 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table VIII.D-1. Strait of Juan de Fuca - Bunker C, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table VIII.D-2. Strait of Juan de Fuca - Bunker C, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table VIII.D-3. Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 49
Table VIII.D-4. Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 49
Table VIII.E-1. Strait of Juan de Fuca - Bunker C, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 51
Table VIII.E-2. Strait of Juan de Fuca - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 52
Table VIII.E-3. Strait of Juan de Fuca - Bunker C, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 53
Table VIII.E-4. Strait of Juan de Fuca - Bunker C, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 54
Table VIII.E-5. Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 55
Table VIII.E-6. Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 56
Table VIII.E-7. Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 57
Table VIII.E-8. Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 58
Table VIII.F-1. Strait of Juan de Fuca - Bunker C, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59
Table VIII.F-2. Strait of Juan de Fuca - Bunker C, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59

Table VIII.F-3. Strait of Juan de Fuca - Bunker C, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59
Table VIII.F-4. Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 60

VIII.A. INTRODUCTION

The results of the alternate response scenarios for the Strait of Juan de Fuca – Bunker C 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Locations of the sensitive sites are shown in Figure XVIII.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.

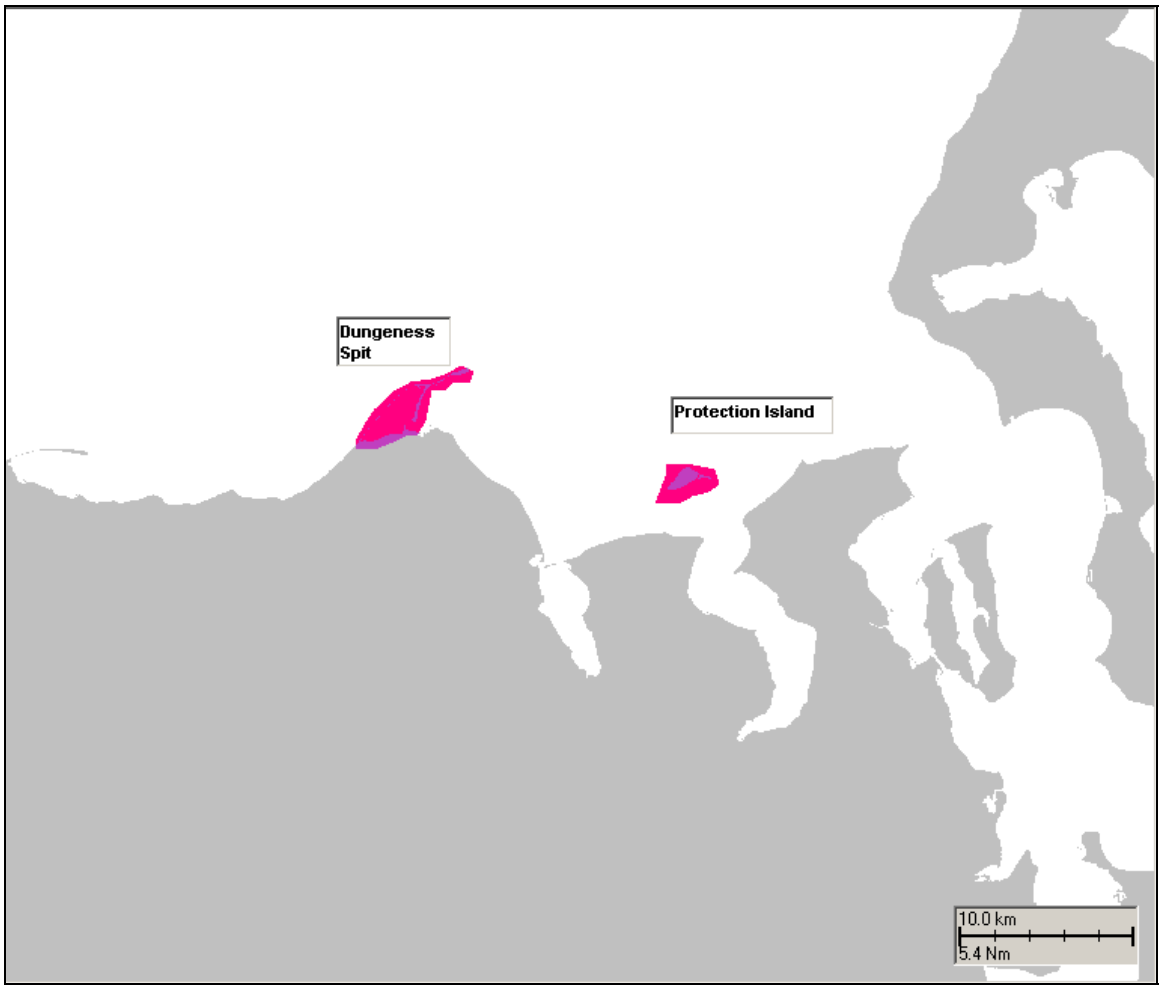
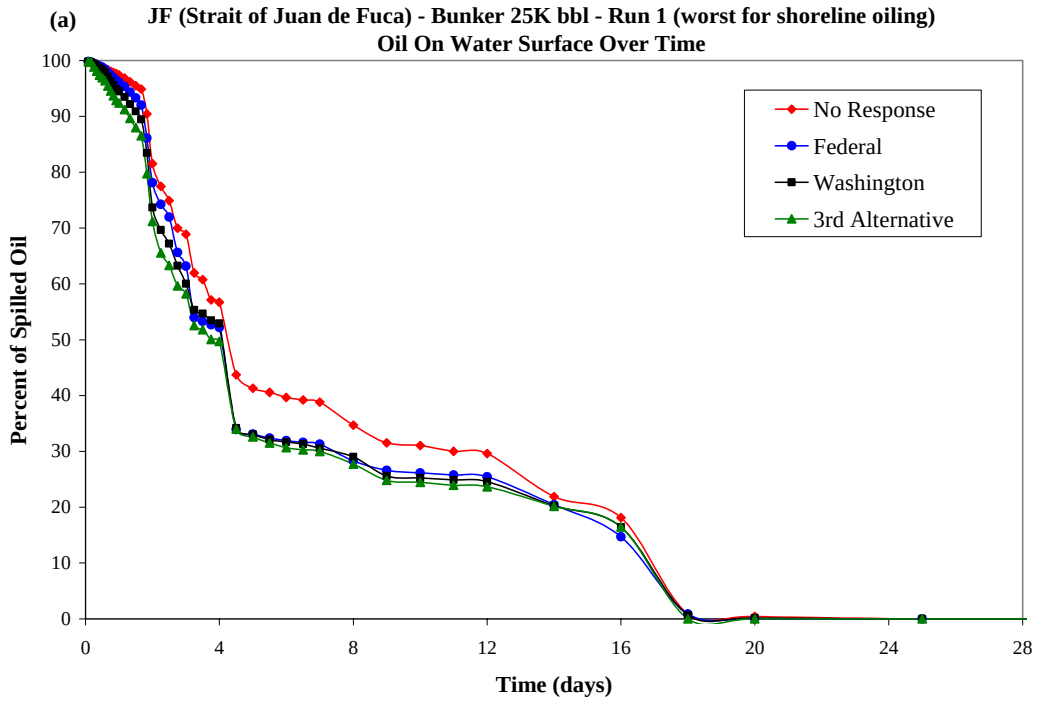


Figure XVIII.A-1 Sensitive sites for location: Strait of Juan de Fuca.

VIII.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables VIII.B-1 to VIII.B-12 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 VIII.B-1 to VIII.B-11 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 VIII.B-13 to VIII.B-16 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.



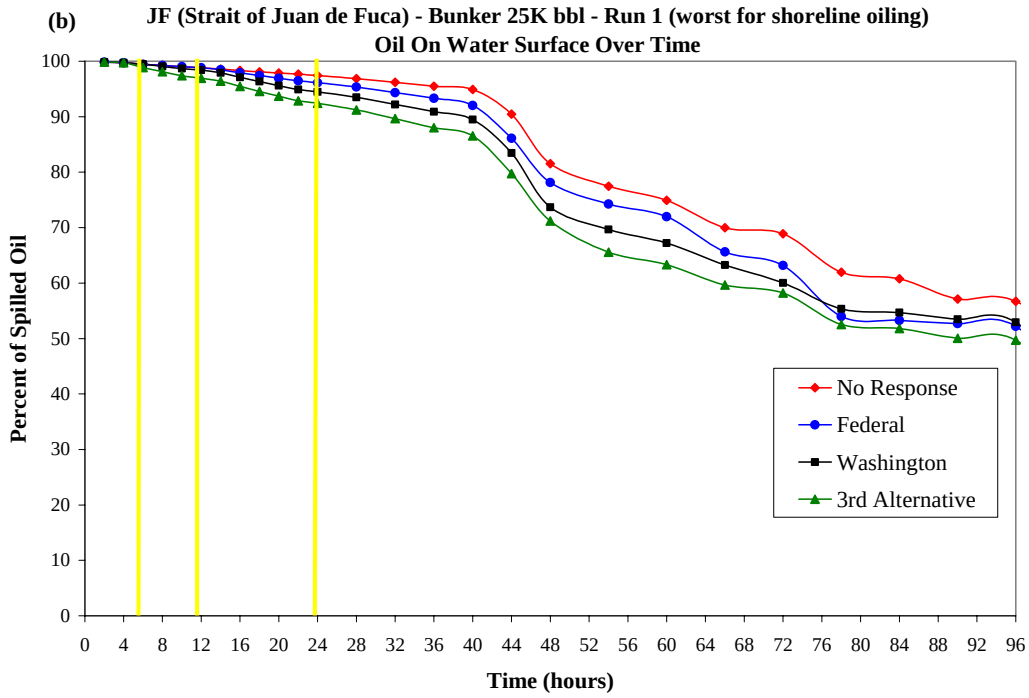


Figure VIII.B-1 Strait of Juan de Fuca - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

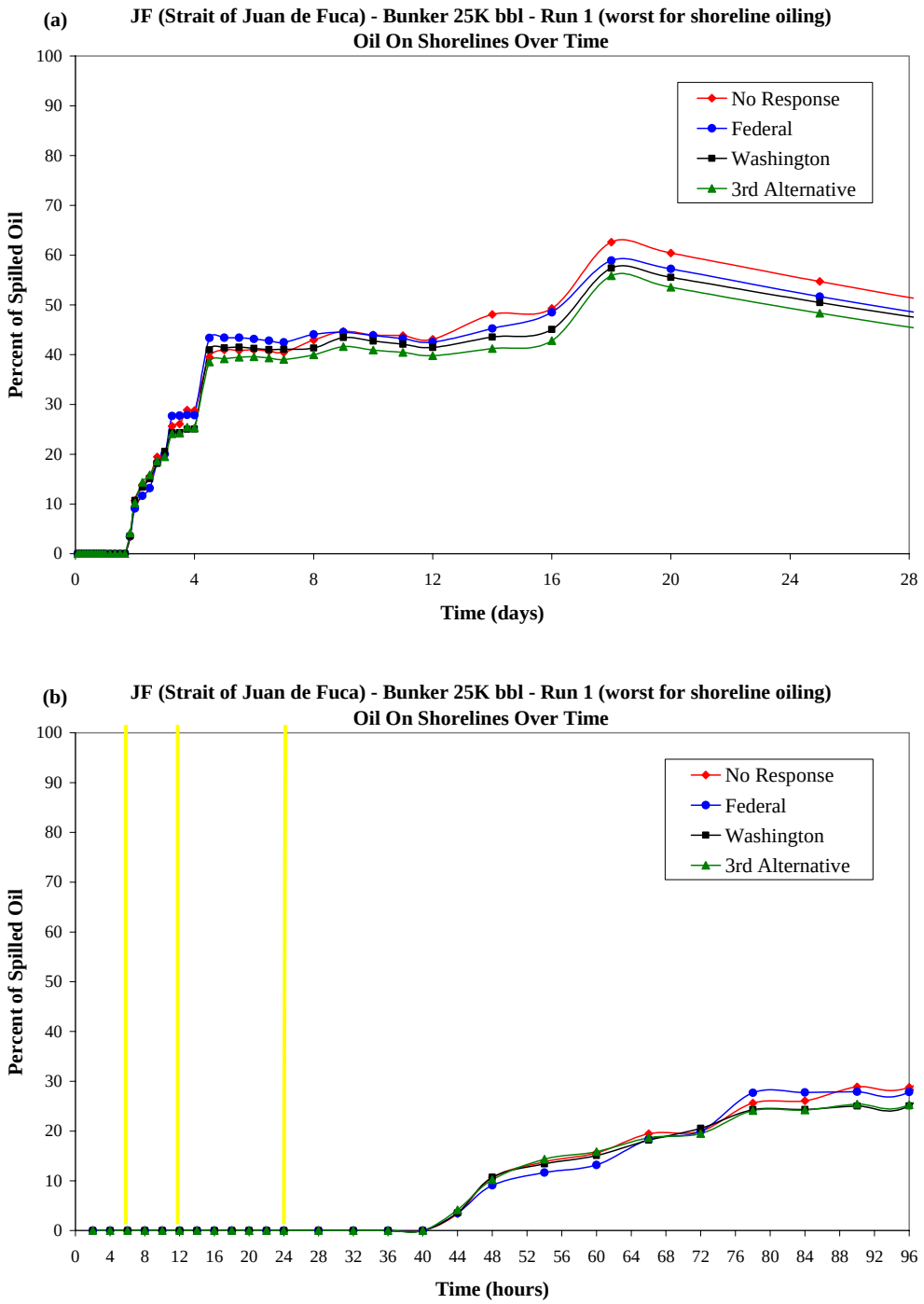


Figure VIII.B-2 Strait of Juan de Fuca - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

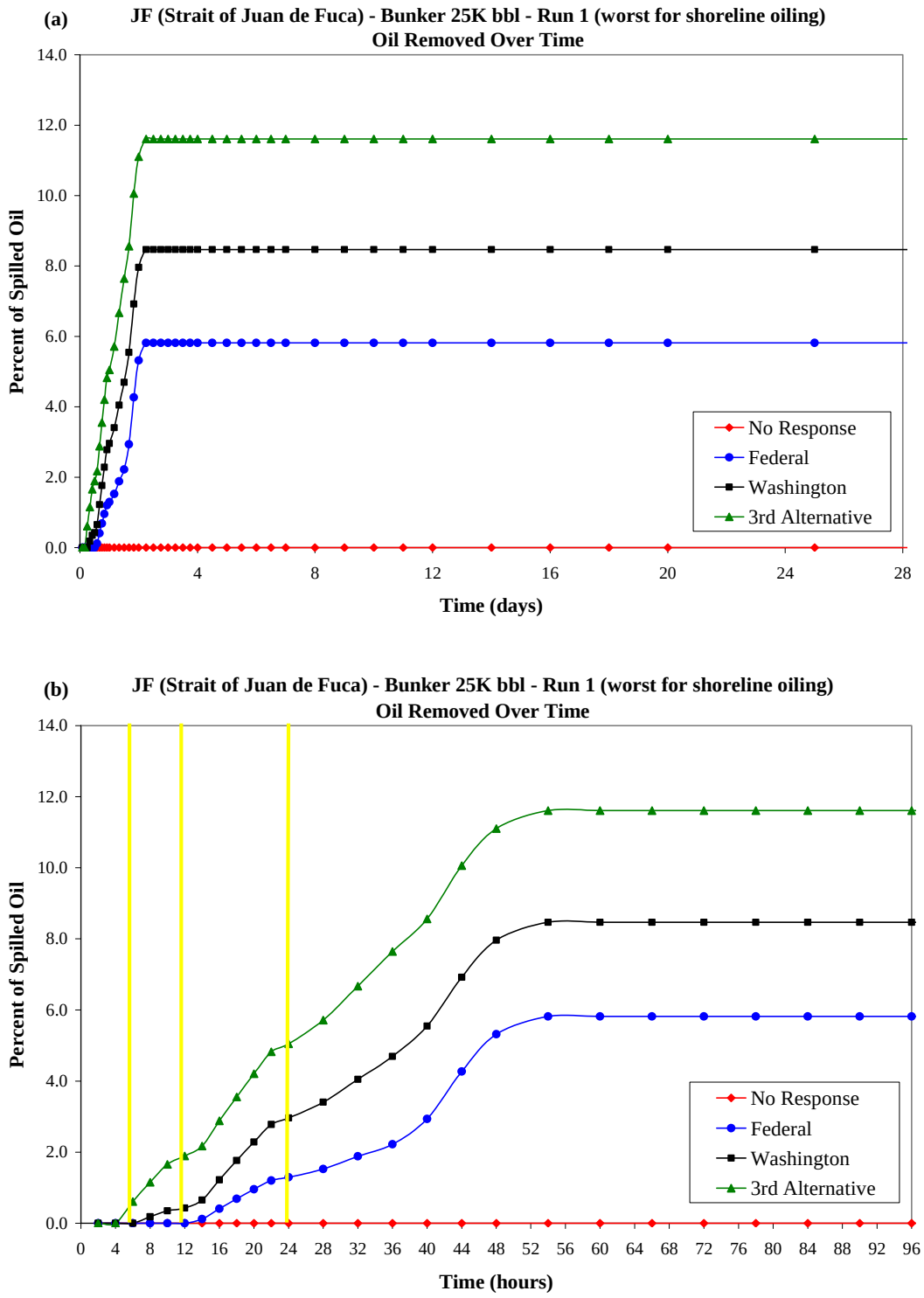
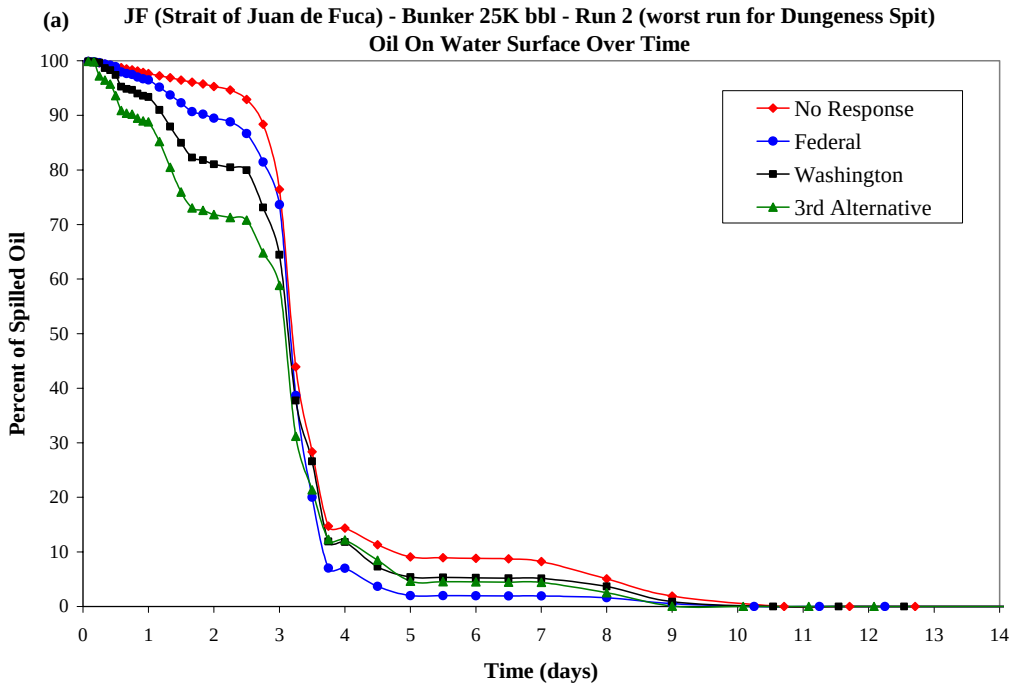


Figure VIII.B-3 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



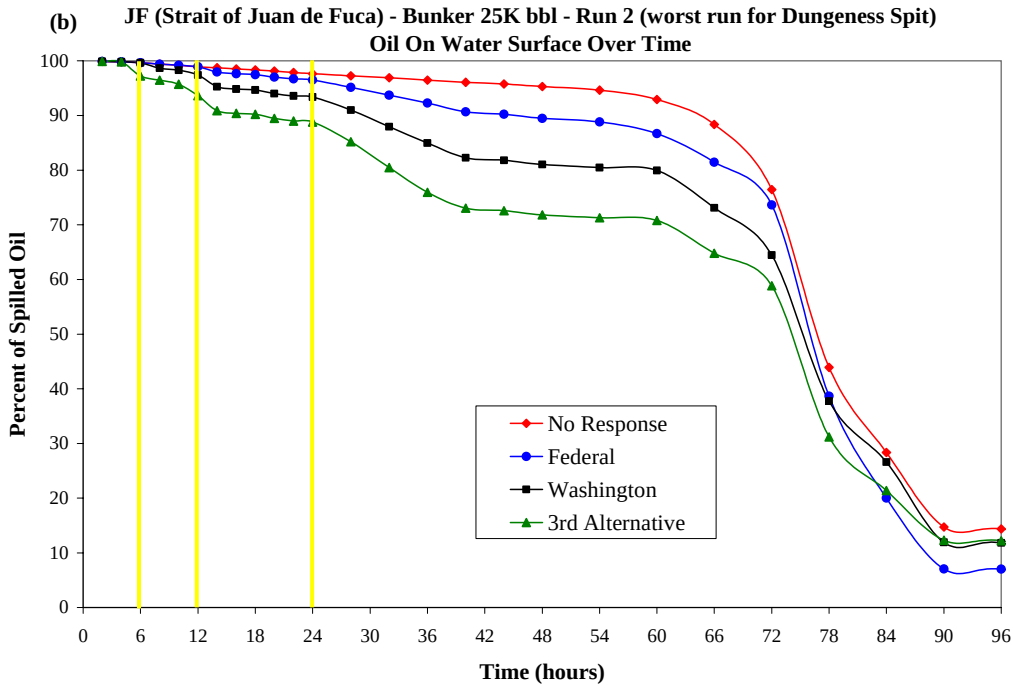
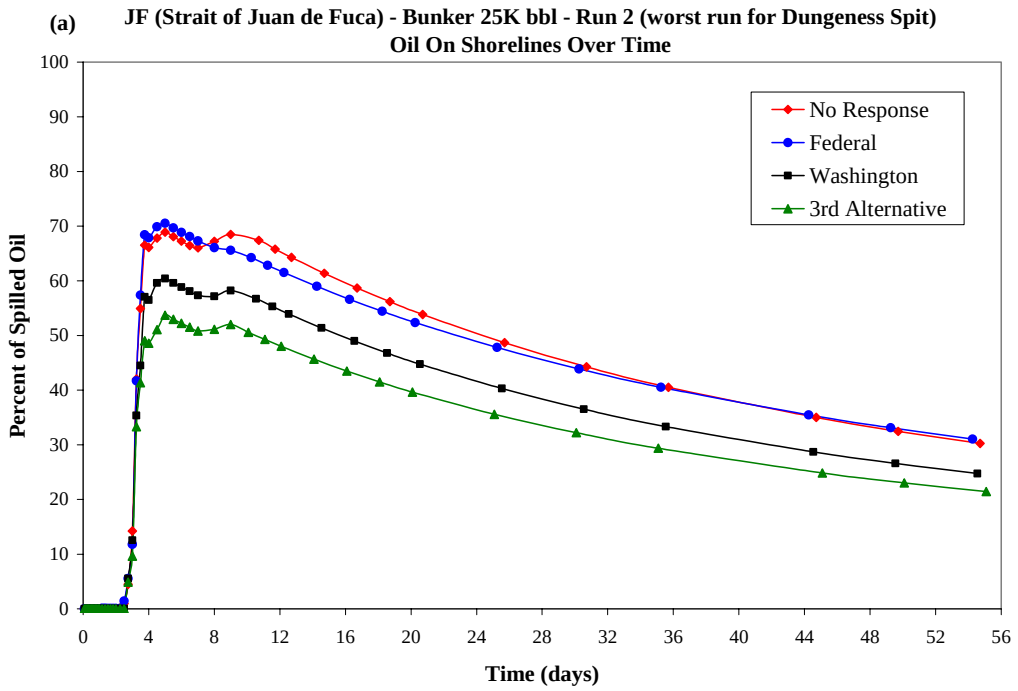


Figure VIII.B-4 Strait of Juan de Fuca - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



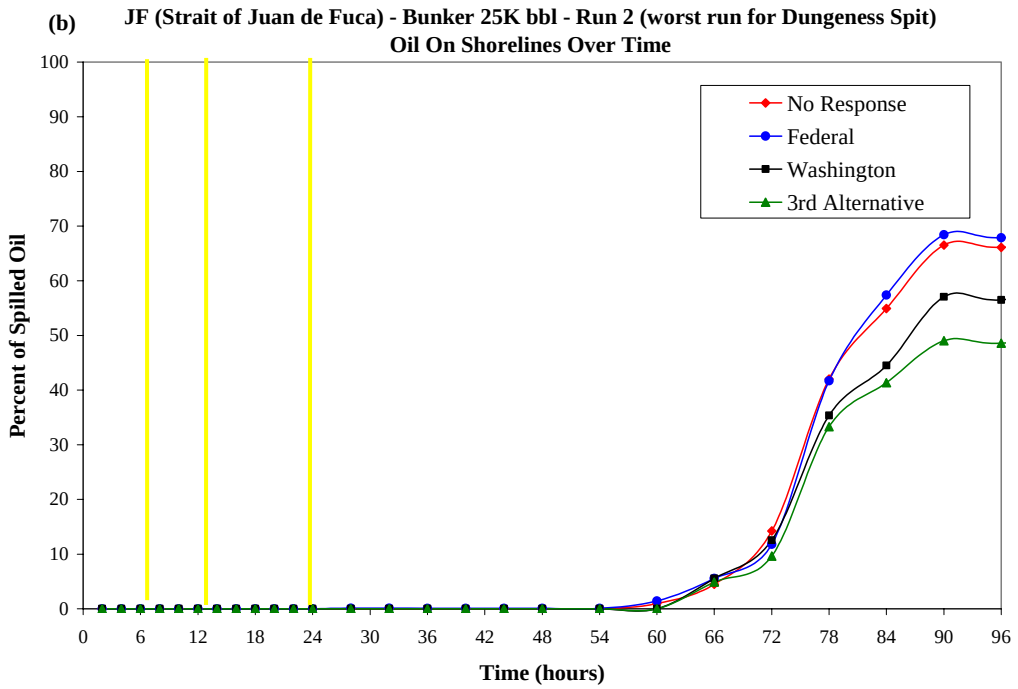
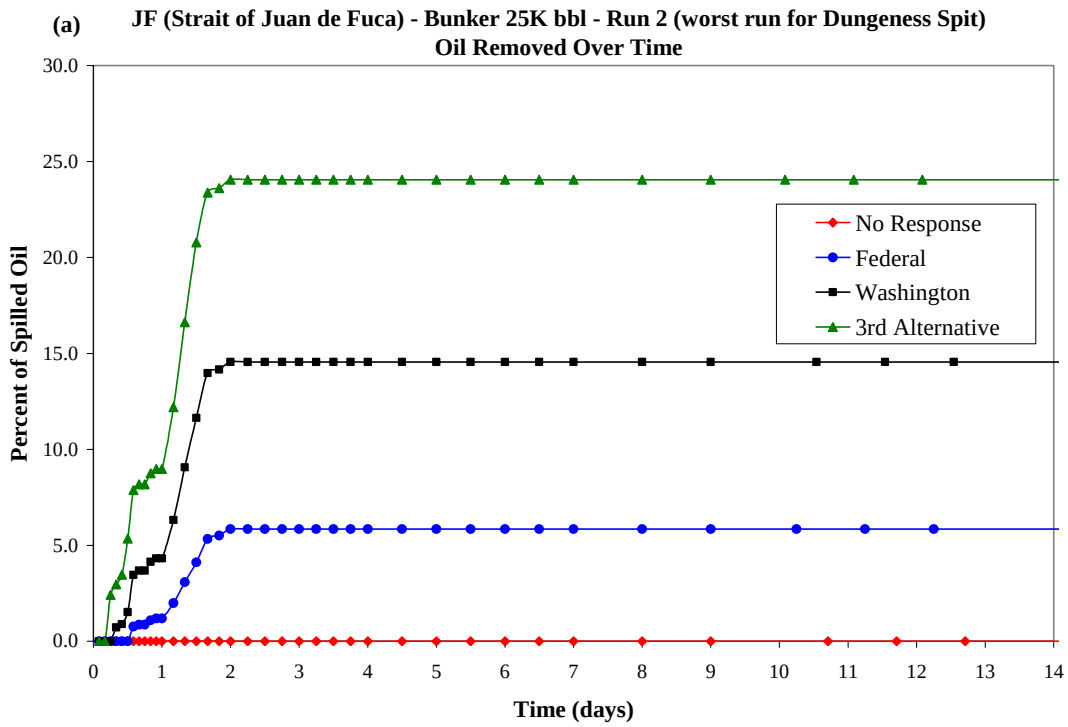


Figure VIII.B-5 Strait of Juan de Fuca - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



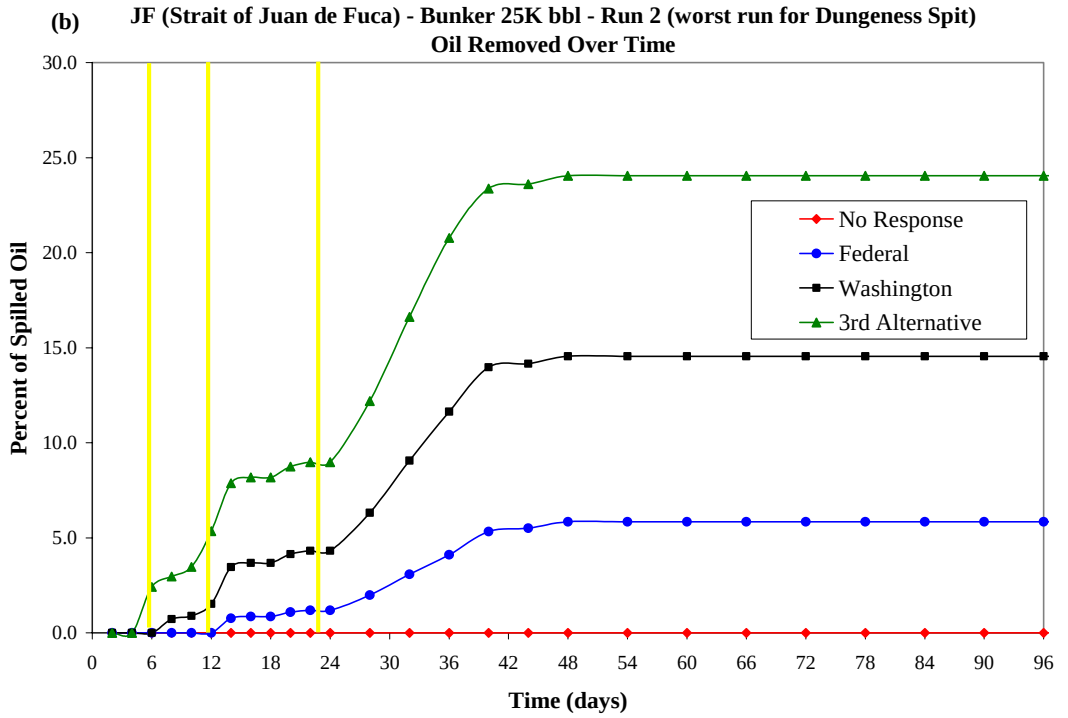
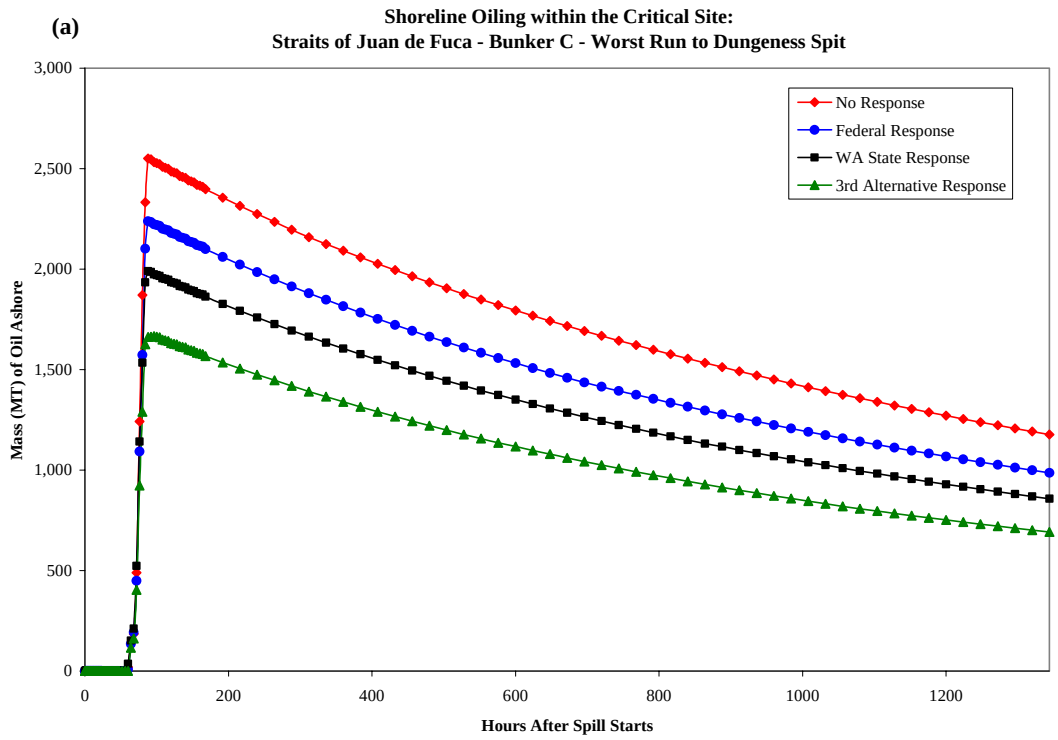


Figure VIII.B-6 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a.



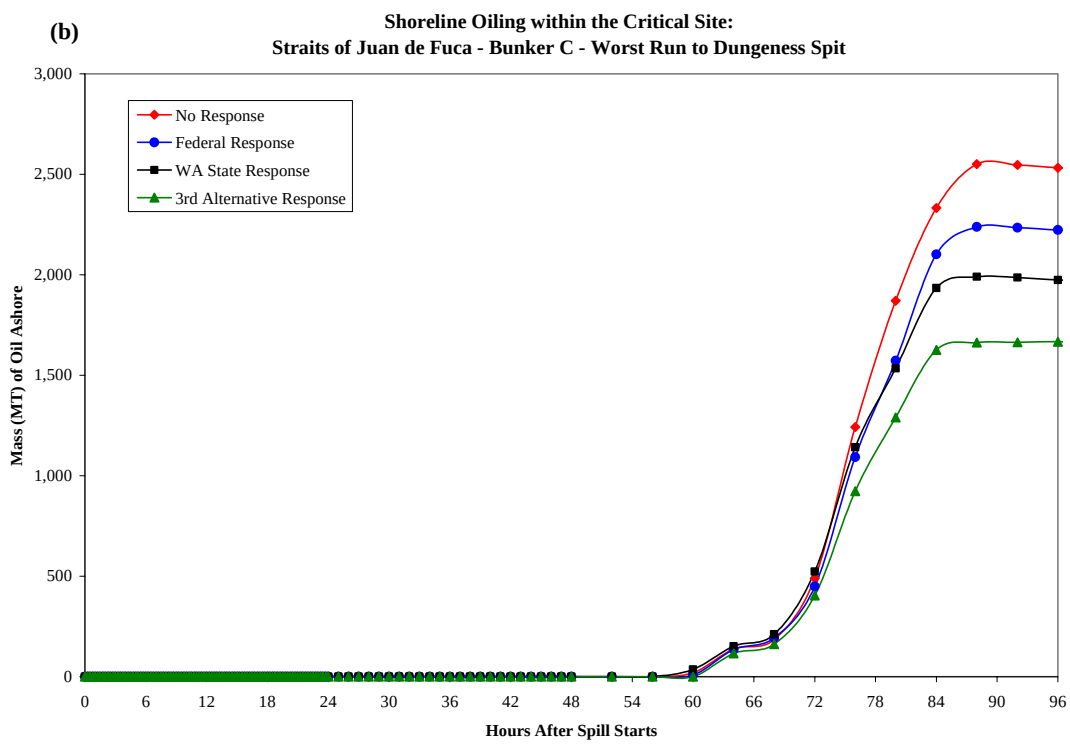
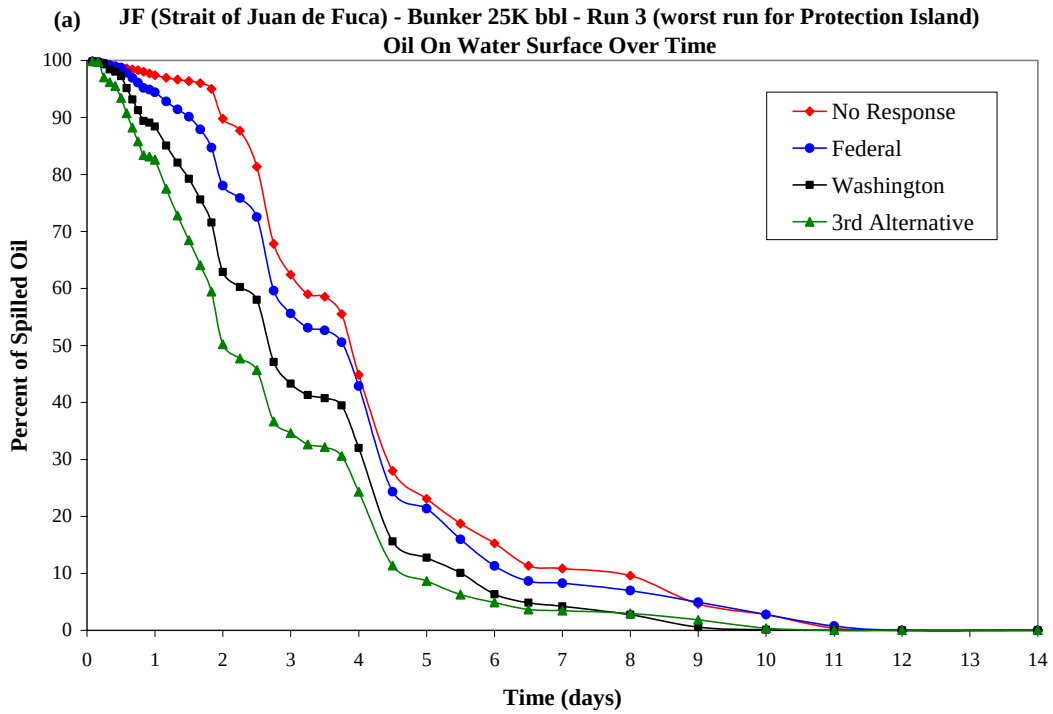


Figure VIII.B-7 Strait of Juan de Fuca - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a.



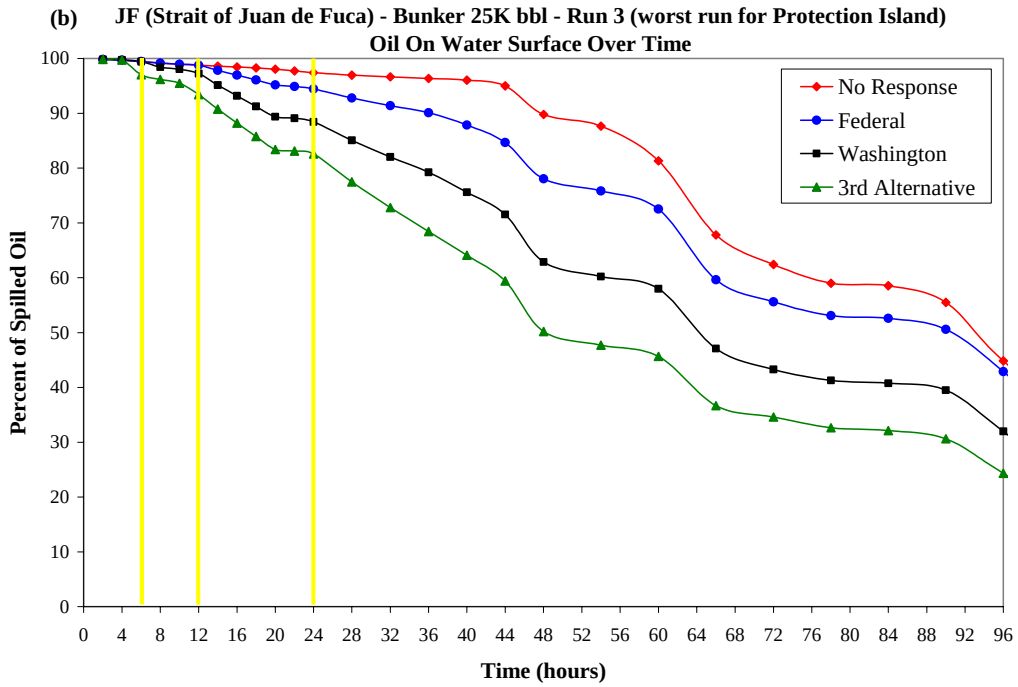


Figure VIII.B-8 Strait of Juan de Fuca - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a.

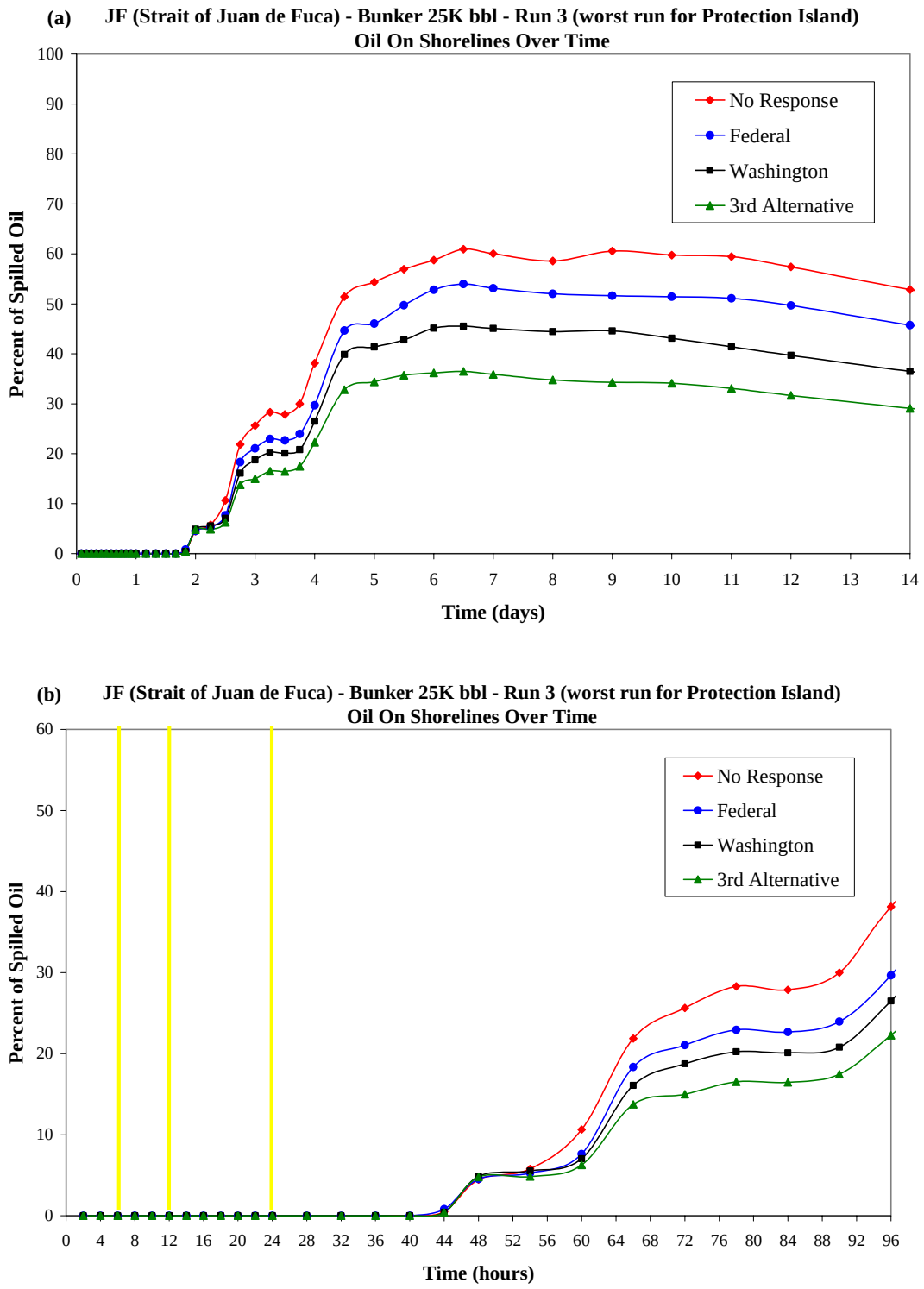


Figure VIII.B-9 Strait of Juan de Fuca - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. Part b of this figure is a subset of Part a.

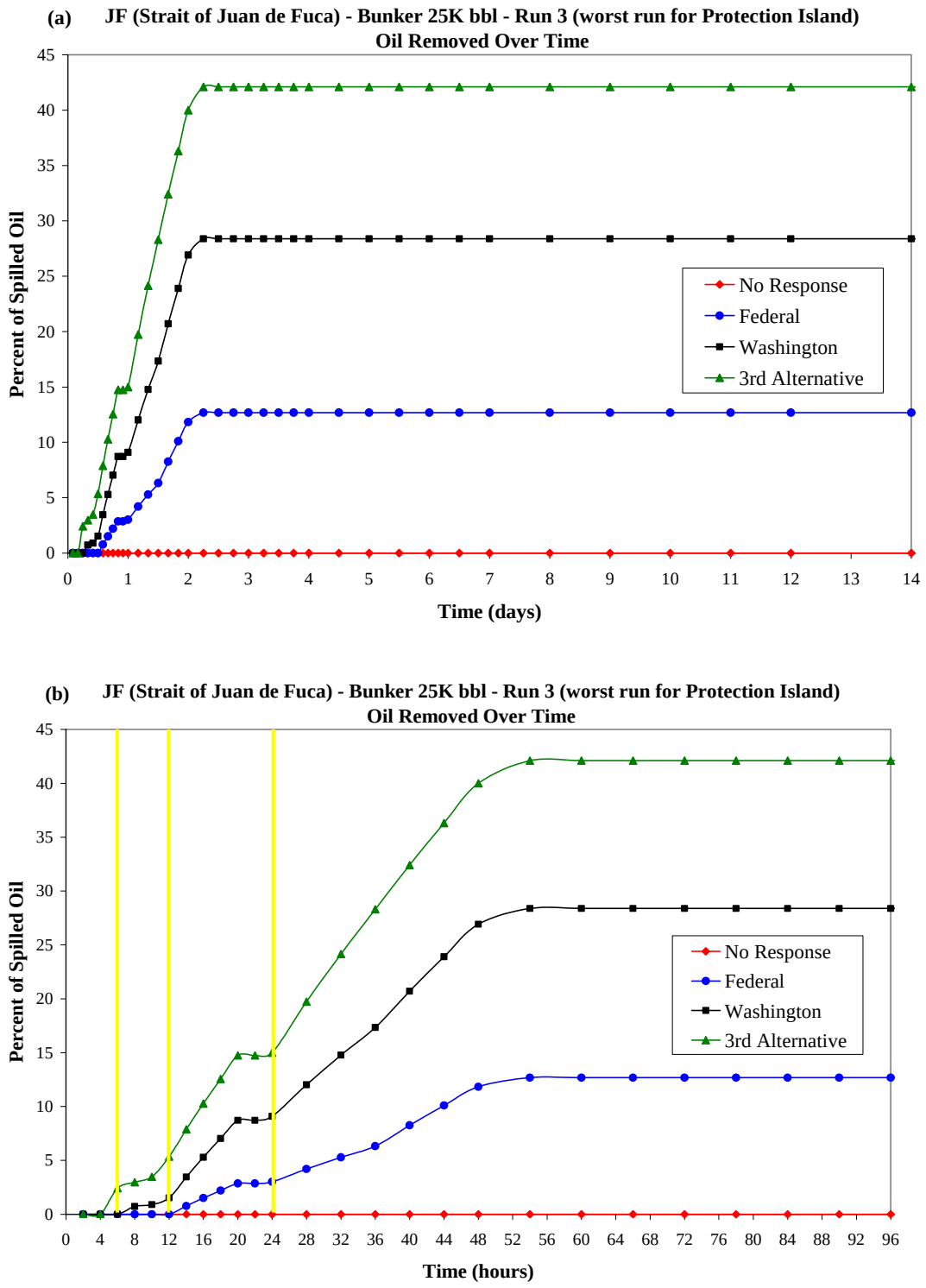


Figure VIII.B-10 Strait of Juan de Fuca - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a.

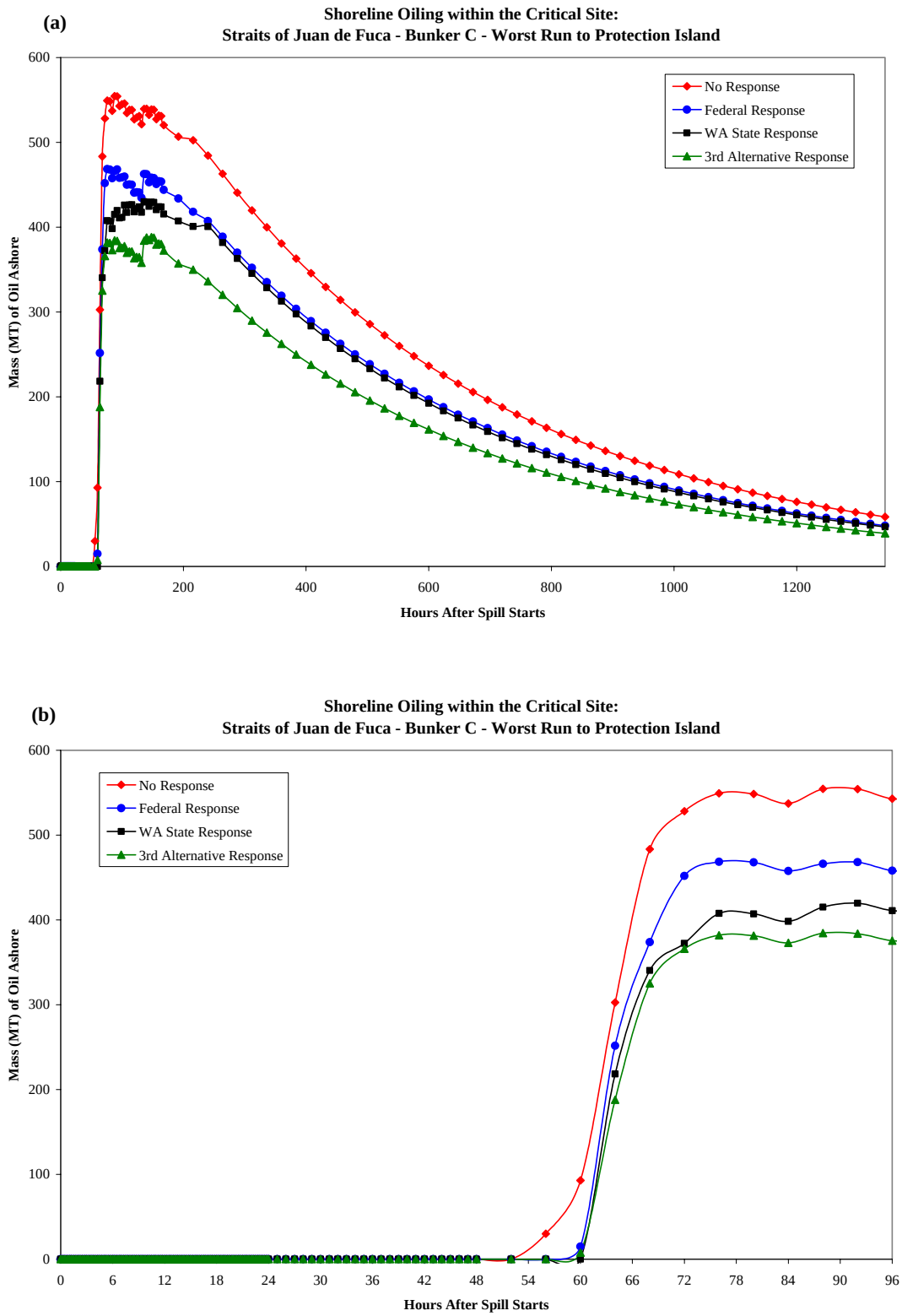


Figure VIII.B-11 Strait of Juan de Fuca - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a.

Table VIII.B-1 Strait of Juan de Fuca - Bunker C, 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.72	0.19	0.00	0.00	0.00	0.09	0.00	0.00	99.72
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	99.24	0.50	0.00	0.00	0.00	0.25	0.00	0.00	99.24
10	0.42	99.03	0.64	0.00	0.00	0.00	0.34	0.00	0.00	99.03
12	0.50	98.81	0.77	0.00	0.00	0.00	0.42	0.00	0.00	98.81
14	0.58	98.56	0.94	0.00	0.00	0.00	0.50	0.00	0.00	98.56
16	0.67	98.30	1.11	0.00	0.00	0.00	0.58	0.00	0.00	98.30
18	0.75	98.08	1.26	0.00	0.00	0.00	0.67	0.00	0.00	98.08
20	0.83	97.86	1.39	0.00	0.00	0.00	0.75	0.00	0.00	97.86
22	0.92	97.65	1.52	0.00	0.00	0.00	0.83	0.00	0.00	97.65
24	1.00	97.42	1.67	0.00	0.00	0.00	0.91	0.00	0.00	97.42
28	1.17	96.86	2.07	0.00	0.00	0.00	1.07	0.00	0.00	96.86
32	1.33	96.20	2.57	0.00	0.00	0.00	1.23	0.00	0.00	96.20
36	1.50	95.49	3.12	0.00	0.00	0.00	1.39	0.00	0.00	95.49
40	1.67	94.90	3.55	0.00	0.00	0.00	1.55	0.00	0.00	94.90
44	1.83	90.46	4.45	0.00	0.00	3.39	1.71	0.00	0.00	90.46
48	2.00	81.52	5.89	0.06	0.00	10.66	1.86	0.00	0.00	81.52
54	2.25	77.44	6.59	0.04	0.02	13.82	2.10	0.00	0.00	77.44
60	2.50	74.89	7.06	0.11	0.03	15.58	2.33	0.00	0.00	74.89
66	2.75	69.96	7.90	0.06	0.07	19.45	2.56	0.00	0.00	69.96
72	3.00	68.87	8.14	0.17	0.09	19.94	2.78	0.00	0.00	68.87
78	3.25	61.96	9.15	0.11	0.15	25.63	3.01	0.00	0.00	61.96
84	3.50	60.77	9.53	0.19	0.20	26.08	3.24	0.00	0.00	60.77
90	3.75	57.13	10.16	0.10	0.28	28.87	3.46	0.00	0.00	57.13
96	4.00	56.72	10.31	0.21	0.32	28.76	3.68	0.00	0.00	56.72
108	4.50	43.73	11.99	0.22	0.44	39.50	4.12	0.00	0.00	43.73

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	41.32	12.37	0.26	0.54	40.96	4.55	0.00	0.00	41.32
132	5.50	40.58	12.64	0.23	0.70	40.86	4.98	0.00	0.00	40.58
144	6.00	39.67	12.88	0.23	0.84	40.98	5.41	0.00	0.00	39.67
156	6.50	39.20	13.03	0.24	0.96	40.73	5.83	0.00	0.00	39.20
168	7.00	38.80	13.16	0.24	1.09	40.45	6.25	0.00	0.00	38.80
192	8.00	34.69	13.69	0.22	1.38	42.94	7.08	0.00	0.00	34.69
216	9.00	31.52	14.04	0.26	1.65	44.65	7.89	0.00	0.00	31.52
240	10.00	31.05	14.12	0.25	1.94	43.95	8.69	0.00	0.00	31.05
264	11.00	29.98	14.23	0.27	2.21	43.83	9.48	0.00	0.00	29.98
288	12.00	29.61	14.27	0.26	2.51	43.10	10.25	0.00	0.00	29.61
336	14.00	21.90	14.84	0.33	3.07	48.09	11.77	0.00	0.00	21.90
384	16.00	18.13	15.10	0.40	3.84	49.29	13.23	0.00	0.00	18.13
432	18.00	0.90	16.34	0.47	5.01	62.63	14.65	0.00	0.00	0.90
480	20.00	0.40	16.38	0.45	6.35	60.41	16.01	0.00	0.00	0.40
600	25.00	0.00	16.41	0.52	9.21	54.71	19.16	0.00	0.00	0.00
720	30.00	0.00	16.41	0.41	11.73	49.49	21.98	0.00	0.00	0.00
840	35.00	0.00	16.41	0.45	13.66	44.98	24.51	0.00	0.00	0.00
1080	45.00	0.00	16.41	0.20	16.87	37.65	28.88	0.00	0.00	0.00
1200	50.00	0.00	16.41	0.24	17.94	34.66	30.76	0.00	0.00	0.00
1320	55.00	0.00	16.41	0.18	18.91	32.02	32.48	0.00	0.00	0.00
Maximum	56.00	99.87	16.41	0.58	19.09	62.63	32.81	0.00	0.00	99.87

Table VIII.B-2 Strait of Juan de Fuca - Bunker C, 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.72	0.19	0.00	0.00	0.00	0.09	0.00	0.00	99.72
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	99.24	0.50	0.00	0.00	0.00	0.25	0.00	0.00	99.24
10	0.42	99.03	0.64	0.00	0.00	0.00	0.34	0.00	0.00	99.03
12	0.50	98.81	0.77	0.00	0.00	0.00	0.42	0.00	0.00	98.81
14	0.58	98.45	0.94	0.00	0.00	0.00	0.50	0.12	0.00	98.45
16	0.67	97.89	1.11	0.00	0.00	0.00	0.58	0.41	0.00	97.89
18	0.75	97.39	1.26	0.00	0.00	0.00	0.66	0.69	0.00	97.39
20	0.83	96.91	1.39	0.00	0.00	0.00	0.75	0.96	0.00	96.91
22	0.92	96.45	1.52	0.00	0.00	0.00	0.83	1.20	0.00	96.45
24	1.00	96.13	1.67	0.00	0.00	0.00	0.91	1.30	0.00	96.13
28	1.17	95.34	2.07	0.00	0.00	0.00	1.07	1.53	0.00	95.34
32	1.33	94.34	2.55	0.00	0.00	0.00	1.22	1.88	0.00	94.34
36	1.50	93.31	3.09	0.00	0.00	0.00	1.38	2.22	0.00	93.31
40	1.67	92.01	3.52	0.00	0.00	0.00	1.54	2.94	0.00	92.01
44	1.83	86.11	4.42	0.00	0.00	3.51	1.69	4.27	0.00	86.11
48	2.00	78.11	5.60	0.05	0.00	9.09	1.83	5.31	0.00	78.11
54	2.25	74.23	6.20	0.03	0.01	11.66	2.05	5.82	0.00	74.23
60	2.50	71.96	6.63	0.09	0.02	13.20	2.27	5.82	0.00	71.96
66	2.75	65.62	7.65	0.05	0.06	18.31	2.48	5.82	0.00	65.62
72	3.00	63.18	8.06	0.17	0.07	19.99	2.70	5.82	0.00	63.18
78	3.25	53.98	9.35	0.11	0.13	27.70	2.91	5.82	0.00	53.98
84	3.50	53.28	9.65	0.20	0.18	27.74	3.12	5.82	0.00	53.28
90	3.75	52.68	9.90	0.10	0.28	27.89	3.33	5.82	0.00	52.68
96	4.00	52.20	10.06	0.22	0.31	27.86	3.54	5.82	0.00	52.20

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	33.91	12.28	0.23	0.44	43.37	3.95	5.82	0.00	33.91
120	5.00	33.13	12.47	0.27	0.54	43.42	4.36	5.82	0.00	33.13
132	5.50	32.37	12.71	0.24	0.71	43.40	4.76	5.82	0.00	32.37
144	6.00	31.91	12.88	0.24	0.85	43.14	5.16	5.82	0.00	31.91
156	6.50	31.60	13.00	0.25	0.98	42.80	5.56	5.82	0.00	31.60
168	7.00	31.28	13.10	0.25	1.12	42.50	5.95	5.82	0.00	31.28
192	8.00	28.28	13.50	0.22	1.41	44.06	6.72	5.82	0.00	28.28
216	9.00	26.59	13.70	0.23	1.66	44.51	7.48	5.82	0.00	26.59
240	10.00	26.16	13.78	0.23	1.92	43.86	8.23	5.82	0.00	26.16
264	11.00	25.75	13.83	0.24	2.16	43.23	8.97	5.82	0.00	25.75
288	12.00	25.44	13.87	0.22	2.41	42.54	9.70	5.82	0.00	25.44
336	14.00	20.45	14.23	0.26	2.88	45.25	11.11	5.82	0.00	20.45
384	16.00	14.70	14.64	0.36	3.49	48.51	12.49	5.82	0.00	14.70
432	18.00	0.87	15.63	0.42	4.53	58.91	13.83	5.82	0.00	0.87
480	20.00	0.00	15.70	0.41	5.73	57.24	15.10	5.82	0.00	0.00
600	25.00	0.00	15.70	0.47	8.28	51.68	18.07	5.82	0.00	0.00
720	30.00	0.00	15.70	0.36	10.52	46.88	20.73	5.82	0.00	0.00
840	35.00	0.00	15.70	0.40	12.23	42.72	23.13	5.82	0.00	0.00
1080	45.00	0.00	15.70	0.18	15.08	35.94	27.29	5.82	0.00	0.00
1200	50.00	0.00	15.70	0.22	16.03	33.16	29.08	5.82	0.00	0.00
1320	55.00	0.00	15.70	0.17	16.88	30.70	30.73	5.82	0.00	0.00
Maximum	56.00	99.87	15.70	0.52	17.05	58.91	31.04	5.82	0.00	99.87

Table VIII.B-3 Strait of Juan de Fuca - Bunker C, 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.72	0.19	0.00	0.00	0.00	0.09	0.00	0.00	99.72
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	99.06	0.50	0.00	0.00	0.00	0.25	0.18	0.00	99.06
10	0.42	98.68	0.64	0.00	0.00	0.00	0.34	0.35	0.00	98.68
12	0.50	98.38	0.77	0.00	0.00	0.00	0.42	0.43	0.00	98.38
14	0.58	97.91	0.94	0.00	0.00	0.00	0.50	0.65	0.00	97.91
16	0.67	97.09	1.11	0.00	0.00	0.00	0.58	1.22	0.00	97.09
18	0.75	96.32	1.25	0.00	0.00	0.00	0.66	1.76	0.00	96.32
20	0.83	95.59	1.39	0.00	0.00	0.00	0.74	2.28	0.00	95.59
22	0.92	94.89	1.51	0.00	0.00	0.00	0.82	2.78	0.00	94.89
24	1.00	94.48	1.66	0.00	0.00	0.00	0.90	2.96	0.00	94.48
28	1.17	93.48	2.05	0.00	0.00	0.00	1.06	3.41	0.00	93.48
32	1.33	92.21	2.53	0.00	0.00	0.00	1.21	4.05	0.00	92.21
36	1.50	90.88	3.06	0.00	0.00	0.00	1.36	4.70	0.00	90.88
40	1.67	89.47	3.47	0.00	0.00	0.00	1.52	5.55	0.00	89.47
44	1.83	83.46	4.38	0.00	0.00	3.58	1.66	6.92	0.00	83.46
48	2.00	73.66	5.79	0.06	0.00	10.72	1.81	7.96	0.00	73.66
54	2.25	69.65	6.40	0.04	0.02	13.41	2.02	8.47	0.00	69.65
60	2.50	67.22	6.86	0.10	0.03	15.10	2.23	8.47	0.00	67.22
66	2.75	63.24	7.56	0.06	0.07	18.17	2.44	8.47	0.00	63.24
72	3.00	60.03	8.07	0.16	0.09	20.54	2.64	8.47	0.00	60.03
78	3.25	55.35	8.79	0.10	0.14	24.30	2.85	8.47	0.00	55.35
84	3.50	54.69	9.09	0.17	0.19	24.34	3.05	8.47	0.00	54.69
90	3.75	53.47	9.42	0.09	0.27	25.03	3.26	8.47	0.00	53.47

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	52.93	9.58	0.19	0.30	25.07	3.46	8.47	0.00	52.93
108	4.50	34.21	11.87	0.21	0.41	40.97	3.86	8.47	0.00	34.21
120	5.00	33.06	12.09	0.26	0.51	41.37	4.26	8.47	0.00	33.06
132	5.50	32.11	12.34	0.23	0.67	41.53	4.65	8.47	0.00	32.11
144	6.00	31.68	12.51	0.23	0.81	41.28	5.03	8.47	0.00	31.68
156	6.50	31.30	12.63	0.24	0.93	41.01	5.42	8.47	0.00	31.30
168	7.00	30.56	12.77	0.24	1.06	41.10	5.80	8.47	0.00	30.56
192	8.00	29.02	13.04	0.21	1.36	41.35	6.55	8.47	0.00	29.02
216	9.00	25.59	13.39	0.23	1.60	43.43	7.29	8.47	0.00	25.59
240	10.00	25.24	13.46	0.22	1.85	42.74	8.02	8.47	0.00	25.24
264	11.00	24.88	13.50	0.23	2.09	42.10	8.73	8.47	0.00	24.88
288	12.00	24.57	13.54	0.22	2.34	41.44	9.44	8.47	0.00	24.57
336	14.00	20.27	13.85	0.26	2.79	43.54	10.82	8.47	0.00	20.27
384	16.00	16.46	14.12	0.33	3.40	45.08	12.15	8.47	0.00	16.46
432	18.00	0.71	15.25	0.39	4.35	57.39	13.45	8.47	0.00	0.71
480	20.00	0.18	15.29	0.37	5.44	55.56	14.69	8.47	0.00	0.18
600	25.00	0.00	15.30	0.43	7.75	50.48	17.58	8.47	0.00	0.00
720	30.00	0.00	15.30	0.33	9.78	45.93	20.19	8.47	0.00	0.00
840	35.00	0.00	15.30	0.37	11.35	41.97	22.54	8.47	0.00	0.00
1080	45.00	0.00	15.30	0.17	13.96	35.47	26.63	8.47	0.00	0.00
1200	50.00	0.00	15.30	0.20	14.84	32.79	28.41	8.47	0.00	0.00
1320	55.00	0.00	15.30	0.16	15.63	30.40	30.04	8.47	0.00	0.00
Maximum	56.00	99.87	15.30	0.48	15.78	57.39	30.35	8.47	0.00	99.87

Table VIII.B-4 Strait of Juan de Fuca - Bunker C, 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.72	0.19	0.00	0.00	0.00	0.09	0.00	0.00	99.72
6	0.25	98.85	0.38	0.00	0.00	0.00	0.17	0.61	0.00	98.85
8	0.33	98.09	0.50	0.00	0.00	0.00	0.25	1.15	0.00	98.09
10	0.42	97.38	0.63	0.00	0.00	0.00	0.33	1.65	0.00	97.38
12	0.50	96.93	0.77	0.00	0.00	0.00	0.42	1.89	0.00	96.93
14	0.58	96.40	0.93	0.00	0.00	0.00	0.50	2.17	0.00	96.40
16	0.67	95.44	1.10	0.00	0.00	0.00	0.58	2.88	0.00	95.44
18	0.75	94.55	1.24	0.00	0.00	0.00	0.66	3.56	0.00	94.55
20	0.83	93.69	1.38	0.00	0.00	0.00	0.73	4.20	0.00	93.69
22	0.92	92.87	1.50	0.00	0.00	0.00	0.81	4.82	0.00	92.87
24	1.00	92.42	1.64	0.00	0.00	0.00	0.89	5.05	0.00	92.42
28	1.17	91.21	2.03	0.00	0.00	0.00	1.04	5.71	0.00	91.21
32	1.33	89.64	2.50	0.00	0.00	0.00	1.19	6.67	0.00	89.64
36	1.50	88.01	3.01	0.00	0.00	0.00	1.34	7.64	0.00	88.01
40	1.67	86.54	3.41	0.00	0.00	0.00	1.49	8.56	0.00	86.54
44	1.83	79.74	4.41	0.00	0.00	4.17	1.63	10.06	0.00	79.74
48	2.00	71.20	5.63	0.07	0.00	10.22	1.77	11.10	0.00	71.20
54	2.25	65.54	6.46	0.05	0.02	14.35	1.97	11.61	0.00	65.54
60	2.50	63.31	6.88	0.14	0.04	15.85	2.17	11.61	0.00	63.31
66	2.75	59.65	7.53	0.08	0.10	18.66	2.37	11.61	0.00	59.65
72	3.00	58.20	7.81	0.19	0.12	19.49	2.57	11.61	0.00	58.20
78	3.25	52.54	8.65	0.12	0.18	24.13	2.77	11.61	0.00	52.54
84	3.50	51.79	8.95	0.20	0.24	24.24	2.97	11.61	0.00	51.79
90	3.75	50.05	9.33	0.10	0.34	25.41	3.17	11.61	0.00	50.05

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	49.71	9.47	0.21	0.37	25.27	3.36	11.61	0.00	49.71
108	4.50	33.98	11.41	0.22	0.50	38.54	3.75	11.61	0.00	33.98
120	5.00	32.58	11.65	0.26	0.60	39.18	4.13	11.61	0.00	32.58
132	5.50	31.49	11.92	0.24	0.76	39.49	4.50	11.61	0.00	31.49
144	6.00	30.67	12.12	0.24	0.90	39.59	4.88	11.61	0.00	30.67
156	6.50	30.28	12.24	0.25	1.03	39.34	5.25	11.61	0.00	30.28
168	7.00	30.00	12.34	0.25	1.17	39.02	5.61	11.61	0.00	30.00
192	8.00	27.73	12.66	0.22	1.48	39.97	6.34	11.61	0.00	27.73
216	9.00	24.81	12.96	0.23	1.73	41.61	7.05	11.61	0.00	24.81
240	10.00	24.48	13.03	0.23	1.99	40.93	7.75	11.61	0.00	24.48
264	11.00	23.95	13.09	0.24	2.22	40.45	8.44	11.61	0.00	23.95
288	12.00	23.65	13.12	0.22	2.48	39.80	9.12	11.61	0.00	23.65
336	14.00	20.16	13.38	0.24	2.95	41.22	10.44	11.61	0.00	20.16
384	16.00	16.46	13.63	0.29	3.48	42.80	11.73	11.61	0.00	16.46
432	18.00	0.00	14.81	0.41	4.32	55.88	12.97	11.61	0.00	0.00
480	20.00	0.00	14.81	0.39	5.47	53.56	14.17	11.61	0.00	0.00
600	25.00	0.00	14.81	0.44	7.87	48.33	16.94	11.61	0.00	0.00
720	30.00	0.00	14.81	0.34	9.97	43.83	19.43	11.61	0.00	0.00
840	35.00	0.00	14.81	0.38	11.59	39.94	21.68	11.61	0.00	0.00
1080	45.00	0.00	14.81	0.17	14.27	33.58	25.56	11.61	0.00	0.00
1200	50.00	0.00	14.81	0.20	15.16	30.97	27.24	11.61	0.00	0.00
1320	55.00	0.00	14.81	0.16	15.97	28.67	28.78	11.61	0.00	0.00
Maximum	56.00	99.87	14.81	0.49	16.13	55.88	29.07	11.61	0.00	99.87

Table VIII.B-5 Strait of Juan de Fuca - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.90	0.06	0.00	0.00	0.00	0.05	0.00	0.00	99.90
4	0.17	99.83	0.08	0.00	0.00	0.00	0.09	0.00	0.00	99.83
6	0.25	99.65	0.17	0.00	0.00	0.00	0.17	0.00	0.00	99.65
8	0.33	99.41	0.34	0.00	0.00	0.00	0.25	0.00	0.00	99.41
10	0.42	99.18	0.48	0.00	0.00	0.00	0.34	0.00	0.00	99.18
12	0.50	98.93	0.65	0.00	0.00	0.00	0.42	0.00	0.00	98.93
14	0.58	98.73	0.77	0.00	0.00	0.00	0.50	0.00	0.00	98.73
16	0.67	98.51	0.90	0.00	0.00	0.00	0.58	0.00	0.00	98.51
18	0.75	98.34	0.99	0.00	0.00	0.00	0.67	0.00	0.00	98.34
20	0.83	98.13	1.12	0.00	0.00	0.00	0.75	0.00	0.00	98.13
22	0.92	97.87	1.30	0.00	0.00	0.00	0.83	0.00	0.00	97.87
24	1.00	97.67	1.42	0.00	0.00	0.00	0.91	0.00	0.00	97.67
28	1.17	97.25	1.67	0.00	0.00	0.00	1.07	0.00	0.00	97.25
32	1.33	96.91	1.86	0.00	0.00	0.00	1.24	0.00	0.00	96.91
36	1.50	96.46	2.14	0.00	0.00	0.00	1.40	0.00	0.00	96.46
40	1.67	96.06	2.38	0.00	0.00	0.00	1.56	0.00	0.00	96.06
44	1.83	95.75	2.53	0.00	0.00	0.00	1.72	0.00	0.00	95.75
48	2.00	95.32	2.81	0.00	0.00	0.00	1.88	0.00	0.00	95.32
54	2.25	94.64	3.24	0.00	0.00	0.00	2.11	0.00	0.00	94.64
60	2.50	92.92	3.77	0.01	0.00	0.95	2.35	0.00	0.00	92.92
66	2.75	88.35	4.55	0.01	0.00	4.50	2.58	0.00	0.00	88.35
72	3.00	76.46	6.34	0.12	0.01	14.25	2.82	0.00	0.00	76.46
78	3.25	43.92	10.89	0.09	0.04	42.02	3.04	0.00	0.00	43.92
84	3.50	28.37	13.05	0.32	0.07	54.93	3.27	0.00	0.00	28.37
90	3.75	14.71	14.89	0.18	0.20	66.54	3.49	0.00	0.00	14.71
96	4.00	14.38	14.99	0.53	0.28	66.12	3.71	0.00	0.00	14.38

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	11.33	15.44	0.62	0.62	67.84	4.14	0.00	0.00	11.33
120	5.00	9.06	15.76	0.70	1.01	68.90	4.57	0.00	0.00	9.06
132	5.50	8.93	15.84	0.61	1.55	68.06	5.00	0.00	0.00	8.93
144	6.00	8.82	15.90	0.59	2.02	67.25	5.42	0.00	0.00	8.82
156	6.50	8.72	15.96	0.54	2.50	66.45	5.83	0.00	0.00	8.72
168	7.00	8.23	16.03	0.55	2.91	66.05	6.24	0.00	0.00	8.23
192	8.00	5.07	16.30	0.65	3.70	67.24	7.04	0.00	0.00	5.07
216	9.00	1.89	16.55	0.71	4.53	68.50	7.82	0.00	0.00	1.89
257	10.71	0.00	16.69	1.66	5.14	67.39	9.12	0.00	0.00	0.00
281	11.71	0.00	16.69	2.18	5.46	65.80	9.87	0.00	0.00	0.00
305	12.71	0.00	16.69	2.52	5.92	64.27	10.60	0.00	0.00	0.00
353	14.71	0.00	16.69	2.75	7.17	61.37	12.01	0.00	0.00	0.00
401	16.71	0.00	16.69	3.33	7.93	58.68	13.37	0.00	0.00	0.00
449	18.71	0.00	16.69	3.39	9.06	56.18	14.68	0.00	0.00	0.00
497	20.71	0.00	16.69	3.10	10.44	53.85	15.92	0.00	0.00	0.00
617	25.71	0.00	16.69	1.81	14.06	48.67	18.77	0.00	0.00	0.00
737	30.71	0.00	16.69	1.47	16.25	44.28	21.31	0.00	0.00	0.00
857	35.71	0.00	16.69	1.38	17.79	40.52	23.61	0.00	0.00	0.00
1073	44.71	0.00	16.69	0.89	20.21	35.00	27.21	0.00	0.00	0.00
1193	49.71	0.00	16.69	0.61	21.25	32.47	28.98	0.00	0.00	0.00
1313	54.71	0.00	16.69	0.55	21.92	30.24	30.60	0.00	0.00	0.00
Maximum	56.00	99.93	16.69	3.52	22.06	68.90	31.21	0.00	0.00	99.93

Table VIII.B-6 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.90	0.06	0.00	0.00	0.00	0.05	0.00	0.00	99.90
4	0.17	99.83	0.08	0.00	0.00	0.00	0.09	0.00	0.00	99.83
6	0.25	99.65	0.17	0.00	0.00	0.00	0.17	0.00	0.00	99.65
8	0.33	99.41	0.34	0.00	0.00	0.00	0.25	0.00	0.00	99.41
10	0.42	99.18	0.48	0.00	0.00	0.00	0.34	0.00	0.00	99.18
12	0.50	98.93	0.65	0.00	0.00	0.00	0.42	0.00	0.00	98.93
14	0.58	97.96	0.77	0.00	0.00	0.00	0.50	0.77	0.00	97.96
16	0.67	97.65	0.90	0.00	0.00	0.00	0.58	0.86	0.00	97.65
18	0.75	97.49	0.99	0.00	0.00	0.00	0.66	0.86	0.00	97.49
20	0.83	97.04	1.12	0.00	0.00	0.00	0.75	1.10	0.00	97.04
22	0.92	96.69	1.29	0.00	0.00	0.00	0.83	1.19	0.00	96.69
24	1.00	96.49	1.42	0.00	0.00	0.00	0.91	1.19	0.00	96.49
28	1.17	95.17	1.68	0.00	0.00	0.09	1.07	1.99	0.00	95.17
32	1.33	93.74	1.86	0.00	0.00	0.09	1.22	3.08	0.00	93.74
36	1.50	92.29	2.14	0.00	0.00	0.09	1.38	4.11	0.00	92.29
40	1.67	90.68	2.37	0.00	0.00	0.09	1.53	5.33	0.00	90.68
44	1.83	90.21	2.50	0.00	0.00	0.09	1.68	5.52	0.00	90.21
48	2.00	89.47	2.76	0.00	0.00	0.09	1.83	5.85	0.00	89.47
54	2.25	88.84	3.17	0.00	0.00	0.09	2.06	5.85	0.00	88.84
60	2.50	86.68	3.75	0.02	0.00	1.43	2.28	5.85	0.00	86.68
66	2.75	81.47	4.62	0.02	0.01	5.55	2.50	5.85	0.00	81.47
72	3.00	73.65	5.85	0.14	0.01	11.79	2.72	5.85	0.00	73.65
78	3.25	38.67	10.71	0.09	0.05	41.70	2.93	5.85	0.00	38.67
84	3.50	20.02	13.26	0.30	0.08	57.36	3.14	5.85	0.00	20.02
90	3.75	7.05	14.98	0.16	0.20	68.41	3.35	5.85	0.00	7.05
96	4.00	6.99	15.02	0.47	0.27	67.85	3.55	5.85	0.00	6.99

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	3.68	15.46	0.59	0.57	69.89	3.96	5.85	0.00	3.68
120	5.00	2.01	15.66	0.67	0.94	70.51	4.36	5.85	0.00	2.01
132	5.50	1.98	15.68	0.59	1.46	69.69	4.76	5.85	0.00	1.98
144	6.00	1.96	15.70	0.57	1.90	68.88	5.15	5.85	0.00	1.96
156	6.50	1.93	15.71	0.52	2.36	68.09	5.54	5.85	0.00	1.93
168	7.00	1.92	15.72	0.53	2.75	67.31	5.92	5.85	0.00	1.92
192	8.00	1.61	15.75	0.58	3.49	66.06	6.68	5.85	0.00	1.61
216	9.00	0.51	15.83	0.61	4.21	65.59	7.41	5.85	0.00	0.51
240	10.00	0.00	15.87	1.21	4.52	64.24	8.31	5.85	0.00	0.00
264	11.00	0.00	15.87	1.66	4.75	62.85	9.02	5.85	0.00	0.00
288	12.00	0.00	15.87	1.94	5.12	61.51	9.71	5.85	0.00	0.00
336	14.00	0.00	15.87	1.53	6.73	58.97	11.05	5.85	0.00	0.00
384	16.00	0.00	15.87	2.03	7.30	56.62	12.34	5.85	0.00	0.00
432	18.00	0.00	15.87	1.82	8.47	54.42	13.57	5.85	0.00	0.00
480	20.00	0.00	15.87	1.21	9.97	52.37	14.74	5.85	0.00	0.00
600	25.00	0.00	15.87	1.35	11.67	47.79	17.48	5.85	0.00	0.00
720	30.00	0.00	15.87	0.84	13.60	43.89	19.96	5.85	0.00	0.00
840	35.00	0.00	15.87	0.81	14.73	40.51	22.23	5.85	0.00	0.00
1080	45.00	0.00	15.87	0.49	16.47	35.48	25.84	5.85	0.00	0.00
1200	50.00	0.00	15.87	0.30	17.22	33.14	27.63	5.85	0.00	0.00
1320	55.00	0.00	15.87	0.32	17.63	31.05	29.28	5.85	0.00	0.00
Maximum	56.00	99.93	15.87	2.03	17.78	70.51	29.91	5.85	0.00	99.93

Table VIII.B-7 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.90	0.06	0.00	0.00	0.00	0.05	0.00	0.00	99.90
4	0.17	99.83	0.08	0.00	0.00	0.00	0.09	0.00	0.00	99.83
6	0.25	99.65	0.17	0.00	0.00	0.00	0.17	0.00	0.00	99.65
8	0.33	98.68	0.34	0.00	0.00	0.00	0.25	0.73	0.00	98.68
10	0.42	98.29	0.48	0.00	0.00	0.00	0.34	0.90	0.00	98.29
12	0.50	97.41	0.65	0.00	0.00	0.00	0.42	1.52	0.00	97.41
14	0.58	95.28	0.76	0.00	0.00	0.00	0.50	3.46	0.00	95.28
16	0.67	94.85	0.89	0.00	0.00	0.00	0.58	3.68	0.00	94.85
18	0.75	94.68	0.98	0.00	0.00	0.00	0.66	3.68	0.00	94.68
20	0.83	94.02	1.11	0.00	0.00	0.00	0.74	4.14	0.00	94.02
22	0.92	93.59	1.27	0.00	0.00	0.00	0.81	4.33	0.00	93.59
24	1.00	93.39	1.40	0.00	0.00	0.00	0.89	4.33	0.00	93.39
28	1.17	90.99	1.64	0.00	0.00	0.00	1.05	6.32	0.00	90.99
32	1.33	87.93	1.81	0.00	0.00	0.00	1.19	9.06	0.00	87.93
36	1.50	84.96	2.06	0.00	0.00	0.00	1.34	11.64	0.00	84.96
40	1.67	82.28	2.28	0.00	0.00	0.00	1.48	13.97	0.00	82.28
44	1.83	81.81	2.41	0.00	0.00	0.00	1.61	14.17	0.00	81.81
48	2.00	81.05	2.64	0.00	0.00	0.00	1.75	14.56	0.00	81.05
54	2.25	80.47	3.03	0.00	0.00	0.00	1.95	14.56	0.00	80.47
60	2.50	79.95	3.35	0.00	0.00	0.00	2.15	14.56	0.00	79.95
66	2.75	73.13	4.42	0.00	0.00	5.54	2.35	14.56	0.00	73.13
72	3.00	64.46	5.76	0.12	0.00	12.56	2.55	14.56	0.00	64.46
78	3.25	37.73	9.49	0.08	0.03	35.37	2.74	14.56	0.00	37.73
84	3.50	26.61	11.05	0.29	0.06	44.50	2.93	14.56	0.00	26.61
90	3.75	11.93	13.01	0.16	0.18	57.05	3.12	14.56	0.00	11.93

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	11.82	13.07	0.48	0.25	56.51	3.31	14.56	0.00	11.82
108	4.50	7.29	13.68	0.61	0.57	59.62	3.68	14.56	0.00	7.29
120	5.00	5.40	13.93	0.70	0.95	60.42	4.04	14.56	0.00	5.40
132	5.50	5.31	13.99	0.61	1.50	59.63	4.40	14.56	0.00	5.31
144	6.00	5.25	14.02	0.59	1.97	58.86	4.75	14.56	0.00	5.25
156	6.50	5.19	14.06	0.54	2.46	58.10	5.10	14.56	0.00	5.19
168	7.00	5.14	14.08	0.55	2.87	57.36	5.45	14.56	0.00	5.14
192	8.00	3.67	14.21	0.62	3.65	57.16	6.12	14.56	0.00	3.67
216	9.00	0.87	14.43	0.68	4.45	58.23	6.78	14.56	0.00	0.87
240	10.00	0.00	14.49	1.46	4.99	56.73	7.77	14.56	0.00	0.00
264	11.00	0.00	14.49	2.04	5.20	55.31	8.40	14.56	0.00	0.00
288	12.00	0.00	14.49	2.49	5.49	53.94	9.02	14.56	0.00	0.00
336	14.00	0.00	14.49	2.27	7.10	51.38	10.20	14.56	0.00	0.00
384	16.00	0.00	14.49	2.69	7.92	49.01	11.34	14.56	0.00	0.00
432	18.00	0.00	14.49	2.21	9.52	46.81	12.41	14.56	0.00	0.00
480	20.00	0.00	14.49	1.93	10.81	44.77	13.43	14.56	0.00	0.00
600	25.00	0.00	14.49	1.47	13.40	40.29	15.79	14.56	0.00	0.00
720	30.00	0.00	14.49	1.07	15.47	36.53	17.88	14.56	0.00	0.00
840	35.00	0.00	14.49	1.06	16.78	33.34	19.77	14.56	0.00	0.00
1080	45.00	0.00	14.49	0.67	18.85	28.70	22.73	14.56	0.00	0.00
1200	50.00	0.00	14.49	0.41	19.77	26.60	24.17	14.56	0.00	0.00
1320	55.00	0.00	14.49	0.46	20.25	24.75	25.49	14.56	0.00	0.00
Maximum	56.00	99.93	14.49	2.69	20.39	60.42	26.00	14.56	0.00	99.93

Table VIII.B-8 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.90	0.06	0.00	0.00	0.00	0.05	0.00	0.00	99.90
4	0.17	99.83	0.08	0.00	0.00	0.00	0.09	0.00	0.00	99.83
6	0.25	97.24	0.17	0.00	0.00	0.00	0.17	2.42	0.00	97.24
8	0.33	96.45	0.33	0.00	0.00	0.00	0.25	2.97	0.00	96.45
10	0.42	95.73	0.47	0.00	0.00	0.00	0.33	3.47	0.00	95.73
12	0.50	93.60	0.63	0.00	0.00	0.00	0.41	5.35	0.00	93.60
14	0.58	90.89	0.74	0.00	0.00	0.00	0.49	7.88	0.00	90.89
16	0.67	90.40	0.86	0.00	0.00	0.00	0.56	8.18	0.00	90.40
18	0.75	90.24	0.95	0.00	0.00	0.00	0.64	8.18	0.00	90.24
20	0.83	89.47	1.07	0.00	0.00	0.00	0.71	8.74	0.00	89.47
22	0.92	89.00	1.23	0.00	0.00	0.00	0.79	8.98	0.00	89.00
24	1.00	88.81	1.35	0.00	0.00	0.00	0.86	8.98	0.00	88.81
28	1.17	85.21	1.58	0.00	0.00	0.00	1.01	12.20	0.00	85.21
32	1.33	80.49	1.74	0.00	0.00	0.00	1.15	16.62	0.00	80.49
36	1.50	75.97	1.98	0.00	0.00	0.00	1.28	20.78	0.00	75.97
40	1.67	73.06	2.17	0.00	0.00	0.00	1.40	23.37	0.00	73.06
44	1.83	72.59	2.29	0.00	0.00	0.00	1.52	23.60	0.00	72.59
48	2.00	71.80	2.50	0.00	0.00	0.00	1.64	24.05	0.00	71.80
54	2.25	71.28	2.85	0.00	0.00	0.00	1.82	24.05	0.00	71.28
60	2.50	70.81	3.14	0.00	0.00	0.00	2.00	24.05	0.00	70.81
66	2.75	64.80	4.09	0.00	0.00	4.88	2.17	24.05	0.00	64.80
72	3.00	58.84	5.04	0.09	0.00	9.63	2.35	24.05	0.00	58.84
78	3.25	31.18	8.87	0.06	0.02	33.30	2.52	24.05	0.00	31.18
84	3.50	21.39	10.24	0.24	0.04	41.35	2.69	24.05	0.00	21.39
90	3.75	12.31	11.47	0.13	0.14	49.05	2.85	24.05	0.00	12.31

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	12.21	11.53	0.40	0.20	48.59	3.02	24.05	0.00	12.21
108	4.50	8.50	12.05	0.52	0.46	51.08	3.35	24.05	0.00	8.50
120	5.00	4.64	12.51	0.65	0.79	53.69	3.67	24.05	0.00	4.64
132	5.50	4.57	12.56	0.58	1.29	52.96	3.99	24.05	0.00	4.57
144	6.00	4.51	12.59	0.57	1.74	52.23	4.30	24.05	0.00	4.51
156	6.50	4.46	12.62	0.52	2.21	51.53	4.61	24.05	0.00	4.46
168	7.00	4.42	12.64	0.52	2.61	50.84	4.92	24.05	0.00	4.42
192	8.00	2.54	12.80	0.60	3.36	51.13	5.52	24.05	0.00	2.54
216	9.00	0.08	12.99	0.65	4.13	52.00	6.10	24.05	0.00	0.08
240	10.00	0.00	12.99	1.31	4.33	50.59	6.72	24.05	0.00	0.00
264	11.00	0.00	12.99	1.64	4.76	49.28	7.28	24.05	0.00	0.00
288	12.00	0.00	12.99	1.87	5.24	48.03	7.82	24.05	0.00	0.00
336	14.00	0.00	12.99	1.55	6.87	45.67	8.87	24.05	0.00	0.00
384	16.00	0.00	12.99	2.28	7.30	43.50	9.87	24.05	0.00	0.00
432	18.00	0.00	12.99	1.83	8.81	41.50	10.82	24.05	0.00	0.00
480	20.00	0.00	12.99	1.34	10.25	39.65	11.72	24.05	0.00	0.00
600	25.00	0.00	12.99	1.31	12.26	35.59	13.79	24.05	0.00	0.00
720	30.00	0.00	12.99	0.91	14.20	32.21	15.64	24.05	0.00	0.00
840	35.00	0.00	12.99	0.68	15.61	29.36	17.30	24.05	0.00	0.00
1080	45.00	0.00	12.99	0.45	17.50	24.85	20.15	24.05	0.00	0.00
1200	50.00	0.00	12.99	0.30	18.22	23.04	21.40	24.05	0.00	0.00
1320	55.00	0.00	12.99	0.36	18.61	21.45	22.54	24.05	0.00	0.00
Maximum	56.00	99.93	12.99	2.28	18.67	53.69	22.75	24.05	0.00	99.93

Table VIII.B-9 Strait of Juan de Fuca - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.71	0.20	0.00	0.00	0.00	0.09	0.00	0.00	99.71
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	99.15	0.59	0.00	0.00	0.00	0.25	0.00	0.00	99.15
10	0.42	98.95	0.71	0.00	0.00	0.00	0.34	0.00	0.00	98.95
12	0.50	98.76	0.82	0.00	0.00	0.00	0.42	0.00	0.00	98.76
14	0.58	98.60	0.89	0.00	0.00	0.00	0.50	0.00	0.00	98.60
16	0.67	98.44	0.97	0.00	0.00	0.00	0.58	0.00	0.00	98.44
18	0.75	98.28	1.06	0.00	0.00	0.00	0.67	0.00	0.00	98.28
20	0.83	98.05	1.20	0.00	0.00	0.00	0.75	0.00	0.00	98.05
22	0.92	97.74	1.43	0.00	0.00	0.00	0.83	0.00	0.00	97.74
24	1.00	97.43	1.66	0.00	0.00	0.00	0.91	0.00	0.00	97.43
28	1.17	96.97	1.96	0.00	0.00	0.00	1.07	0.00	0.00	96.97
32	1.33	96.64	2.12	0.00	0.00	0.00	1.23	0.00	0.00	96.64
36	1.50	96.36	2.24	0.00	0.00	0.00	1.39	0.00	0.00	96.36
40	1.67	96.03	2.41	0.00	0.00	0.00	1.55	0.00	0.00	96.03
44	1.83	95.01	2.77	0.00	0.00	0.51	1.71	0.00	0.00	95.01
48	2.00	89.78	3.82	0.07	0.00	4.46	1.87	0.00	0.00	89.78
54	2.25	87.67	4.38	0.04	0.03	5.78	2.11	0.00	0.00	87.67
60	2.50	81.35	5.44	0.18	0.04	10.64	2.34	0.00	0.00	81.35
66	2.75	67.81	7.53	0.10	0.12	21.86	2.57	0.00	0.00	67.81
72	3.00	62.42	8.49	0.49	0.17	25.63	2.80	0.00	0.00	62.42
78	3.25	58.99	9.04	0.34	0.31	28.29	3.03	0.00	0.00	58.99
84	3.50	58.55	9.21	0.67	0.45	27.86	3.25	0.00	0.00	58.55
90	3.75	55.51	9.91	0.26	0.85	29.99	3.48	0.00	0.00	55.51
96	4.00	44.86	11.56	0.72	1.04	38.12	3.70	0.00	0.00	44.86

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	27.98	13.90	0.89	1.69	51.42	4.13	0.00	0.00	27.98
120	5.00	23.08	14.58	0.97	2.47	54.36	4.55	0.00	0.00	23.08
132	5.50	18.75	15.05	1.10	3.22	56.92	4.97	0.00	0.00	18.75
144	6.00	15.27	15.39	1.24	4.00	58.73	5.37	0.00	0.00	15.27
156	6.50	11.35	15.75	1.21	4.98	60.94	5.78	0.00	0.00	11.35
168	7.00	10.87	15.82	1.08	6.05	60.02	6.17	0.00	0.00	10.87
192	8.00	9.61	15.94	1.15	7.81	58.56	6.93	0.00	0.00	9.61
216	9.00	4.63	16.31	1.39	9.44	60.57	7.67	0.00	0.00	4.63
240	10.00	2.75	16.45	1.30	11.39	59.74	8.38	0.00	0.00	2.75
264	11.00	0.39	16.62	1.03	13.47	59.44	9.05	0.00	0.00	0.39
288	12.00	0.00	16.65	1.27	15.01	57.37	9.70	0.00	0.00	0.00
336	14.00	0.00	16.65	0.92	18.69	52.83	10.92	0.00	0.00	0.00
384	16.00	0.00	16.65	0.83	21.81	48.67	12.04	0.00	0.00	0.00
432	18.00	0.00	16.65	0.96	24.46	44.87	13.07	0.00	0.00	0.00
480	20.00	0.00	16.65	0.83	27.11	41.39	14.02	0.00	0.00	0.00
600	25.00	0.00	16.65	0.64	32.73	33.92	16.07	0.00	0.00	0.00
720	30.00	0.00	16.65	0.62	37.09	27.93	17.72	0.00	0.00	0.00
840	35.00	0.00	16.65	0.45	40.73	23.09	19.08	0.00	0.00	0.00
1080	45.00	0.00	16.65	0.36	45.86	16.04	21.09	0.00	0.00	0.00
1200	50.00	0.00	16.65	0.29	47.75	13.49	21.83	0.00	0.00	0.00
1320	55.00	0.00	16.65	0.21	49.29	11.42	22.43	0.00	0.00	0.00
Maximum	56.00	99.86	16.65	1.39	49.51	60.94	22.54	0.00	0.00	99.86

Table VIII.B-10 Strait of Juan de Fuca - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.71	0.20	0.00	0.00	0.00	0.09	0.00	0.00	99.71
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	99.15	0.59	0.00	0.00	0.00	0.25	0.00	0.00	99.15
10	0.42	98.95	0.71	0.00	0.00	0.00	0.34	0.00	0.00	98.95
12	0.50	98.76	0.82	0.00	0.00	0.00	0.42	0.00	0.00	98.76
14	0.58	97.83	0.89	0.00	0.00	0.00	0.50	0.77	0.00	97.83
16	0.67	96.94	0.97	0.00	0.00	0.00	0.58	1.50	0.00	96.94
18	0.75	96.08	1.06	0.00	0.00	0.00	0.66	2.20	0.00	96.08
20	0.83	95.19	1.20	0.00	0.00	0.00	0.74	2.87	0.00	95.19
22	0.92	94.89	1.42	0.00	0.00	0.00	0.82	2.87	0.00	94.89
24	1.00	94.43	1.65	0.00	0.00	0.00	0.90	3.02	0.00	94.43
28	1.17	92.81	1.93	0.00	0.00	0.00	1.06	4.19	0.00	92.81
32	1.33	91.41	2.09	0.00	0.00	0.00	1.21	5.29	0.00	91.41
36	1.50	90.12	2.20	0.00	0.00	0.00	1.36	6.32	0.00	90.12
40	1.67	87.87	2.36	0.00	0.00	0.00	1.51	8.26	0.00	87.87
44	1.83	84.70	2.75	0.00	0.00	0.81	1.65	10.09	0.00	84.70
48	2.00	78.06	3.71	0.07	0.00	4.53	1.79	11.84	0.00	78.06
54	2.25	75.86	4.13	0.04	0.03	5.26	2.00	12.67	0.00	75.86
60	2.50	72.53	4.78	0.14	0.05	7.63	2.20	12.67	0.00	72.53
66	2.75	59.63	6.77	0.08	0.10	18.34	2.40	12.67	0.00	59.63
72	3.00	55.61	7.52	0.41	0.14	21.04	2.60	12.67	0.00	55.61
78	3.25	53.09	7.95	0.29	0.25	22.94	2.80	12.67	0.00	53.09
84	3.50	52.62	8.12	0.56	0.37	22.65	3.00	12.67	0.00	52.62
90	3.75	50.57	8.68	0.22	0.71	23.96	3.19	12.67	0.00	50.57
96	4.00	42.87	9.96	0.58	0.87	29.66	3.38	12.67	0.00	42.87

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	24.34	12.42	0.77	1.39	44.64	3.76	12.67	0.00	24.34
120	5.00	21.38	12.90	0.83	2.07	46.03	4.12	12.67	0.00	21.38
132	5.50	16.00	13.45	0.97	2.71	49.71	4.48	12.67	0.00	16.00
144	6.00	11.29	13.88	1.12	3.40	52.80	4.84	12.67	0.00	11.29
156	6.50	8.67	14.12	1.08	4.28	53.98	5.19	12.67	0.00	8.67
168	7.00	8.27	14.18	0.97	5.24	53.14	5.53	12.67	0.00	8.27
192	8.00	6.98	14.29	1.04	6.82	52.01	6.19	12.67	0.00	6.98
216	9.00	4.97	14.44	1.20	8.27	51.61	6.83	12.67	0.00	4.97
240	10.00	2.78	14.60	1.13	9.96	51.40	7.44	12.67	0.00	2.78
264	11.00	0.77	14.75	0.90	11.78	51.10	8.03	12.67	0.00	0.77
288	12.00	0.00	14.81	1.11	13.14	49.68	8.59	12.67	0.00	0.00
336	14.00	0.00	14.81	0.80	16.36	45.71	9.65	12.67	0.00	0.00
384	16.00	0.00	14.81	0.72	19.09	42.09	10.61	12.67	0.00	0.00
432	18.00	0.00	14.81	0.84	21.40	38.78	11.51	12.67	0.00	0.00
480	20.00	0.00	14.81	0.73	23.72	35.75	12.32	12.67	0.00	0.00
600	25.00	0.00	14.81	0.55	28.61	29.26	14.09	12.67	0.00	0.00
720	30.00	0.00	14.81	0.54	32.40	24.06	15.52	12.67	0.00	0.00
840	35.00	0.00	14.81	0.39	35.57	19.88	16.69	12.67	0.00	0.00
1080	45.00	0.00	14.81	0.31	40.01	13.79	18.42	12.67	0.00	0.00
1200	50.00	0.00	14.81	0.25	41.63	11.59	19.05	12.67	0.00	0.00
1320	55.00	0.00	14.81	0.18	42.96	9.81	19.57	12.67	0.00	0.00
Maximum	56.00	99.86	14.81	1.20	43.16	53.98	19.66	12.67	0.00	99.86

Table VIII.B-11 Strait of Juan de Fuca - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.71	0.20	0.00	0.00	0.00	0.09	0.00	0.00	99.71
6	0.25	99.45	0.38	0.00	0.00	0.00	0.17	0.00	0.00	99.45
8	0.33	98.43	0.59	0.00	0.00	0.00	0.25	0.73	0.00	98.43
10	0.42	98.06	0.71	0.00	0.00	0.00	0.34	0.90	0.00	98.06
12	0.50	97.24	0.82	0.00	0.00	0.00	0.42	1.52	0.00	97.24
14	0.58	95.16	0.89	0.00	0.00	0.00	0.50	3.46	0.00	95.16
16	0.67	93.17	0.97	0.00	0.00	0.00	0.58	5.29	0.00	93.17
18	0.75	91.26	1.05	0.00	0.00	0.00	0.65	7.04	0.00	91.26
20	0.83	89.38	1.18	0.00	0.00	0.00	0.73	8.71	0.00	89.38
22	0.92	89.09	1.39	0.00	0.00	0.00	0.80	8.71	0.00	89.09
24	1.00	88.42	1.61	0.00	0.00	0.00	0.88	9.10	0.00	88.42
28	1.17	85.07	1.88	0.00	0.00	0.00	1.02	12.03	0.00	85.07
32	1.33	82.05	2.02	0.00	0.00	0.00	1.16	14.77	0.00	82.05
36	1.50	79.23	2.13	0.00	0.00	0.00	1.30	17.34	0.00	79.23
40	1.67	75.60	2.26	0.00	0.00	0.00	1.42	20.71	0.00	75.60
44	1.83	71.56	2.56	0.00	0.00	0.44	1.55	23.90	0.00	71.56
48	2.00	62.89	3.60	0.07	0.00	4.85	1.66	26.92	0.00	62.89
54	2.25	60.24	3.96	0.04	0.03	5.52	1.83	28.38	0.00	60.24
60	2.50	57.99	4.42	0.12	0.05	7.04	2.00	28.38	0.00	57.99
66	2.75	47.10	6.10	0.07	0.10	16.09	2.16	28.38	0.00	47.10
72	3.00	43.27	6.79	0.36	0.13	18.74	2.32	28.38	0.00	43.27
78	3.25	41.28	7.13	0.26	0.24	20.24	2.48	28.38	0.00	41.28
84	3.50	40.74	7.30	0.50	0.34	20.10	2.64	28.38	0.00	40.74
90	3.75	39.49	7.70	0.20	0.64	20.80	2.80	28.38	0.00	39.49

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	32.00	8.87	0.52	0.78	26.50	2.95	28.38	0.00	32.00
108	4.50	15.62	10.94	0.71	1.25	39.85	3.26	28.38	0.00	15.62
120	5.00	12.75	11.33	0.76	1.87	41.36	3.55	28.38	0.00	12.75
132	5.50	10.07	11.61	0.86	2.46	42.77	3.85	28.38	0.00	10.07
144	6.00	6.37	11.93	0.98	3.07	45.14	4.13	28.38	0.00	6.37
156	6.50	4.84	12.07	0.93	3.85	45.51	4.41	28.38	0.00	4.84
168	7.00	4.23	12.13	0.83	4.68	45.06	4.69	28.38	0.00	4.23
192	8.00	2.77	12.24	0.90	6.05	44.44	5.22	28.38	0.00	2.77
216	9.00	0.54	12.41	1.05	7.31	44.58	5.74	28.38	0.00	0.54
240	10.00	0.09	12.44	0.96	8.77	43.12	6.23	28.38	0.00	0.09
264	11.00	0.00	12.45	0.74	10.32	41.41	6.70	28.38	0.00	0.00
288	12.00	0.00	12.45	0.90	11.43	39.69	7.15	28.38	0.00	0.00
336	14.00	0.00	12.45	0.65	14.05	36.49	7.99	28.38	0.00	0.00
384	16.00	0.00	12.45	0.59	16.26	33.56	8.76	28.38	0.00	0.00
432	18.00	0.00	12.45	0.68	18.14	30.89	9.47	28.38	0.00	0.00
480	20.00	0.00	12.45	0.59	20.02	28.45	10.12	28.38	0.00	0.00
600	25.00	0.00	12.45	0.45	23.98	23.22	11.53	28.38	0.00	0.00
720	30.00	0.00	12.45	0.43	27.05	19.03	12.66	28.38	0.00	0.00
840	35.00	0.00	12.45	0.32	29.60	15.68	13.58	28.38	0.00	0.00
1080	45.00	0.00	12.45	0.25	33.20	10.80	14.93	28.38	0.00	0.00
1200	50.00	0.00	12.45	0.20	34.51	9.04	15.43	28.38	0.00	0.00
1320	55.00	0.00	12.45	0.15	35.58	7.62	15.83	28.38	0.00	0.00
Maximum	56.00	99.86	12.45	1.05	35.74	45.51	15.90	28.38	0.00	99.86

Table VIII.B-12 Strait of Juan de Fuca - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	99.81	0.14	0.00	0.00	0.00	0.05	0.00	0.00	99.81
4	0.17	99.71	0.20	0.00	0.00	0.00	0.09	0.00	0.00	99.71
6	0.25	97.03	0.38	0.00	0.00	0.00	0.17	2.42	0.00	97.03
8	0.33	96.20	0.58	0.00	0.00	0.00	0.25	2.97	0.00	96.20
10	0.42	95.50	0.70	0.00	0.00	0.00	0.33	3.47	0.00	95.50
12	0.50	93.43	0.81	0.00	0.00	0.00	0.41	5.35	0.00	93.43
14	0.58	90.76	0.88	0.00	0.00	0.00	0.49	7.88	0.00	90.76
16	0.67	88.22	0.95	0.00	0.00	0.00	0.56	10.27	0.00	88.22
18	0.75	85.78	1.03	0.00	0.00	0.00	0.63	12.56	0.00	85.78
20	0.83	83.40	1.15	0.00	0.00	0.00	0.70	14.75	0.00	83.40
22	0.92	83.12	1.36	0.00	0.00	0.00	0.77	14.75	0.00	83.12
24	1.00	82.60	1.56	0.00	0.00	0.00	0.84	15.00	0.00	82.60
28	1.17	77.48	1.81	0.00	0.00	0.00	0.98	19.73	0.00	77.48
32	1.33	72.81	1.95	0.00	0.00	0.00	1.10	24.15	0.00	72.81
36	1.50	68.44	2.04	0.00	0.00	0.00	1.22	28.30	0.00	68.44
40	1.67	64.09	2.16	0.00	0.00	0.00	1.33	32.42	0.00	64.09
44	1.83	59.43	2.42	0.00	0.00	0.41	1.43	36.31	0.00	59.43
48	2.00	50.20	3.41	0.07	0.00	4.79	1.53	40.00	0.00	50.20
54	2.25	47.70	3.62	0.04	0.03	4.85	1.66	42.10	0.00	47.70
60	2.50	45.66	4.03	0.11	0.05	6.25	1.80	42.10	0.00	45.66
66	2.75	36.65	5.42	0.06	0.10	13.75	1.93	42.10	0.00	36.65
72	3.00	34.61	5.84	0.29	0.13	14.99	2.06	42.10	0.00	34.61
78	3.25	32.63	6.16	0.20	0.21	16.52	2.18	42.10	0.00	32.63
84	3.50	32.13	6.30	0.41	0.29	16.46	2.31	42.10	0.00	32.13
90	3.75	30.61	6.69	0.16	0.54	17.47	2.44	42.10	0.00	30.61

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	24.33	7.65	0.45	0.65	22.25	2.56	42.10	0.00	24.33
108	4.50	11.39	9.26	0.59	1.06	32.80	2.80	42.10	0.00	11.39
120	5.00	8.66	9.59	0.64	1.57	34.40	3.04	42.10	0.00	8.66
132	5.50	6.29	9.82	0.72	2.07	35.72	3.27	42.10	0.00	6.29
144	6.00	4.89	9.94	0.80	2.59	36.17	3.50	42.10	0.00	4.89
156	6.50	3.67	10.05	0.76	3.22	36.47	3.73	42.10	0.00	3.67
168	7.00	3.44	10.08	0.67	3.89	35.87	3.95	42.10	0.00	3.44
192	8.00	2.96	10.12	0.71	4.99	34.75	4.37	42.10	0.00	2.96
216	9.00	1.84	10.20	0.82	5.99	34.27	4.78	42.10	0.00	1.84
240	10.00	0.40	10.30	0.77	7.14	34.11	5.17	42.10	0.00	0.40
264	11.00	0.00	10.33	0.60	8.38	33.04	5.55	42.10	0.00	0.00
288	12.00	0.00	10.33	0.73	9.27	31.66	5.91	42.10	0.00	0.00
336	14.00	0.00	10.33	0.52	11.37	29.09	6.58	42.10	0.00	0.00
384	16.00	0.00	10.33	0.47	13.15	26.75	7.20	42.10	0.00	0.00
432	18.00	0.00	10.33	0.54	14.65	24.62	7.76	42.10	0.00	0.00
480	20.00	0.00	10.33	0.47	16.15	22.67	8.28	42.10	0.00	0.00
600	25.00	0.00	10.33	0.36	19.30	18.51	9.40	42.10	0.00	0.00
720	30.00	0.00	10.33	0.34	21.73	15.19	10.30	42.10	0.00	0.00
840	35.00	0.00	10.33	0.25	23.74	12.54	11.04	42.10	0.00	0.00
1080	45.00	0.00	10.33	0.19	26.56	8.69	12.12	42.10	0.00	0.00
1200	50.00	0.00	10.33	0.16	27.58	7.31	12.52	42.10	0.00	0.00
1320	55.00	0.00	10.33	0.11	28.41	6.19	12.85	42.10	0.00	0.00
Maximum	56.00	99.86	10.33	0.82	28.54	36.47	12.91	42.10	0.00	99.86

Table VIII.B-13 Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	790	321	183
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	789	321	183
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	904	752	342
Shoreline length (km) oiled by > 100 g/m^2	901	751	301
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	330,060	290,630	81,483
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	573,760	461,300	260,220
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	108	95	43

Table VIII.B-14 Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	740	250	181
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	740	250	181
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	846	711	296
Shoreline length (km) oiled by > 100 g/m^2	846	711	296
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	292,700	288,380	56,700
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	553,670	422,430	238,820
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	102	90	37

Table VIII.B-15 Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	771	281	150
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	761	275	149
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	919	742	264
Shoreline length (km) oiled by > 100 g/m^2	918	695	264
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	329,870	298,710	86,740
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	589,150	443,460	177,230
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	111	93	30

Table VIII.B-16 Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	707	250	146
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	701	246	146
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	816	674	270
Shoreline length (km) oiled by > 100 g/m^2	816	634	269
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	295,890	208,960	134,050
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	519,690	464,870	135,930
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	96	90	28

VIII.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 VIII.C-1 Strait of Juan de Fuca - Bunker C, 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)	21,075	9,260	38	2,399	1	0	2	-	32,775	32,772	2
Worst run for Dungeness Spit	11,436	3,360	32	2,024	0	0	1	-	16,853	16,852	1
Worst run for Protection Island	8,586	1,615	14	901	3	0	1	-	11,120	11,119	1

Table VIII.C-2 Strait of Juan de Fuca - Bunker C, 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)	20,074	8,647	36	2,263	1	0	2	-	31,023	31,020	2
Worst run for Dungeness Spit	9,976	2,466	30	1,924	0	0	1	-	14,398	14,397	1
Worst run for Protection Island	8,541	1,587	14	887	3	0	1	-	11,034	11,033	1

Table VIII.C-3 Strait of Juan de Fuca - Bunker C, 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)	20,499	8,907	39	2,441	0	0	2	-	31,889	31,886	2
Worst run for Dungeness Spit	10,486	2,778	30	1,884	0	0	1	-	15,180	15,179	1
Worst run for Protection Island	7,884	1,185	13	808	2	0	1	-	9,893	9,892	1

Table VIII.C-4 Strait of Juan de Fuca - Bunker C, 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)	19,262	8,150	35	2,186	1	0	2	-	29,636	29,633	2
Worst run for Dungeness Spit	9,887	2,411	27	1,733	0	0	1	-	14,060	14,059	1
Worst run for Protection Island	7,817	1,144	13	820	2	0	1	-	9,796	9,796	1

VIII.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 VIII.D-1. Strait of Juan de Fuca - Bunker C, 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)	0.6	26	3.8	-	22	122,377	122,429
Worst run for Dungeness Spit	3.8	53	7.2	-	22	106,837	106,923
Worst run for Protection Island	1.5	33	4.7	-	22	16,997	17,058

Table VIII.D-2. Strait of Juan de Fuca - Bunker C, 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)	0.6	25	3.7	-	22	115,578	115,629
Worst run for Dungeness Spit	2.2	39	5.4	-	22	108,294	108,363
Worst run for Protection Island	1.3	31	4.5	-	227	16,511	16,570

Table VIII.D-3. Strait of Juan de Fuca - Bunker C, 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)	0.5	25	3.6	-	22	129,176	129,227
Worst run for Dungeness Spit	2.9	45	6.2	-	22	100,524	100,600
Worst run for Protection Island	1.1	30	4.3	-	22	16,511	16,569

Table VIII.D-4. Strait of Juan de Fuca - Bunker C, 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)	0.5	25	3.7	-	22	110,722	110,773
Worst run for Dungeness Spit	2.5	41	5.7	-	22	94,211	94,283
Worst run for Protection Island	0.9	28	4.0	-	22	21,853	21,908

VIII.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 VIII.E-1. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	0.6	3.8	1.5
Large pelagic fish	26	53	33
Demersal fish	3.8	7.2	4.7
Decapods	-	-	-
Molluscs	122,399	106,859	17,019
Birds:			
Waterfowl (# * kg each)	14,875	8,072	6,060
Seabirds (# * kg each)	9,175	3,329	1,600
Waders (# * kg each)	38	32	14
Shorebirds (# * kg each)	2,377	2,005	892
Raptors (# * kg each)	0.7	0.4	2.9
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.4	1.2	0.9
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	122,429	106,923	17,058
Subtotal birds	26,466	13,438	8,570
Subtotal other wildlife	2	1	1
Total all species	148,897	120,362	25,629

Table VIII.E-2. Strait of Juan de Fuca - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	91	46	20
Saltmarsh Area (acres)	226	113	50
Saltmarsh Cost (millions of 2004$)	42.3	21.1	9.4
Eelgrass Area (m2)	57	29	13
Eelgrass Area (acres)	141	70	31
Eelgrass Cost (millions of 2004$)	16.8	8.4	3.8

Table VIII.E-3. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	0.6	2.2	1.3
Large pelagic fish	25	39	31
Demersal fish	3.7	5.4	4.5
Decapods	-	-	-
Molluscs	115,600	108,316	16,533
Birds:			
Waterfowl (# * kg each)	14,169	7,042	6,029
Seabirds (# * kg each)	8,568	2,443	1,573
Waders (# * kg each)	35	30	14
Shorebirds (# * kg each)	2,242	1,907	879
Raptors (# * kg each)	0.6	0.4	3.2
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.3	1.1	0.9
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	115,629	108,363	16,570
Subtotal birds	25,015	11,422	8,497
Subtotal other wildlife	2	1	1
Total all species	140,646	119,786	25,069

Table VIII.E-4. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	86	39	20
Saltmarsh Area (acres)	212	96	50
Saltmarsh Cost (millions of 2004$)	39.7	18.0	9.3
Eelgrass Area (m2)	54	24	13
Eelgrass Area (acres)	133	60	31
Eelgrass Cost (millions of 2004$)	15.8	7.2	3.7

Table VIII.E-5. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	0.5	2.9	1.1
Large pelagic fish	25	45	30
Demersal fish	3.6	6.2	4.3
Decapods	-	-	-
Molluscs	129,198	100,546	16,533
Birds:			
Waterfowl (# * kg each)	14,469	7,402	5,565
Seabirds (# * kg each)	8,826	2,753	1,174
Waders (# * kg each)	38	29	13
Shorebirds (# * kg each)	2,419	1,867	801
Raptors (# * kg each)	0.5	0.4	1.9
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.4	1.1	0.8
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	129,227	100,600	16,569
Subtotal birds	25,752	12,051	7,555
Subtotal other wildlife	2	1	1
Total all species	154,981	112,652	24,124

Table VIII.E-6. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	90	40	17
Saltmarsh Area (acres)	222	100	42
Saltmarsh Cost (millions of 2004$)	41.5	18.7	7.9
Eelgrass Area (m2)	56	25	11
Eelgrass Area (acres)	138	62	26
Eelgrass Cost (millions of 2004$)	16.5	7.4	3.1

Table VIII.E-7. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	0.5	2.5	0.9
Large pelagic fish	25	41	28
Demersal fish	3.7	5.7	4.0
Decapods	-	-	-
Molluscs	110,744	94,233	21,875
Birds:			
Waterfowl (# * kg each)	13,596	6,978	5,517
Seabirds (# * kg each)	8,075	2,389	1,133
Waders (# * kg each)	34	27	13
Shorebirds (# * kg each)	2,166	1,718	812
Raptors (# * kg each)	0.5	0.4	2.0
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.2	1.0	0.8
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	110,773	94,283	21,908
Subtotal birds	23,872	11,113	7,478
Subtotal other wildlife	2	1	1
Total all species	134,647	105,396	29,387

Table VIII.E-8. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	82	37	17
Saltmarsh Area (acres)	201	91	43
Saltmarsh Cost (millions of 2004$)	37.7	17.0	8.0
Eelgrass Area (m2)	51	23	11
Eelgrass Area (acres)	126	57	27
Eelgrass Cost (millions of 2004$)	15.0	6.8	3.2

VIII.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 VIII.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table VIII.F-1. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	28.18	26.96	27.04
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	29.6	28.3	28.4

Table VIII.F-2. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	28.18	26.96	27.05
% Removed by 24 hours	1.30	1.19	3.02
Compensation (millions $)	29.2	28.0	27.5

Table VIII.F-3. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	28.18	26.96	27.02
% Removed by 24 hours	2.96	4.33	9.10
Compensation (millions $)	28.7	27.1	25.8

Table VIII.F-4. Strait of Juan de Fuca - Bunker C, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	28.18	26.96	27.02
% Removed by 24 hours	5.05	8.98	15.00
Compensation (millions $)	28.1	25.8	24.1

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 IX: Model Inputs for Strait of Juan de Fuca – Diesel

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

IX.A. Introduction 1
IX.B. Geographical Data 1
IX.B.1. Maps of the Vicinity of the Modeled Spill Locations 1
IX.B.2. Gridded Habitat Mapping 2
IX.B-3. Gridded Depth Data 3
IX.B-4. Areas Where Response Actions Assumed 4
IX.C. Current Data 6
IX.C.1. Basis of Current Data 6
IX.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 7
IX.D: Oil Properties 10
IX.E: Inputs to the SIMAP Physical Fates Model 13

List of Figures

Figure IX.B.1-1 Map of the vicinity of the potential spill locations.IX.B.2. Gridded Habitat Mapping 1
IX.B.2. Gridded Habitat Mapping 2
Figure IX.B.2-1 Habitat grid used for modeling the potential spills. 2
Figure IX.B.2-2 Habitat grid used for modeling the potential spills (closer view). 2
Figure IX.B.3-1 Depth grid used for modeling the potential spills. 3
Figure IX.B.3-2 Depth grid used for modeling the potential spills (closer view). 3
Figure IX.B.4-1 Jurisdictions in the area of the potential spills. 4
Figure IX.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 4
Figure IX.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 5
Figure IX.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 5
Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data. 6
Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC). 7
Figure VI.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. 8
Figure VI.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. 8
Figure VI.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. 9
Figure VI.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. 9
Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit. 16
Figure IX.E-2 Wind Station Locations. 20

List of Tables

Table IX.D-1. Oil properties for Diesel assumed in the modeling. 10
Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel. 11
Table IX.E-1. Inputs to the Fates Model for Stochastic Scenarios 13
Table IX.E-2. Time, date and location inputs for each of the 100 stochastic runs. 17
Table IX.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 19
Table IX.E-4. Water temperature by month of the year (from French et al., 1996b). 19
Table IX.E-5. Wind data sources and records used. 20

IX.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.

IX.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.

IX.B.1. Maps of the Vicinity of the Modeled Spill Locations

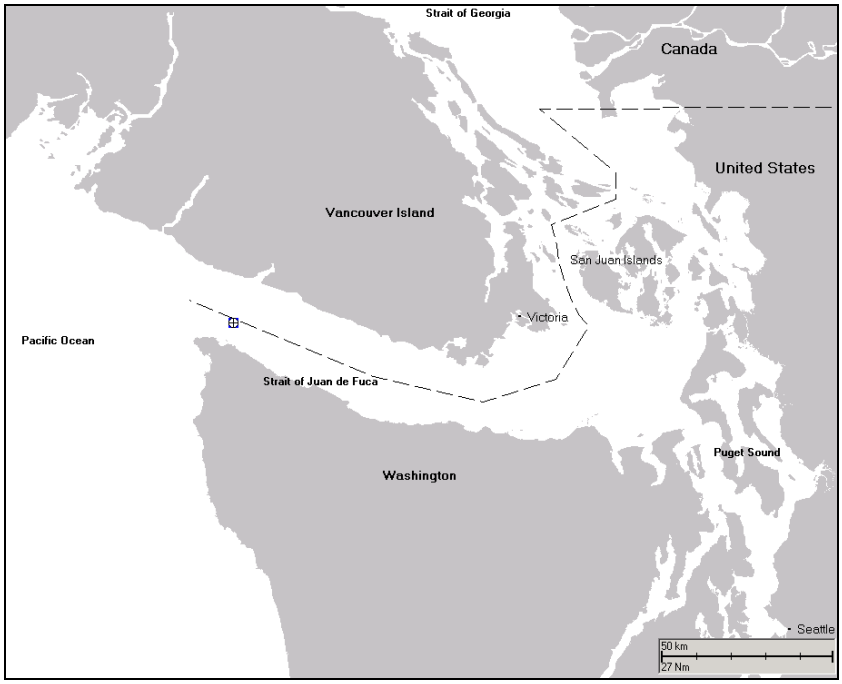


Figure IX.B.1-1 Map of the vicinity of the potential spill locations.

IX.B.2. Gridded Habitat Mapping

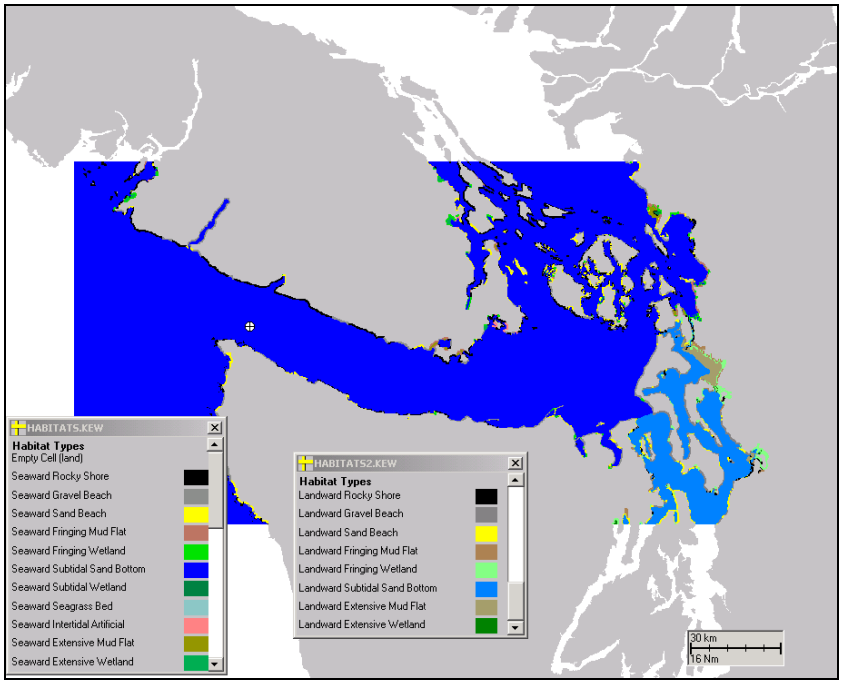


Figure IX.B.2-1 Habitat grid used for modeling the potential spills.

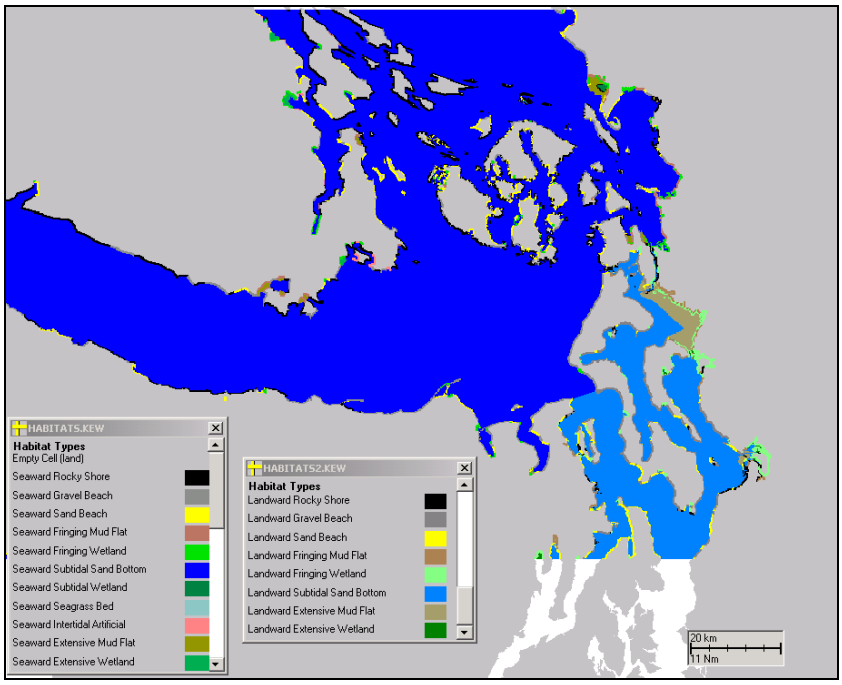


Figure IX.B.2-2 Habitat grid used for modeling the potential spills (closer view).

IX.B-3. Gridded Depth Data

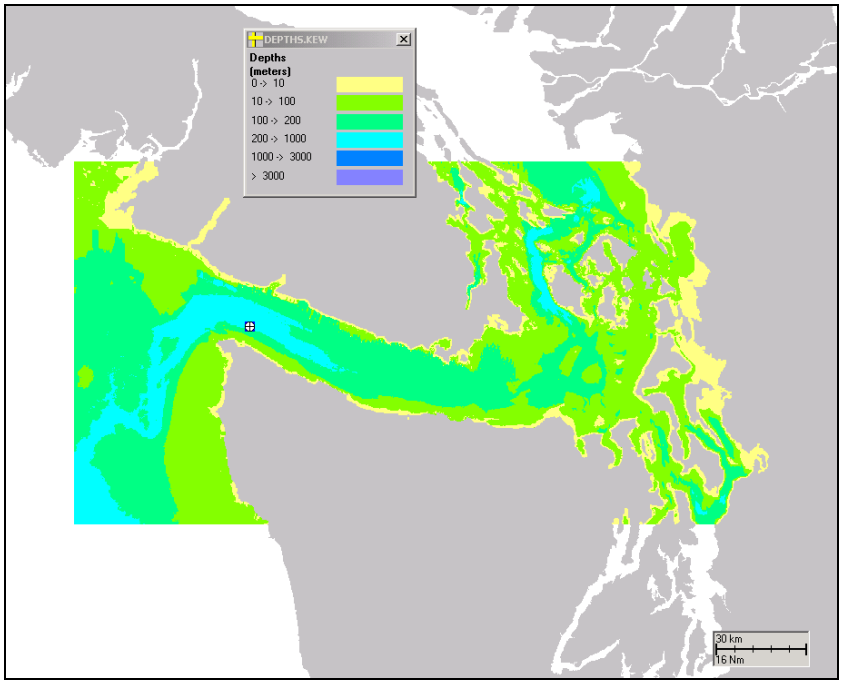


Figure IX.B.3-1 Depth grid used for modeling the potential spills.

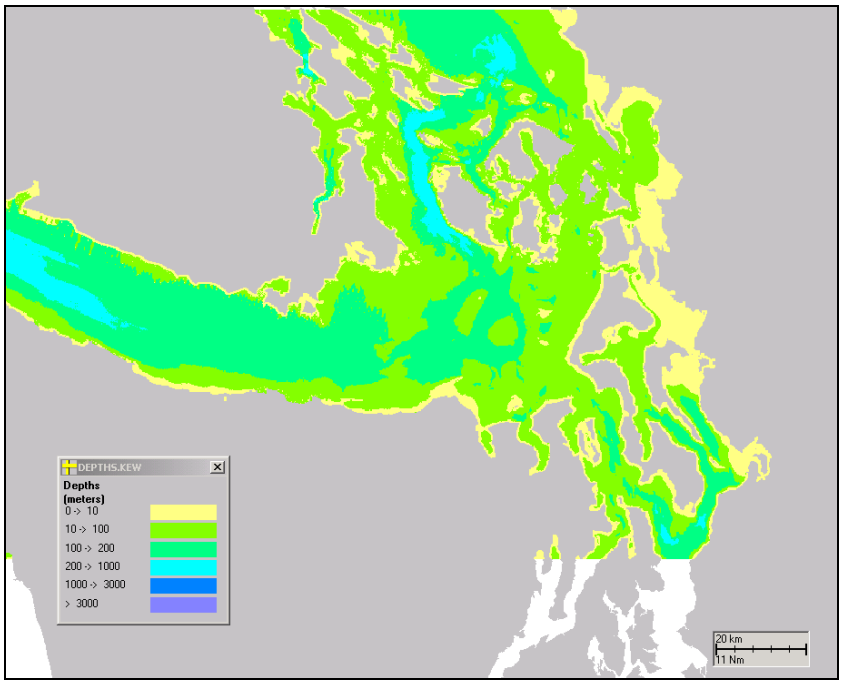


Figure IX.B.3-2 Depth grid used for modeling the potential spills (closer view).

IX.B-4. Areas Where Response Actions Assumed

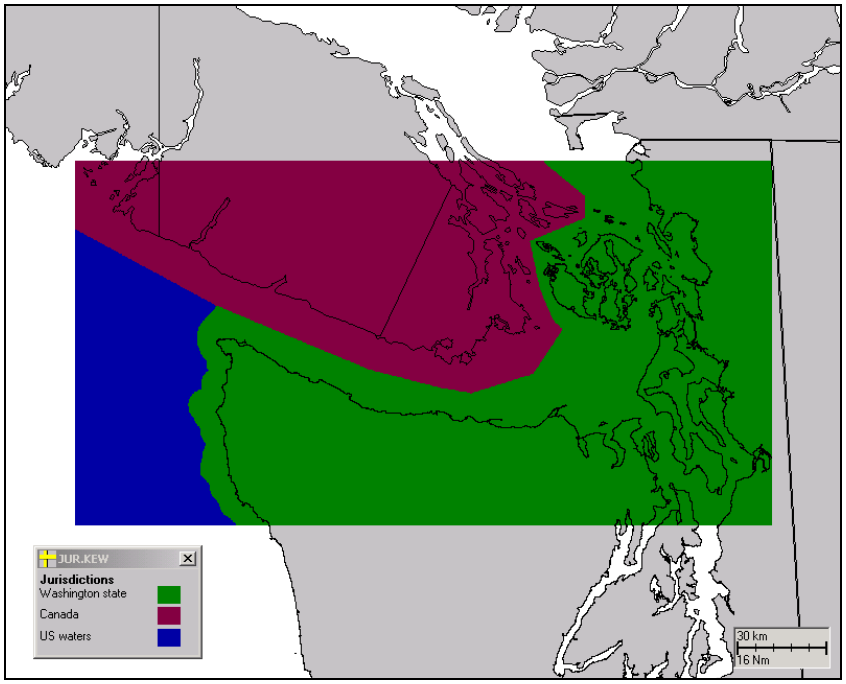


Figure IX.B.4-1 Jurisdictions in the area of the potential spills.

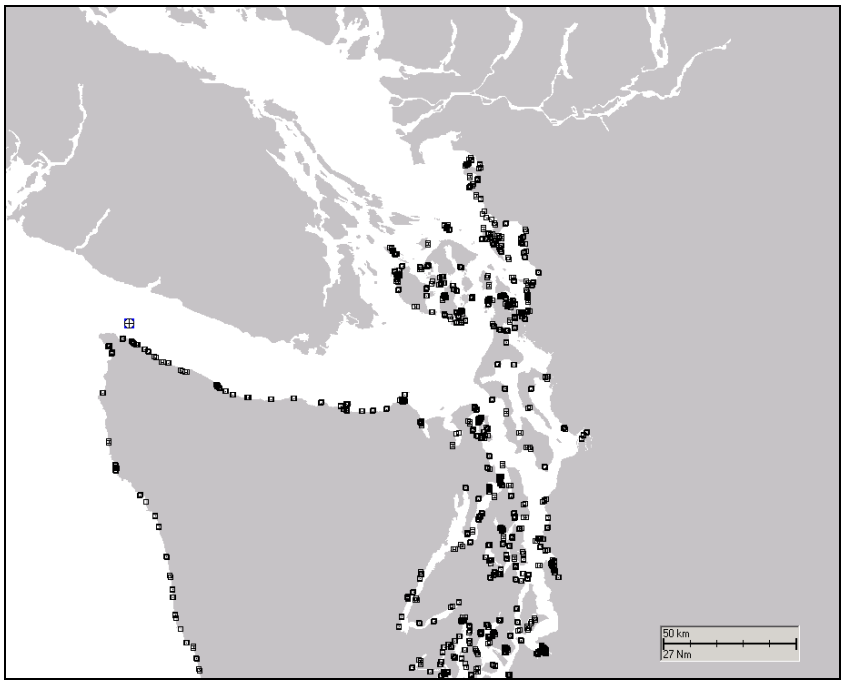


Figure IX.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

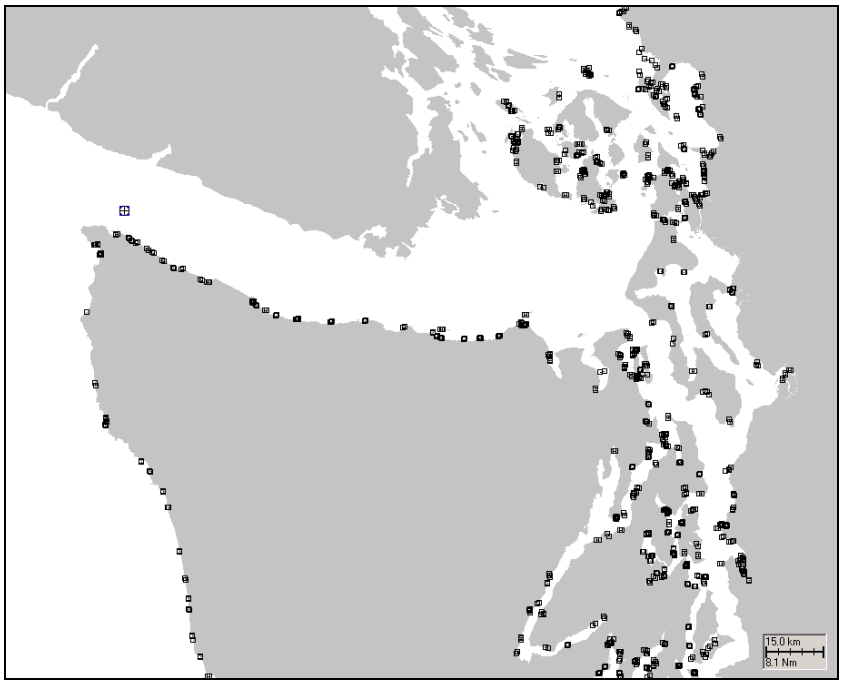


Figure IX.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

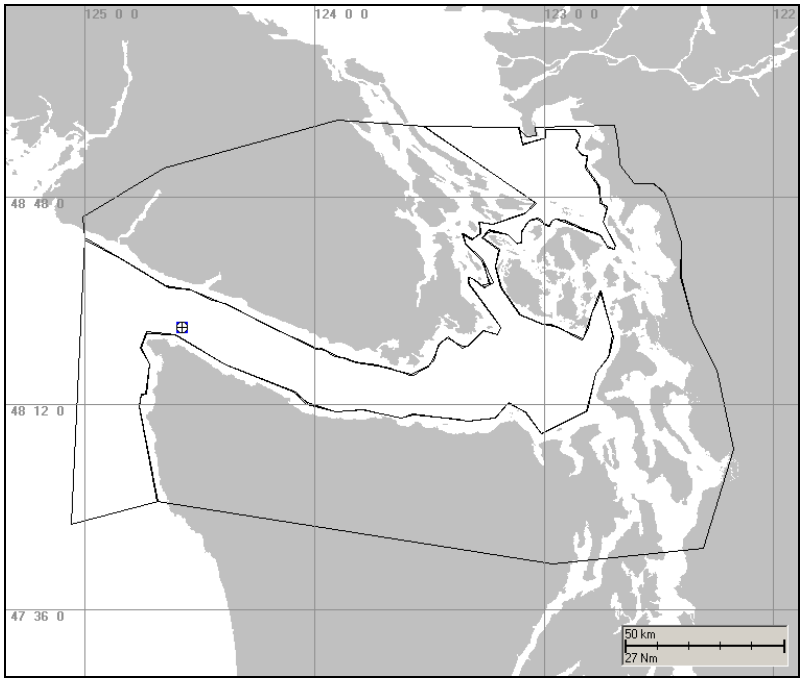


Figure IX.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

IX.C. CURRENT DATA

IX.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).

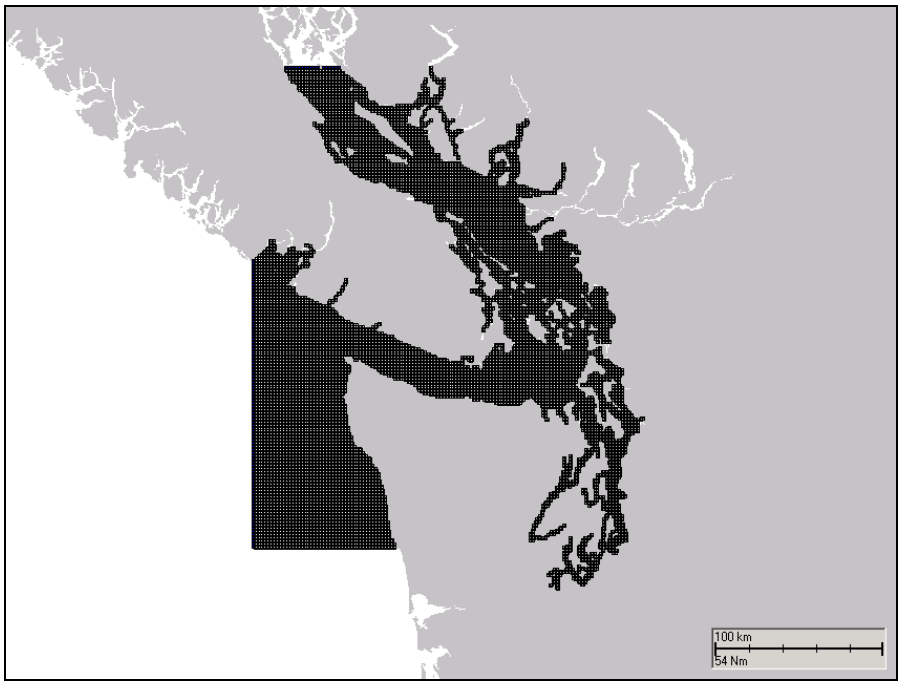


Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data.

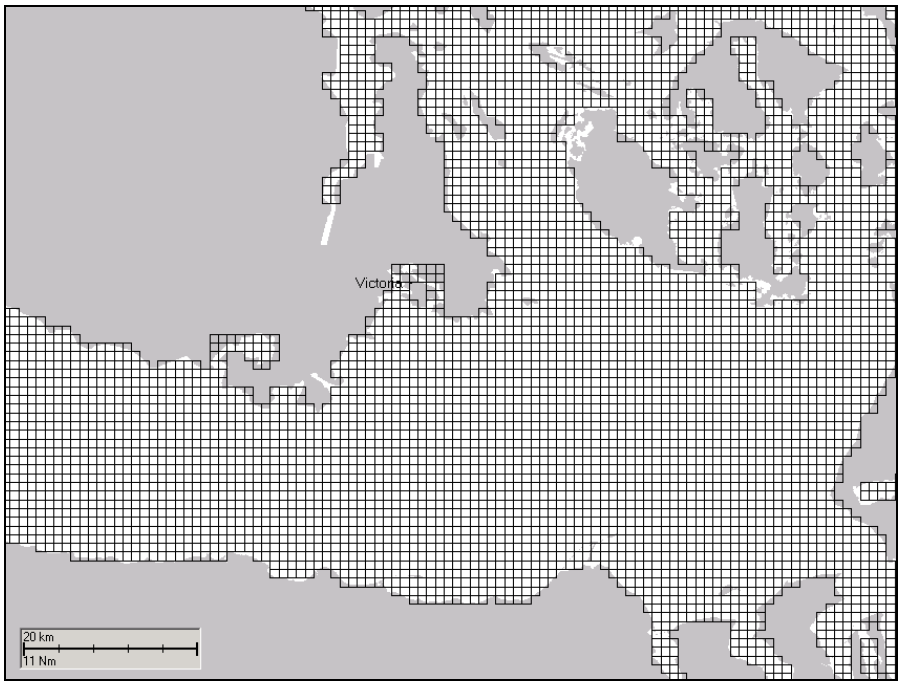


Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

IX.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.

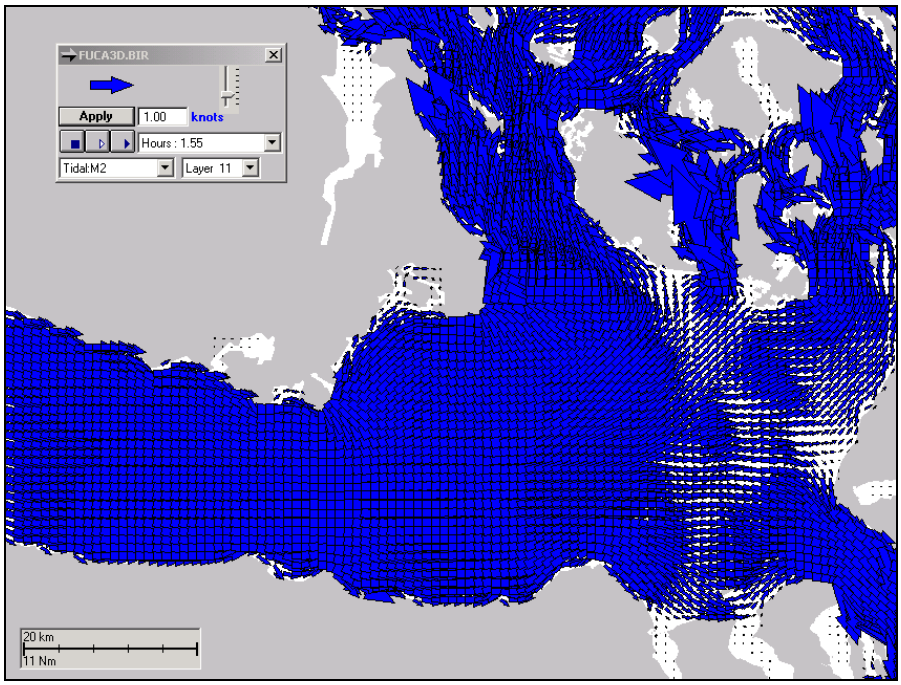


Figure VI.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Victoria, BC.

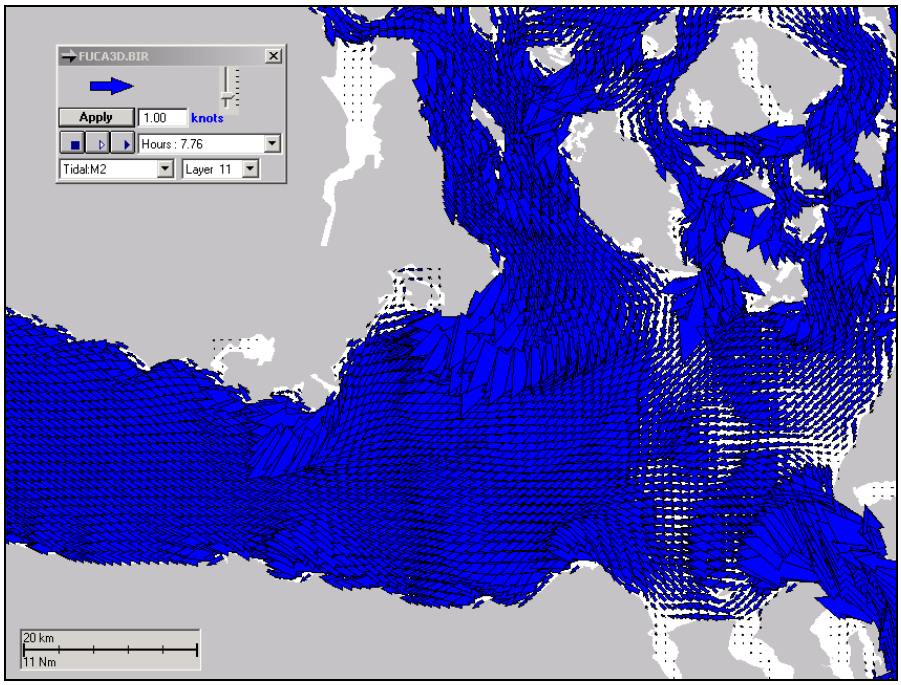


Figure VI.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Victoria, BC.

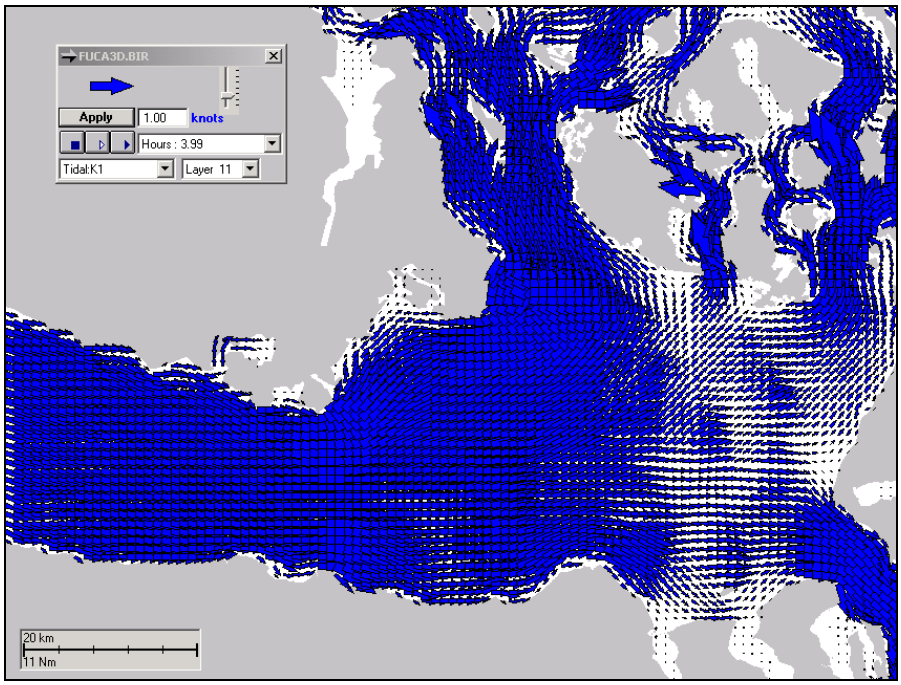


Figure VI.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Victoria, BC.

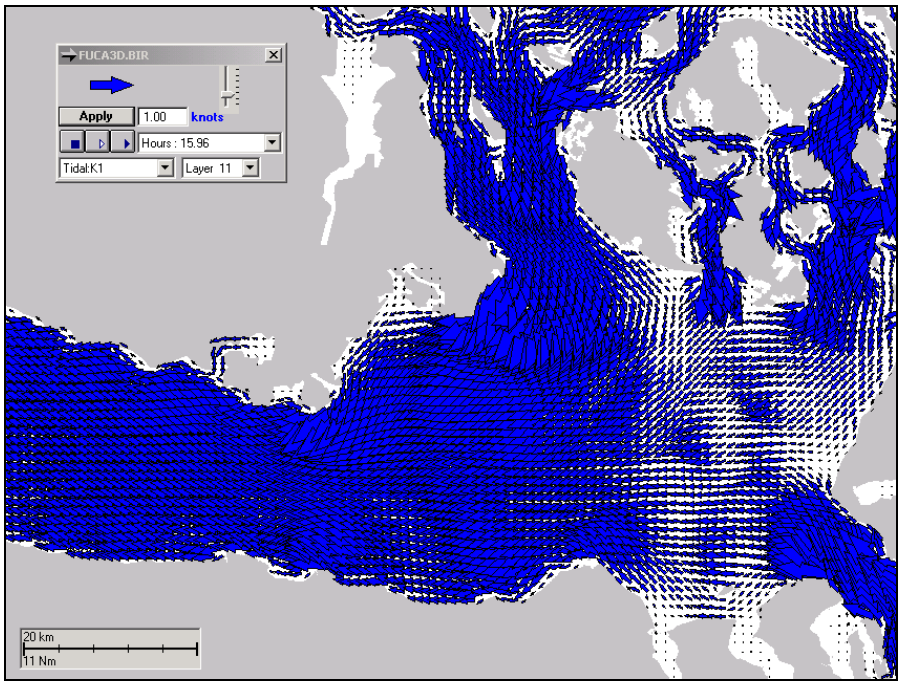


Figure VI.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Victoria, BC.

IX.D: OIL PROPERTIES

Table IX.D-1. Oil properties for Diesel assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.83	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	2	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27.4	Jokuty et al. (1999)
Pour Point (deg. C)	-36	Jokuty 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)	0.023336	Jokuty et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.012151	Lee et al. (1992)
Fraction 2-ring aromatics (included in PAHs above)	0.010175	Lee et al. (1992)
Fraction 3-ring aromatics (included in PAHs above)	0.001976	Lee et al. (1992)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.186664	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.426825	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.000000	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.0000130	McAuliffe (1987)
Maximum Mousse Water Content (%)	0	Whiticar et al. (1994)
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] – Jokuty et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel.

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	925
C1-naphthalenes	3.87	9,250
C2-naphthalenes	4.37	0.0
C3-naphthalenes	5.00	0.0
C4-naphthalenes	5.55	0.0
biphenyls	3.9	0.0
acenaphthylene	4.07	0.0
acenaphthene	3.92	350
dibenzofuran	4.31	0.0
Fluorene	4.18	625
C1-fluorenes	4.97	0.0
C2-fluorenes	5.20	0.0
C3-fluorenes	5.50	0.0

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	0.0
C1-dibenzothiophene	4.86	0.0
C2-dibenzothiophene	5.50	0.0
C3-dibenzothiophene	5.73	0.0
phenanthrene	4.57	800
anthracene	4.54	200
C1-phenanthrenes/anthracenes	5.14	0.0
C2-phenanthrenes/anthracenes	5.25	0.0
C3-phenanthrenes/anthracenes	6.00	0.0
C4-phenanthrenes/anthracenes	6.51	0.0
fluoranthene	5.22	1.4
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	12,151.4

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

IX.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 IX.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	Shipping Lane from Neah Bay to Port Angeles
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure IX.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure IX.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 IX.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table IX.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 IX.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table IX.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

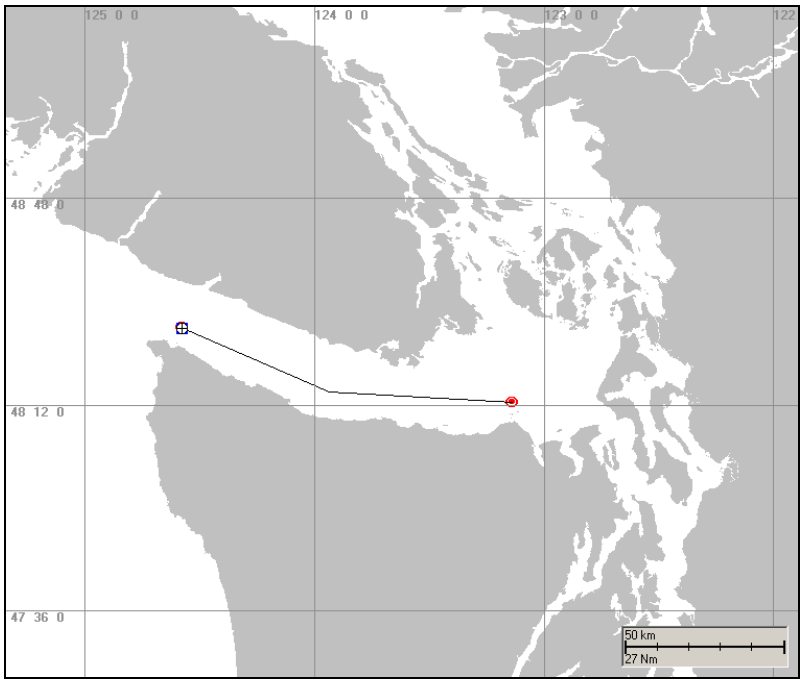


Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit.

Table IX.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	48.21379	123.2517
2	1998	5	16	3	48.35398	124.3277
3	2000	8	16	18	48.23584	123.8275
4	1998	5	31	11	48.30383	124.1553
5	1996	12	29	21	48.36623	124.3698
6	1993	2	13	17	48.2269	123.5942
7	2001	3	14	23	48.37146	124.3878
8	1999	3	9	17	48.23059	123.6904
9	1992	4	23	10	48.26945	124.0371
10	2002	8	18	0	48.35533	124.3323
11	1995	4	22	7	48.22297	123.4916
12	1993	3	17	9	48.22572	123.5633
13	2001	2	9	19	48.22152	123.4537
14	1998	9	7	21	48.26863	124.0342
15	2000	6	23	20	48.21664	123.3261
16	1995	10	12	13	48.22702	123.5974
17	2003	5	10	6	48.3818	124.4233
18	1994	4	16	9	48.23095	123.6999
19	1993	10	14	10	48.2202	123.419
20	1992	12	26	22	48.25145	123.9752
21	2002	12	9	23	48.21216	123.2092
22	2001	9	20	18	48.40139	124.4907
23	1993	9	16	15	48.23939	123.9203
24	2002	3	17	7	48.40671	124.509
25	1998	7	1	21	48.3761	124.4037
26	1996	5	24	1	48.23529	123.8134
27	1999	6	5	17	48.32106	124.2145
28	2002	12	30	22	48.22251	123.4795
29	1994	5	27	7	48.22664	123.5873
30	1994	6	15	3	48.23724	123.8641
31	1996	3	30	15	48.23138	123.7111
32	1998	6	10	3	48.34926	124.3114
33	1993	3	14	3	48.29057	124.1097
34	1998	1	9	19	48.34612	124.3007
35	1992	4	27	14	48.21187	123.2016
36	2003	1	18	8	48.27315	124.0498
37	1998	5	29	11	48.39717	124.4762
38	1993	5	21	6	48.23506	123.8073
39	2000	11	29	23	48.2805	124.0751
40	2003	6	3	2	48.23059	123.6905
41	1999	5	8	8	48.39666	124.4744
42	2001	4	6	0	48.22833	123.6315
43	2003	8	17	3	48.21769	123.3536
44	1993	12	13	4	48.42231	124.5626
45	1992	8	8	14	48.33296	124.2554
46	2003	5	16	21	48.34842	124.3086
47	1998	12	17	12	48.22304	123.4932
48	2003	12	13	0	48.40501	124.5031
49	2002	6	11	1	48.22442	123.5294
50	1999	5	20	22	48.2099	123.1501

51	2000	5	4	17	48.21176	123.1988
52	1992	4	29	2	48.33371	124.258
53	2000	3	10	1	48.23357	123.7683
54	1998	10	24	2	48.22515	123.5484
55	2000	6	26	19	48.29064	124.1099
56	2001	9	18	8	48.2097	123.1448
57	1994	7	29	15	48.25507	123.9876
58	2000	4	24	0	48.23152	123.7147
59	1993	10	14	14	48.22433	123.5271
60	1992	1	12	13	48.232	123.7273
61	2003	5	3	16	48.21412	123.2603
62	1995	7	13	7	48.2271	123.5994
63	1998	10	26	18	48.4141	124.5344
64	2003	3	29	13	48.23093	123.6994
65	1993	8	7	14	48.21514	123.287
66	1996	12	18	16	48.22802	123.6234
67	2003	3	11	17	48.23922	123.916
68	1999	2	24	6	48.27987	124.0729
69	1993	7	2	21	48.22791	123.6206
70	2002	6	14	7	48.22212	123.4694
71	1993	1	23	10	48.39468	124.4676
72	2000	11	26	20	48.21262	123.2211
73	1992	10	4	5	48.25719	123.9949
74	1993	11	10	12	48.23956	123.9249
75	1999	7	3	11	48.28352	124.0854
76	2003	12	28	8	48.41305	124.5308
77	1996	8	27	4	48.39962	124.4846
78	2002	7	23	15	48.21898	123.3871
79	2000	12	16	5	48.22886	123.6453
80	1996	2	3	6	48.33045	124.2468
81	1997	3	27	6	48.3782	124.411
82	1998	4	9	1	48.21639	123.3198
83	1992	12	29	0	48.25483	123.9868
84	2002	3	8	0	48.22649	123.5833
85	1996	4	24	20	48.31348	124.1884
86	1995	9	22	21	48.2798	124.0726
87	2000	12	1	4	48.22873	123.6419
88	2001	7	2	0	48.32529	124.229
89	2000	11	30	9	48.27863	124.0686
90	1997	1	1	1	48.28	124.0733
91	1995	9	7	5	48.40139	124.4907
92	2001	10	24	10	48.23219	123.7324
93	1994	9	13	5	48.23891	123.9078
94	1993	12	25	23	48.21067	123.1703
95	1996	11	6	15	48.27063	124.0411
96	1999	7	24	13	48.23011	123.678
97	1997	1	5	11	48.22245	123.478
98	1997	2	20	8	48.22589	123.5678
99	1999	5	6	17	48.25146	123.9752
100	2003	12	11	6	48.41277	124.5298

Table IX.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	S1_S2-COARSE.HAB
Grid W edge	125° 23.40180'W
Grid S edge	47° 48.72180' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^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)	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 IX.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 IX.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 IX.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.

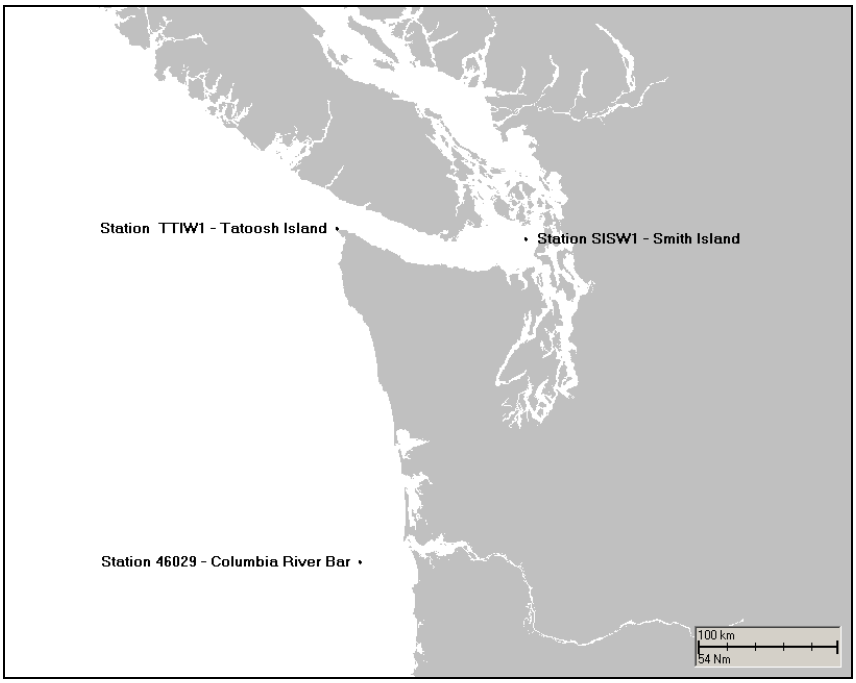


Figure IX.E-2 Wind Station Locations.

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 IX: Model Inputs for Strait of Juan de Fuca – Diesel

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

IX.A. Introduction 1
IX.B. Geographical Data 1
IX.B.1. Maps of the Vicinity of the Modeled Spill Locations 1
IX.B.2. Gridded Habitat Mapping 2
IX.B-3. Gridded Depth Data 3
IX.B-4. Areas Where Response Actions Assumed 4
IX.C. Current Data 6
IX.C.1. Basis of Current Data 6
IX.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 7
IX.D: Oil Properties 10
IX.E: Inputs to the SIMAP Physical Fates Model 13

List of Figures

Figure IX.B.1-1 Map of the vicinity of the potential spill locations.IX.B.2. Gridded Habitat Mapping 1
IX.B.2. Gridded Habitat Mapping 2
Figure IX.B.2-1 Habitat grid used for modeling the potential spills. 2
Figure IX.B.2-2 Habitat grid used for modeling the potential spills (closer view). 2
Figure IX.B.3-1 Depth grid used for modeling the potential spills. 3
Figure IX.B.3-2 Depth grid used for modeling the potential spills (closer view). 3
Figure IX.B.4-1 Jurisdictions in the area of the potential spills. 4
Figure IX.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 4
Figure IX.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 5
Figure IX.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 5
Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data. 6
Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC). 7
Figure VI.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. 8
Figure VI.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. 8
Figure VI.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. 9
Figure VI.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. 9
Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit. 16
Figure IX.E-2 Wind Station Locations. 20

List of Tables

Table IX.D-1. Oil properties for Diesel assumed in the modeling. 10
Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel. 11
Table IX.E-1. Inputs to the Fates Model for Stochastic Scenarios 13
Table IX.E-2. Time, date and location inputs for each of the 100 stochastic runs. 17
Table IX.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 19
Table IX.E-4. Water temperature by month of the year (from French et al., 1996b). 19
Table IX.E-5. Wind data sources and records used. 20

IX.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.

IX.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.

IX.B.1. Maps of the Vicinity of the Modeled Spill Locations

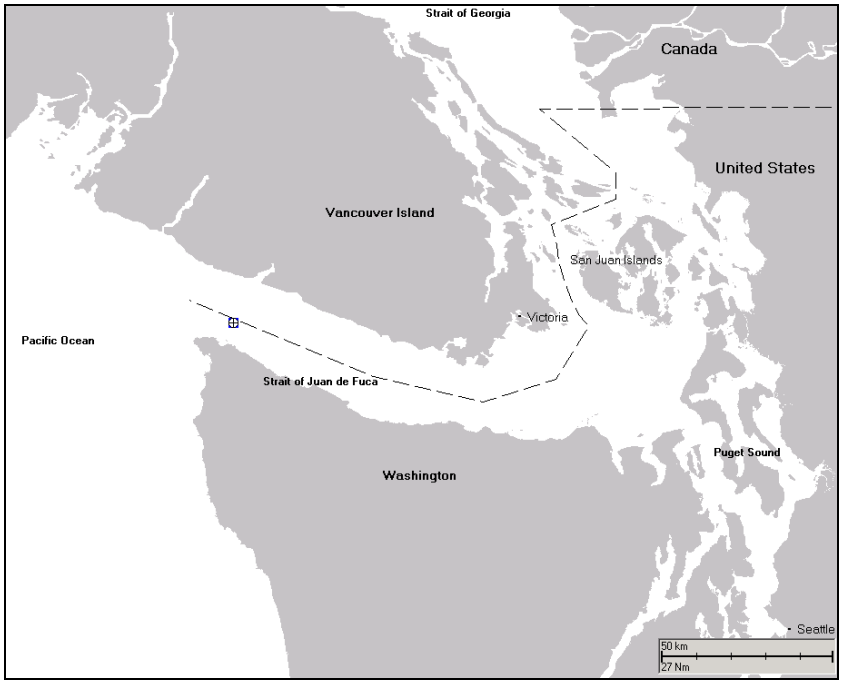


Figure IX.B.1-1 Map of the vicinity of the potential spill locations.

IX.B.2. Gridded Habitat Mapping

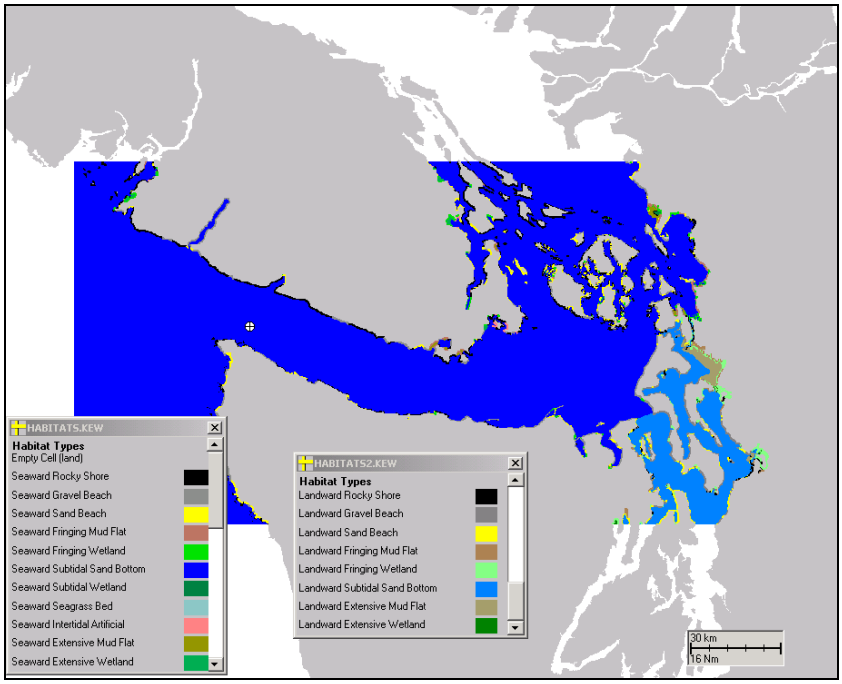


Figure IX.B.2-1 Habitat grid used for modeling the potential spills.

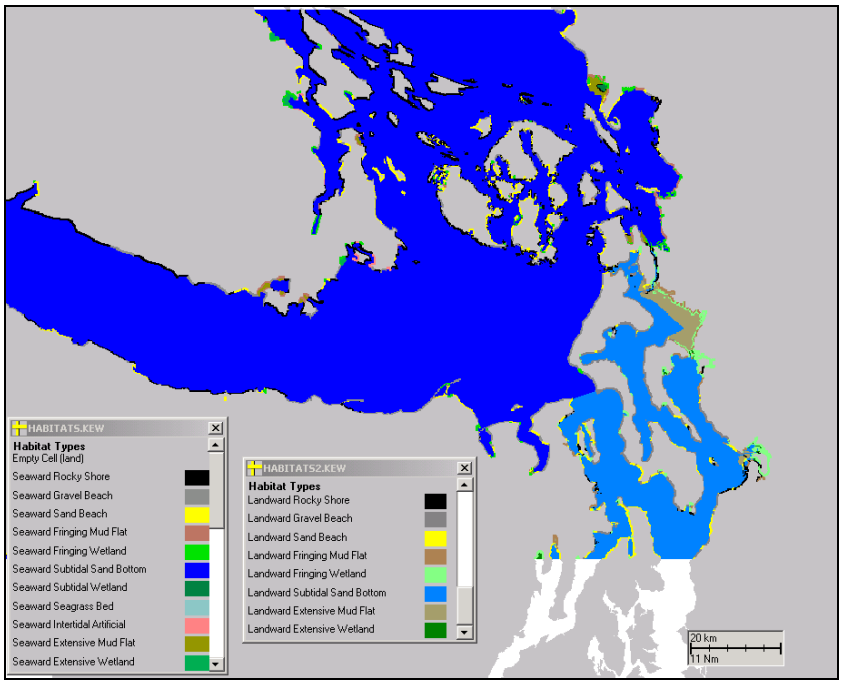


Figure IX.B.2-2 Habitat grid used for modeling the potential spills (closer view).

IX.B-3. Gridded Depth Data

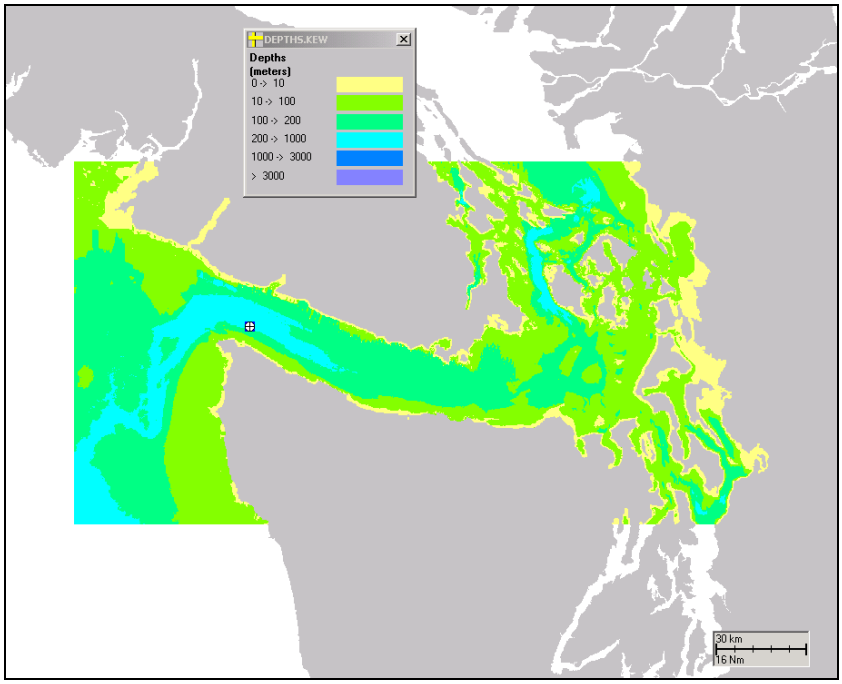


Figure IX.B.3-1 Depth grid used for modeling the potential spills.

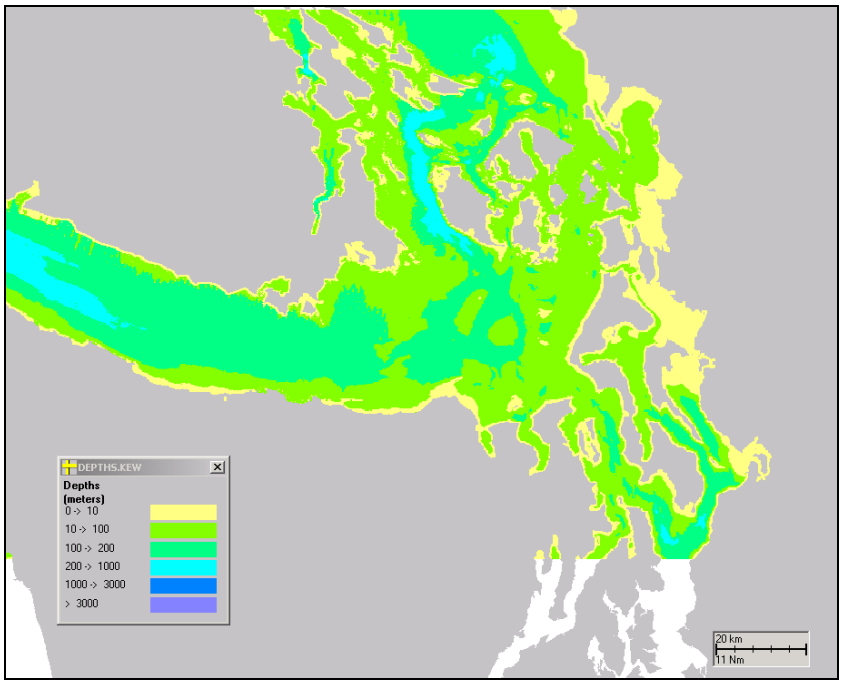


Figure IX.B.3-2 Depth grid used for modeling the potential spills (closer view).

IX.B-4. Areas Where Response Actions Assumed

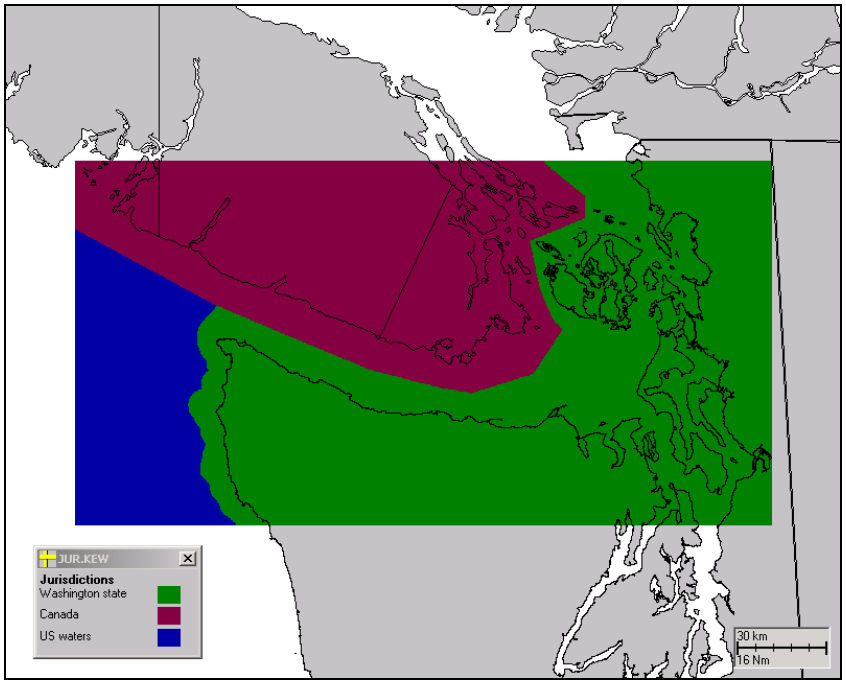


Figure IX.B.4-1 Jurisdictions in the area of the potential spills.

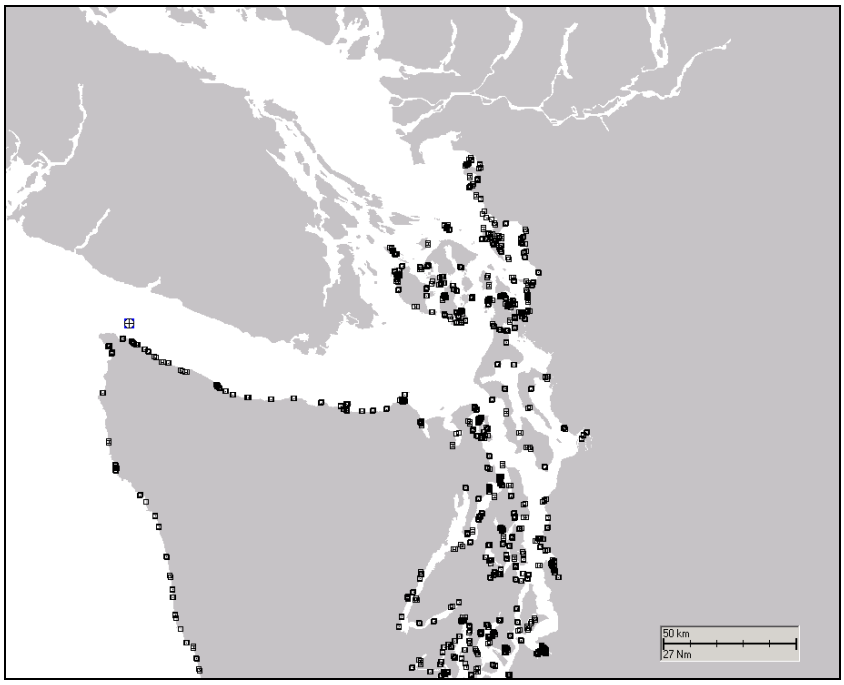


Figure IX.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

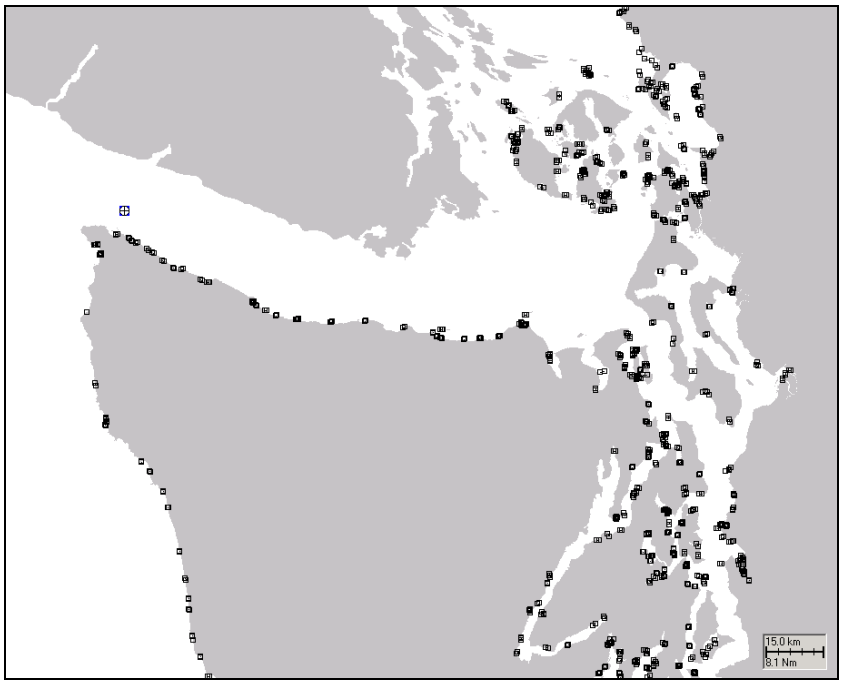


Figure IX.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

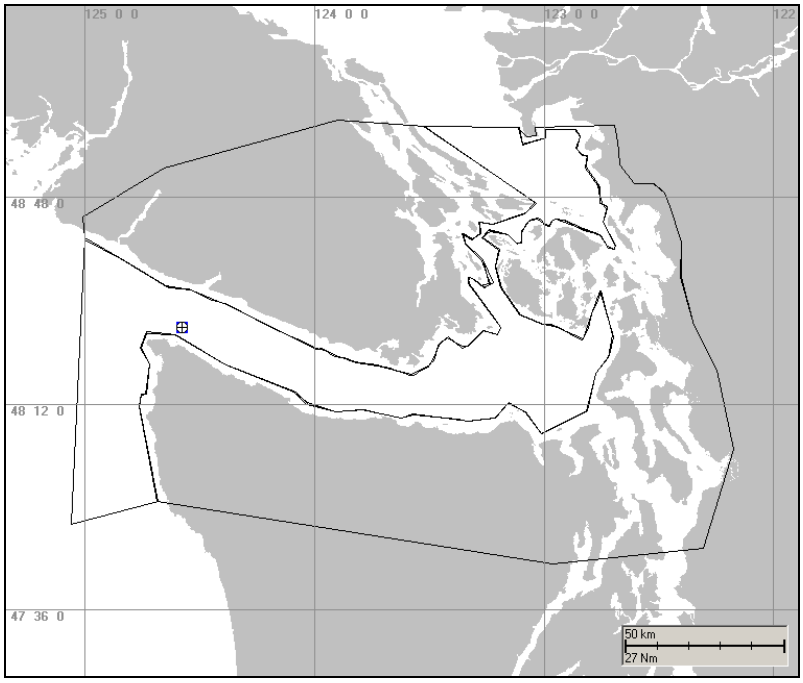


Figure IX.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

IX.C. CURRENT DATA

IX.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).

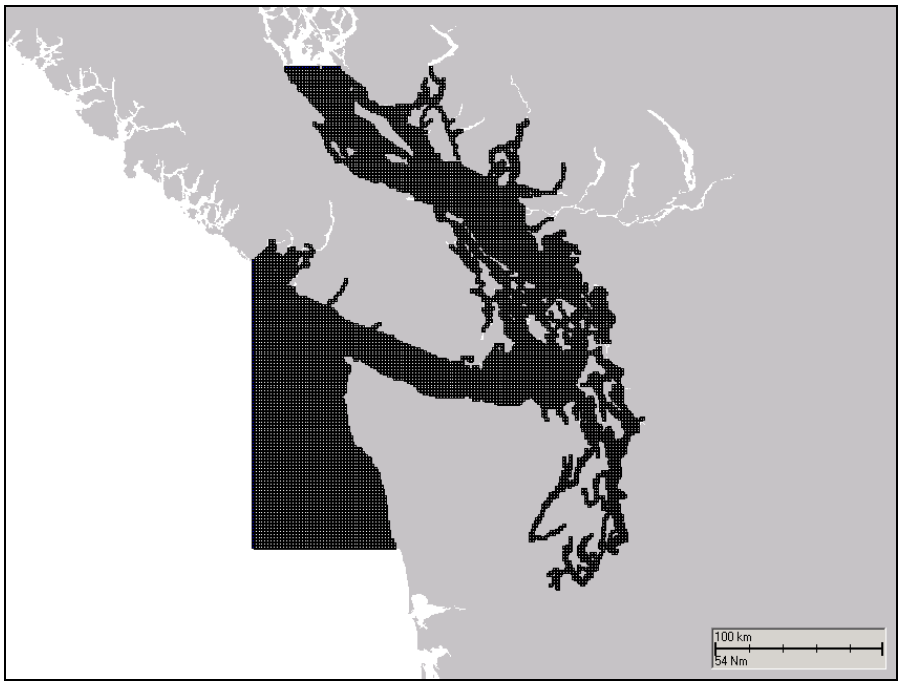


Figure VI.C.1-1 Grid used for the hydrodynamic model-generated current data.

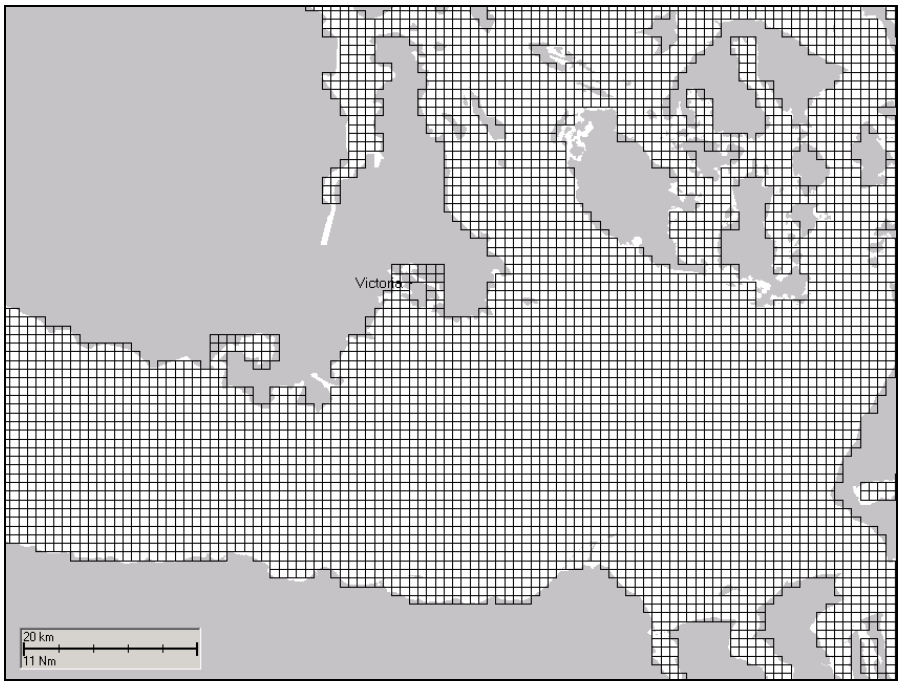


Figure VI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

IX.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.

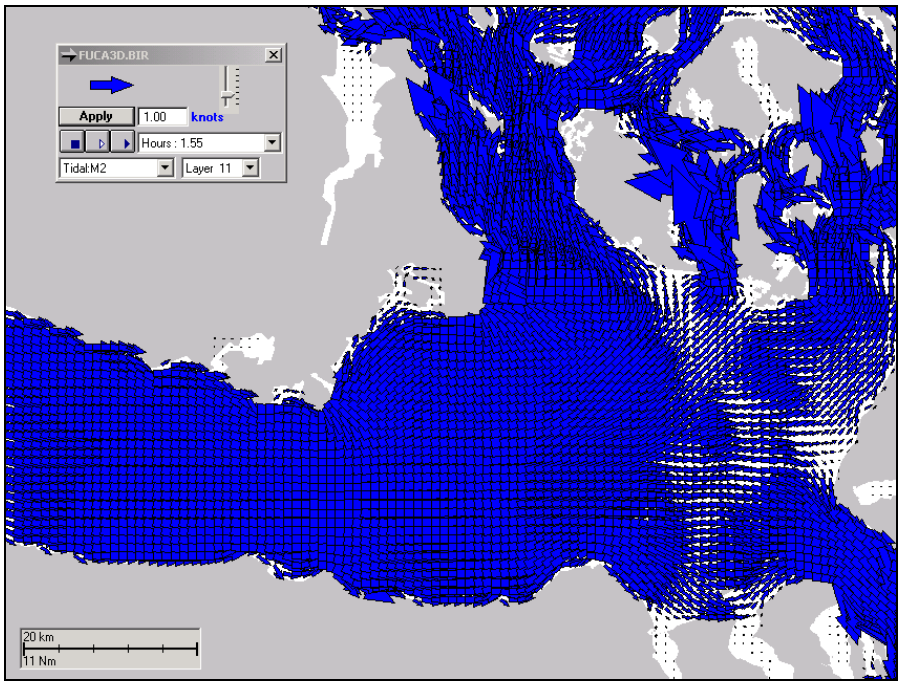


Figure VI.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Victoria, BC.

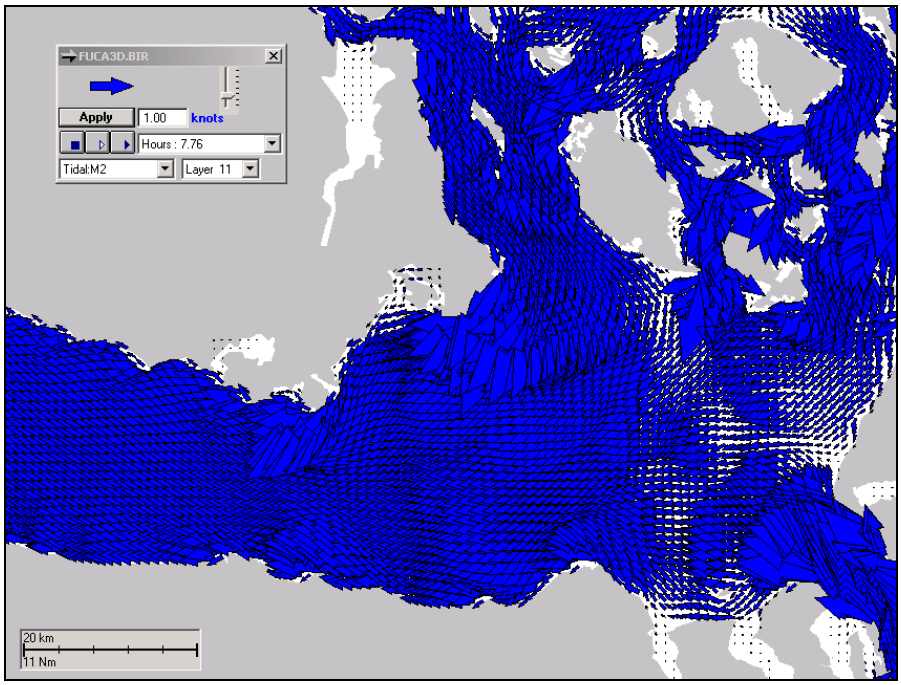


Figure VI.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Victoria, BC.

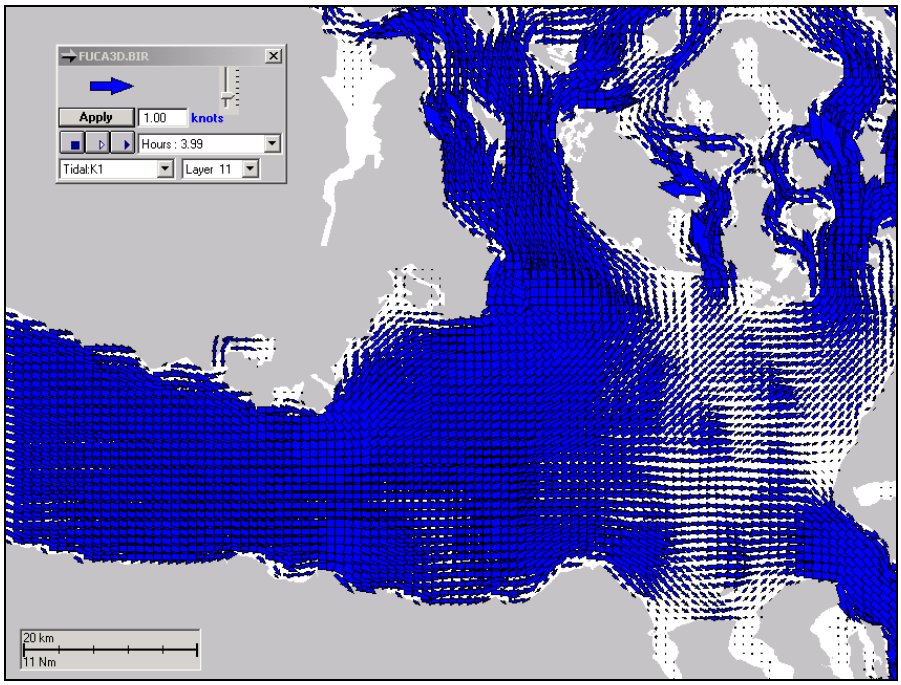


Figure VI.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Victoria, BC.

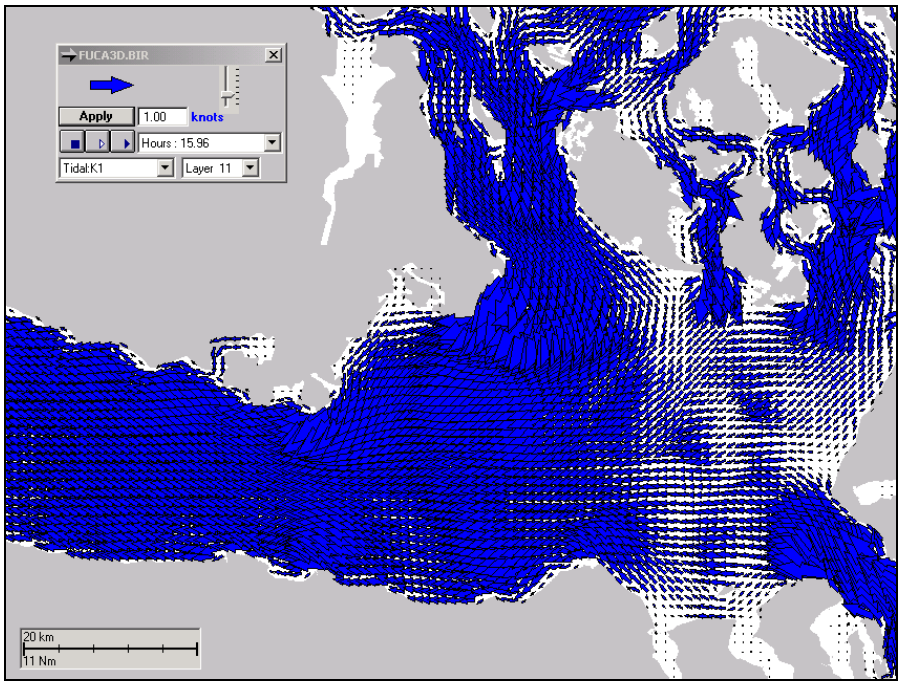


Figure VI.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Victoria, BC.

IX.D: OIL PROPERTIES

Table IX.D-1. Oil properties for Diesel assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.83	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	2	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27.4	Jokuty et al. (1999)
Pour Point (deg. C)	-36	Jokuty 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)	0.023336	Jokuty et al. (1999)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.012151	Lee et al. (1992)
Fraction 2-ring aromatics (included in PAHs above)	0.010175	Lee et al. (1992)
Fraction 3-ring aromatics (included in PAHs above)	0.001976	Lee et al. (1992)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.186664	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.426825	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.000000	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.0000130	McAuliffe (1987)
Maximum Mousse Water Content (%)	0	Whiticar et al. (1994)
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] – Jokuty et al. (1999) provided total hydrocarbon data. The aromatic hydrocarbon fraction was subtracted from the total hydrocarbon fraction to obtain the aliphatic fraction.

Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel.

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	925
C1-naphthalenes	3.87	9,250
C2-naphthalenes	4.37	0.0
C3-naphthalenes	5.00	0.0
C4-naphthalenes	5.55	0.0
biphenyls	3.9	0.0
acenaphthylene	4.07	0.0
acenaphthene	3.92	350
dibenzofuran	4.31	0.0
Fluorene	4.18	625
C1-fluorenes	4.97	0.0
C2-fluorenes	5.20	0.0
C3-fluorenes	5.50	0.0

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table IX.D-2. Aromatic concentrations (mg/kg) for Diesel (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	0.0
C1-dibenzothiophene	4.86	0.0
C2-dibenzothiophene	5.50	0.0
C3-dibenzothiophene	5.73	0.0
phenanthrene	4.57	800
anthracene	4.54	200
C1-phenanthrenes/anthracenes	5.14	0.0
C2-phenanthrenes/anthracenes	5.25	0.0
C3-phenanthrenes/anthracenes	6.00	0.0
C4-phenanthrenes/anthracenes	6.51	0.0
fluoranthene	5.22	1.4
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	12,151.4

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

IX.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 IX.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	Shipping Lane from Neah Bay to Port Angeles
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure IX.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure IX.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 IX.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table IX.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 IX.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table IX.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

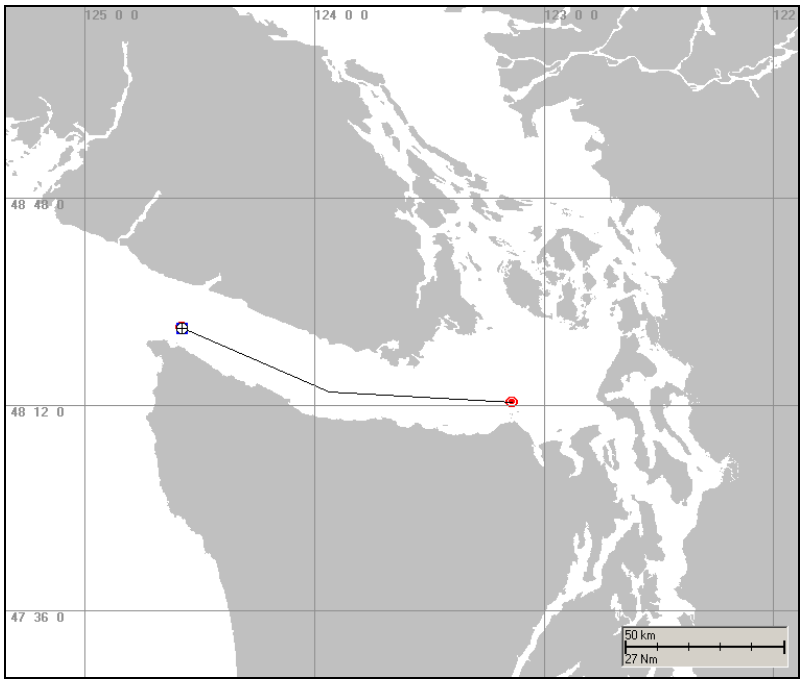


Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit.

Table IX.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	48.21379	123.2517
2	1998	5	16	3	48.35398	124.3277
3	2000	8	16	18	48.23584	123.8275
4	1998	5	31	11	48.30383	124.1553
5	1996	12	29	21	48.36623	124.3698
6	1993	2	13	17	48.2269	123.5942
7	2001	3	14	23	48.37146	124.3878
8	1999	3	9	17	48.23059	123.6904
9	1992	4	23	10	48.26945	124.0371
10	2002	8	18	0	48.35533	124.3323
11	1995	4	22	7	48.22297	123.4916
12	1993	3	17	9	48.22572	123.5633
13	2001	2	9	19	48.22152	123.4537
14	1998	9	7	21	48.26863	124.0342
15	2000	6	23	20	48.21664	123.3261
16	1995	10	12	13	48.22702	123.5974
17	2003	5	10	6	48.3818	124.4233
18	1994	4	16	9	48.23095	123.6999
19	1993	10	14	10	48.2202	123.419
20	1992	12	26	22	48.25145	123.9752
21	2002	12	9	23	48.21216	123.2092
22	2001	9	20	18	48.40139	124.4907
23	1993	9	16	15	48.23939	123.9203
24	2002	3	17	7	48.40671	124.509
25	1998	7	1	21	48.3761	124.4037
26	1996	5	24	1	48.23529	123.8134
27	1999	6	5	17	48.32106	124.2145
28	2002	12	30	22	48.22251	123.4795
29	1994	5	27	7	48.22664	123.5873
30	1994	6	15	3	48.23724	123.8641
31	1996	3	30	15	48.23138	123.7111
32	1998	6	10	3	48.34926	124.3114
33	1993	3	14	3	48.29057	124.1097
34	1998	1	9	19	48.34612	124.3007
35	1992	4	27	14	48.21187	123.2016
36	2003	1	18	8	48.27315	124.0498
37	1998	5	29	11	48.39717	124.4762
38	1993	5	21	6	48.23506	123.8073
39	2000	11	29	23	48.2805	124.0751
40	2003	6	3	2	48.23059	123.6905
41	1999	5	8	8	48.39666	124.4744
42	2001	4	6	0	48.22833	123.6315
43	2003	8	17	3	48.21769	123.3536
44	1993	12	13	4	48.42231	124.5626
45	1992	8	8	14	48.33296	124.2554
46	2003	5	16	21	48.34842	124.3086
47	1998	12	17	12	48.22304	123.4932
48	2003	12	13	0	48.40501	124.5031
49	2002	6	11	1	48.22442	123.5294
50	1999	5	20	22	48.2099	123.1501

51	2000	5	4	17	48.21176	123.1988
52	1992	4	29	2	48.33371	124.258
53	2000	3	10	1	48.23357	123.7683
54	1998	10	24	2	48.22515	123.5484
55	2000	6	26	19	48.29064	124.1099
56	2001	9	18	8	48.2097	123.1448
57	1994	7	29	15	48.25507	123.9876
58	2000	4	24	0	48.23152	123.7147
59	1993	10	14	14	48.22433	123.5271
60	1992	1	12	13	48.232	123.7273
61	2003	5	3	16	48.21412	123.2603
62	1995	7	13	7	48.2271	123.5994
63	1998	10	26	18	48.4141	124.5344
64	2003	3	29	13	48.23093	123.6994
65	1993	8	7	14	48.21514	123.287
66	1996	12	18	16	48.22802	123.6234
67	2003	3	11	17	48.23922	123.916
68	1999	2	24	6	48.27987	124.0729
69	1993	7	2	21	48.22791	123.6206
70	2002	6	14	7	48.22212	123.4694
71	1993	1	23	10	48.39468	124.4676
72	2000	11	26	20	48.21262	123.2211
73	1992	10	4	5	48.25719	123.9949
74	1993	11	10	12	48.23956	123.9249
75	1999	7	3	11	48.28352	124.0854
76	2003	12	28	8	48.41305	124.5308
77	1996	8	27	4	48.39962	124.4846
78	2002	7	23	15	48.21898	123.3871
79	2000	12	16	5	48.22886	123.6453
80	1996	2	3	6	48.33045	124.2468
81	1997	3	27	6	48.3782	124.411
82	1998	4	9	1	48.21639	123.3198
83	1992	12	29	0	48.25483	123.9868
84	2002	3	8	0	48.22649	123.5833
85	1996	4	24	20	48.31348	124.1884
86	1995	9	22	21	48.2798	124.0726
87	2000	12	1	4	48.22873	123.6419
88	2001	7	2	0	48.32529	124.229
89	2000	11	30	9	48.27863	124.0686
90	1997	1	1	1	48.28	124.0733
91	1995	9	7	5	48.40139	124.4907
92	2001	10	24	10	48.23219	123.7324
93	1994	9	13	5	48.23891	123.9078
94	1993	12	25	23	48.21067	123.1703
95	1996	11	6	15	48.27063	124.0411
96	1999	7	24	13	48.23011	123.678
97	1997	1	5	11	48.22245	123.478
98	1997	2	20	8	48.22589	123.5678
99	1999	5	6	17	48.25146	123.9752
100	2003	12	11	6	48.41277	124.5298

Table IX.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	S1_S2-COARSE.HAB
Grid W edge	125° 23.40180'W
Grid S edge	47° 48.72180' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^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)	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 IX.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 IX.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 IX.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.

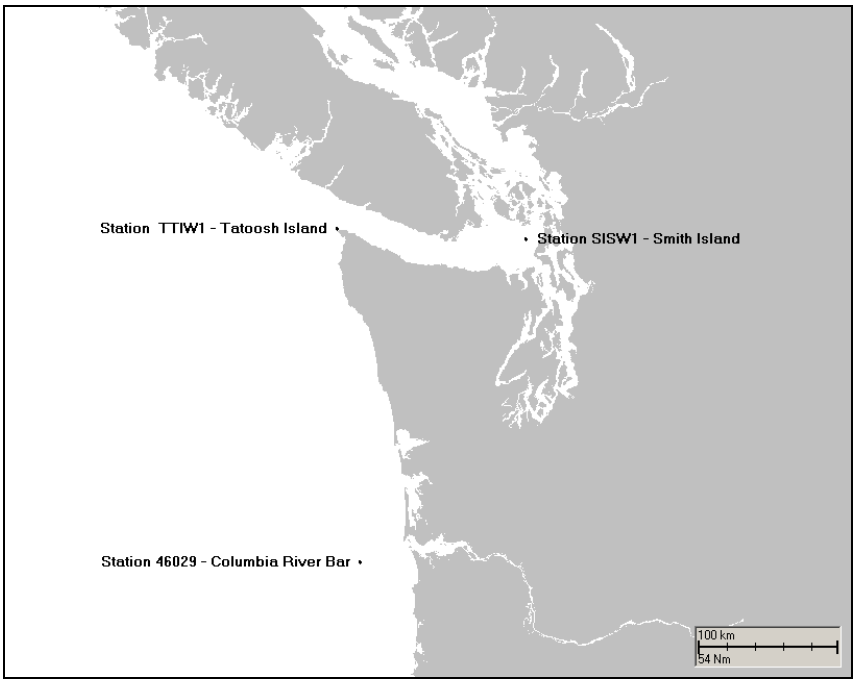


Figure IX.E-2 Wind Station Locations.

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 X: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – Diesel

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

X.A. Introduction 1
X.B. Maps of Exposure Probability and Time First Exposed 1
X.C. Statistics for All Model Runs 4
X.D. Shoreline Areas Exposed by Shore Type 7
X.E. Exposure for Representative Individual Model Runs 9
X.F. Estimated Biological Impacts: Wildlife 13
X.G. Estimated Biological Impacts: Fish and Invertebrates 16
X.H. Estimated NRDA Costs: Habitat Restoration Costs 18
X.I. Estimated NRDA Costs: Washington Compensation schedule 21

List of Figures

Figure X.B-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure X.B-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. 2
Figure X.B-3. Strait of Juan de Fuca – Diesel, No mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill. 3
Figure X.C-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 6
Figure X.C-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill..... 6
Figure X.E-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 10
Figure X.E-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit. 10
Figure X.E-3. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island... 11
Figure X.E-4. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run based on shoreline costs. 11
Figure X.E-5. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run for Dungeness Spit. 12
Figure X.E-6. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run for Protection Island. 12

List of Tables

Table IV.C-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 5
Table X.D-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 7
Table X.D-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 7
Table X.D-3. Strait of Juan de Fuca – Diesel, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 8
Table X.D-4. Strait of Juan de Fuca – Diesel, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 8
Table X.F-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose..... 14
Table X.F-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Wildlife injury (as numbers lost)..... 15
Table IV.G-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column..... 17
Table X.G-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg)..... 17
Table X.H-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 19
Table X.H-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 20
Table X.I-1. Strait of Juan de Fuca – Diesel, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 21

X.A. INTRODUCTION

The results of the stochastic scenario for the Strait of Juan de Fuca – Diesel 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).

X.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)

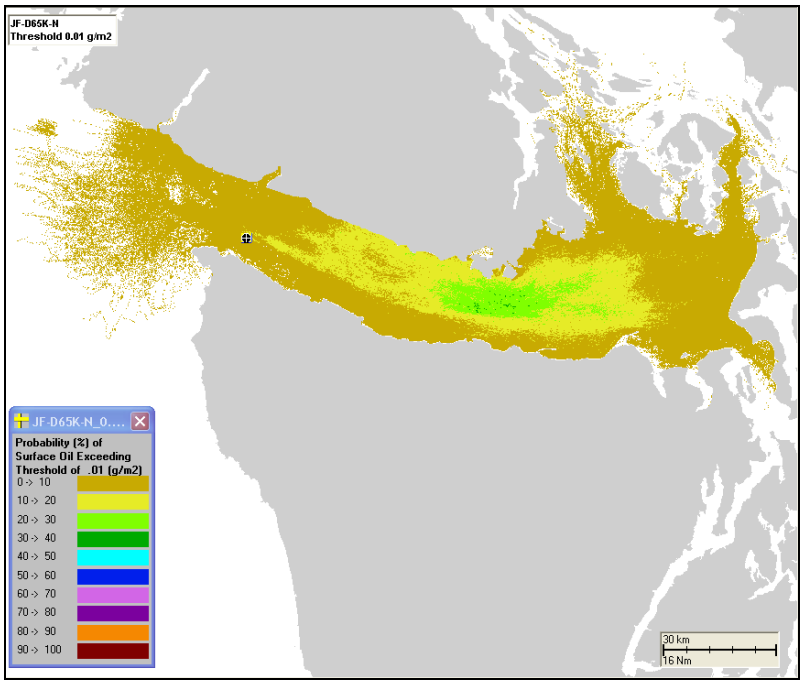


Figure X.B-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

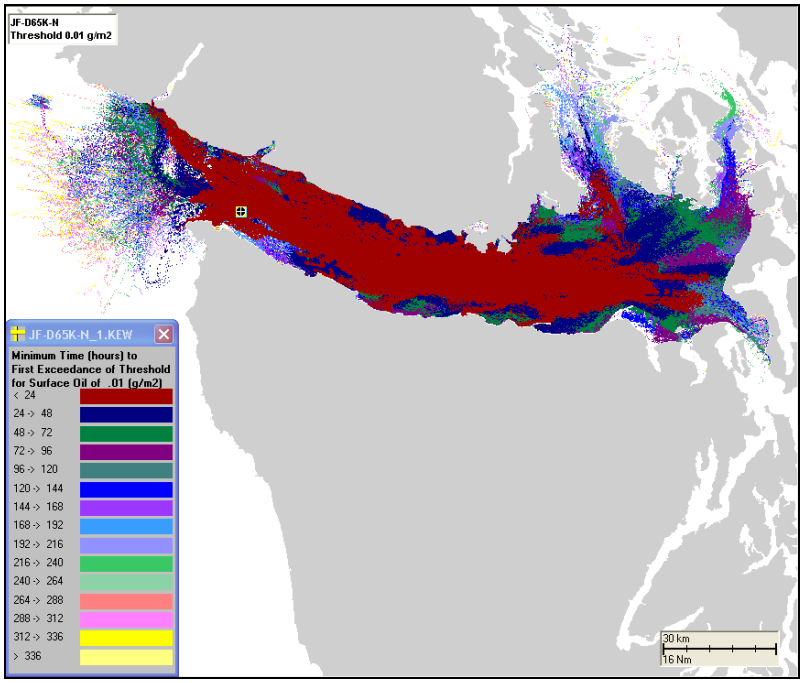


Figure X.B-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

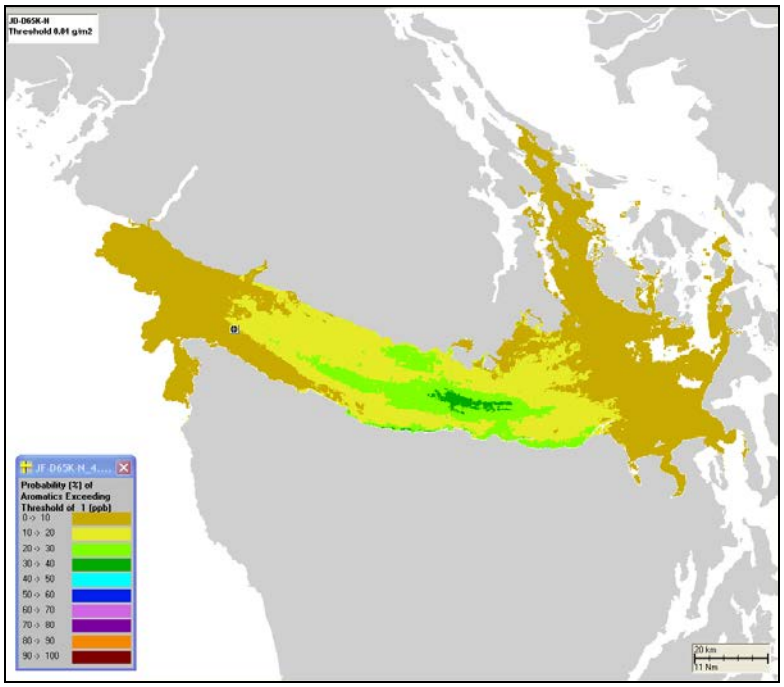


Figure X.B-3. Strait of Juan de Fuca – Diesel, No mechanical removal: Probability (%) of dissolved aromatic concentrations exceeding 1 ppb at any time after a spill.

X.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 and 10 g/m^2 (which is sheen) 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 IV.C-1. Strait of Juan de Fuca – Diesel, 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)	39	25	89	0	35	80	171
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	38	24	86	0	34	78	169
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	3,746	2,396	8,538	0	3,322	7,647	16,405
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	3,740	2,395	8,529	0	3,322	7,641	16,397
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	3,711	2,382	8,475	0	3,317	7,624	16,379
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	3,600	2,338	8,276	0	3,291	7,490	16,220
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	2,552	1,757	6,066	0	2,213	5,338	9,570
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	665	338	1,341	0	657	1,308	1,452
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	2.24E+09	1.26E+09	4.77E+09	0	1.90E+09	4.58E+09	6.51E+09
Average Dose of PAH's in Maximum Volume Exceeding 1 ppb (ppb-hrs)	2,823	1,286	5,395	0	2,540	5,138	6,729
Percent of Spilled Hydrocarbon Mass Coming Ashore (%)	4.21	3.98	12.17	0	3.19	13.76	23.67
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	0.0756	0.5662	1.2080	82	0.0000	0.0148	5.4419
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	44.36	12.94	70.24	0	43.50	67.36	71.93

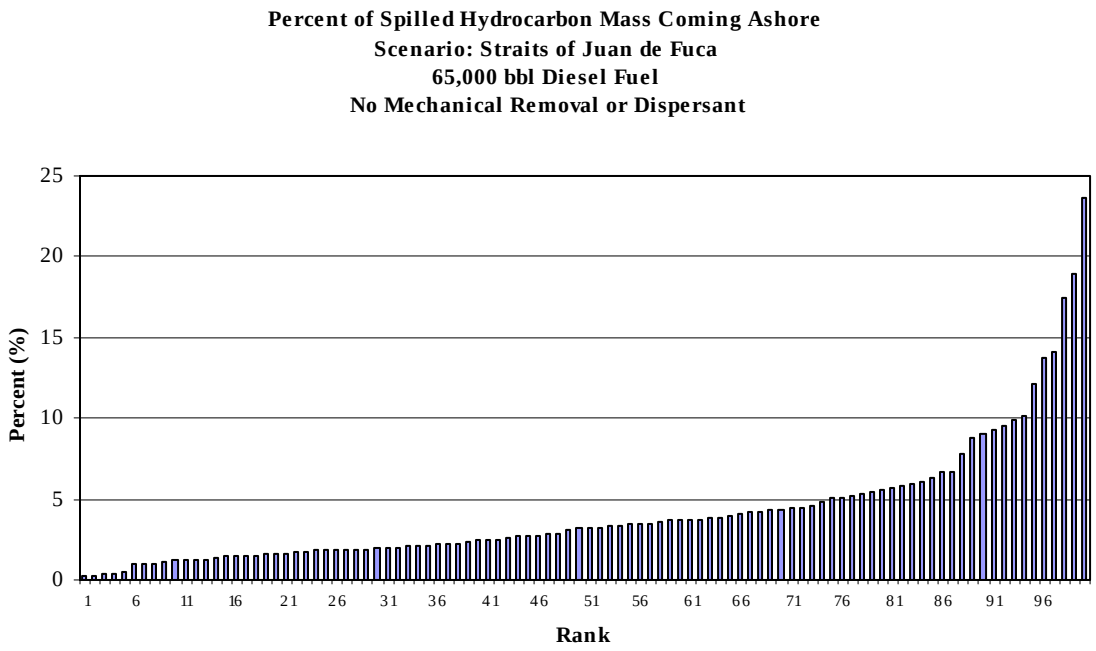


Figure X.C-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

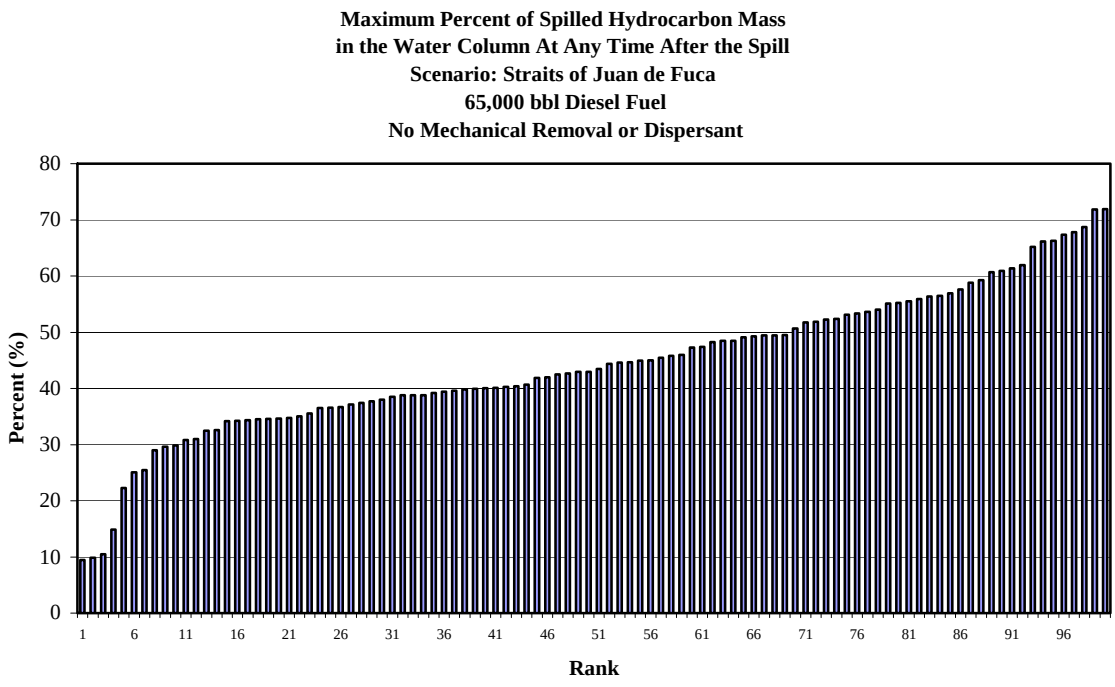


Figure X.C-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

X.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 X.D-1. Strait of Juan de Fuca – Diesel, 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	403,283	105,890	94,625	84,487	39,427	78,854	0
95th	1,518,135	0	174,794	2,816	39,427	1,301,098	0
Maximum	2,441,294	232,058	478,384	337,947	1,143,389	1,301,098	21,403
Mean	553,916	71,059	114,286	55,001	142,332	169,931	1,307
Std. Dev.	470,550	49,817	83,897	60,220	262,004	256,603	3,814
Mean + 2 Std. Dev.	1,495,016	170,693	282,080	175,441	666,340	683,137	8,935

Table X.D-2. Strait of Juan de Fuca – Diesel, 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	321,237	91,809	21,028	115,465	0	78,854	14,081
95th	1,297,343	0	151,138	2,816	0	1,143,389	0
Maximum	2,217,685	231,494	470,499	284,439	1,064,534	1,143,389	18,024
Mean	473,363	68,046	105,941	48,805	109,213	140,361	997
Std. Dev.	413,341	48,448	81,142	54,419	206,576	234,317	3,073
Mean + 2 Std. Dev.	1,300,045	164,942	268,225	157,643	522,365	608,995	7,143

Table X.D-3. Strait of Juan de Fuca – Diesel, 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	207,086	124,477	45,998	36,611	0	0	0
95th	932,922	7,322	170,851	45,060	39,427	670,262	0
Maximum	1,759,579	167,847	310,160	225,298	749,117	985,680	11,265
Mean	307,609	54,167	80,576	32,105	57,564	82,797	400
Std. Dev.	282,906	40,125	67,692	37,258	127,225	170,943	1,602
Mean + 2 Std. Dev.	873,421	134,417	215,960	106,621	312,014	424,683	3,604

Table X.D-4. Strait of Juan de Fuca – Diesel, 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	71,157	6,759	64,398	0	0	0	0
95th	480,073	0	80,169	5,632	394,272	0	0
Maximum	681,902	34,921	269,419	107,017	394,272	512,553	1,126
Mean	123,561	7,784	54,896	16,306	13,405	31,147	23
Std. Dev.	138,895	8,660	55,613	21,896	48,925	91,104	137
Mean + 2 Std. Dev.	401,351	25,104	166,122	60,098	111,255	213,355	297

X.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

In this section, the oil movements for the representative runs are shown, as plots of the following measures of exposure:

- Water surface exposure to floating hydrocarbons (g/m^2) at any time after the spill
- Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill

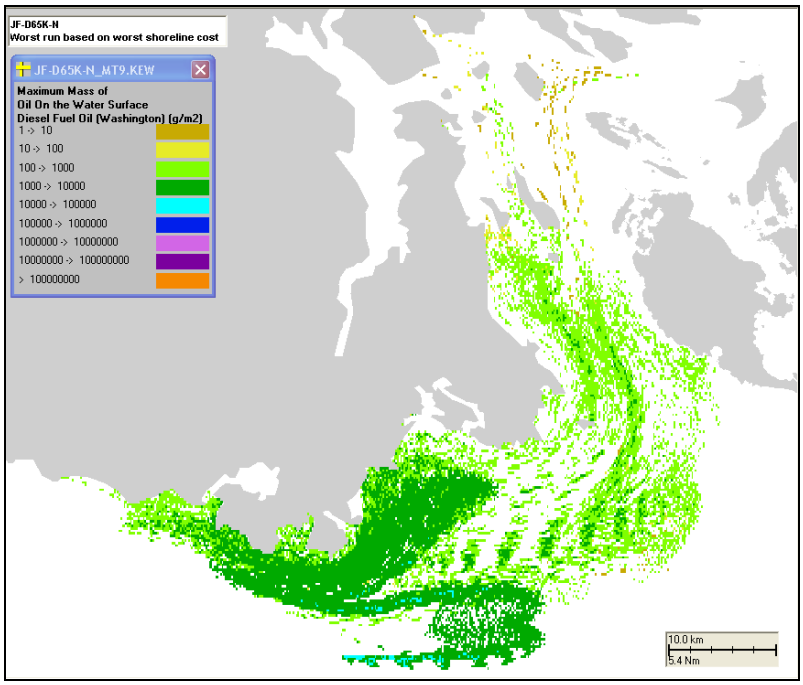


Figure X.E-1. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

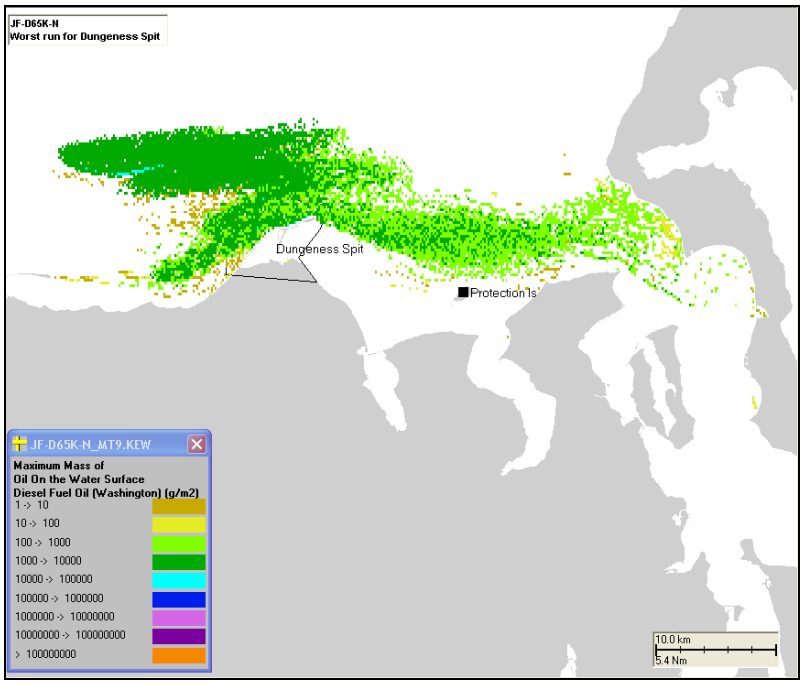


Figure X.E-2. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit.

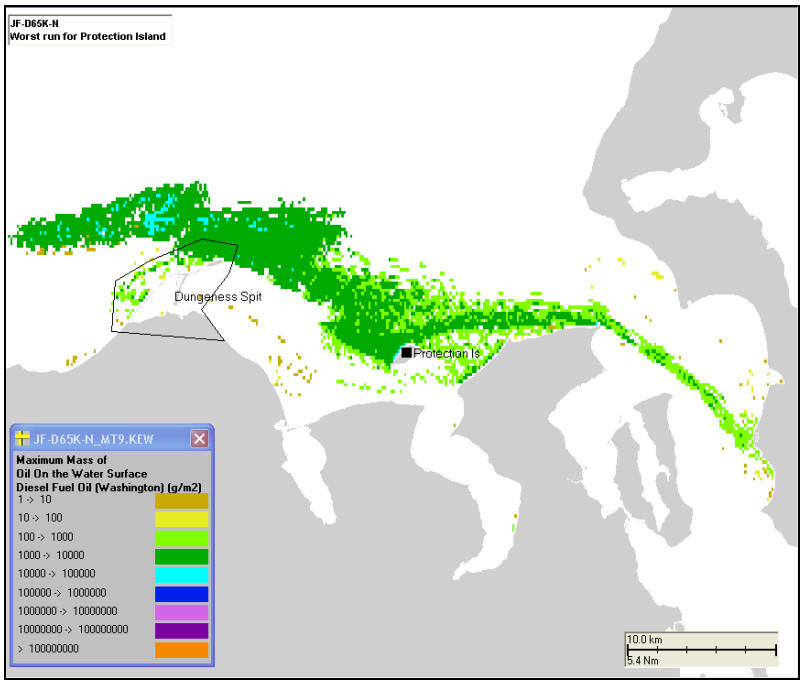


Figure X.E-3. Strait of Juan de Fuca – Diesel, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island.

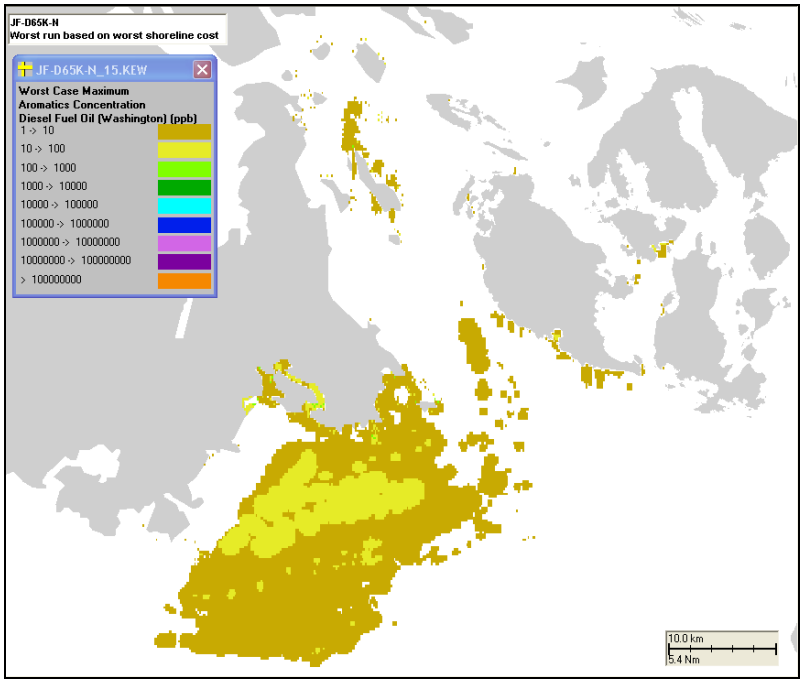


Figure X.E-4. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run based on shoreline costs.

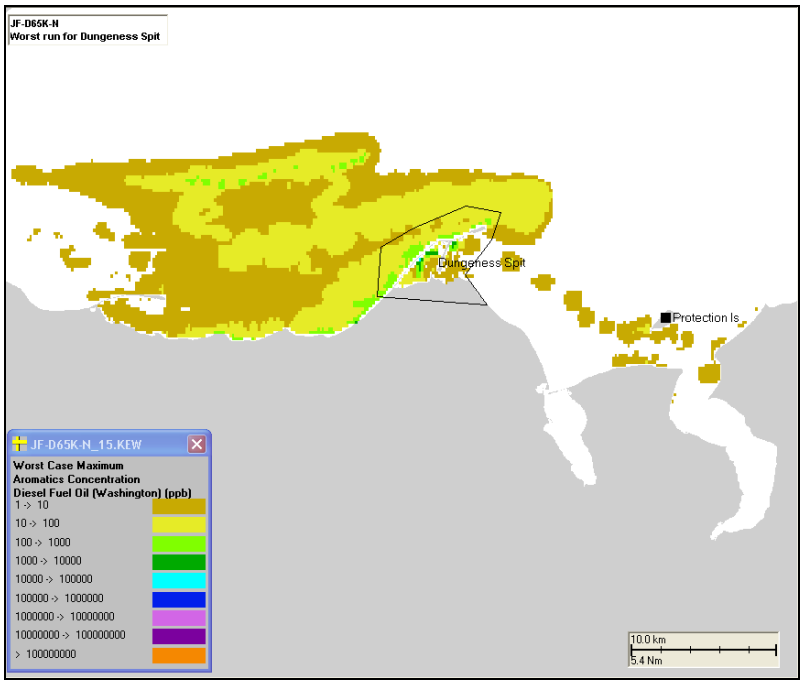


Figure X.E-5. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run for Dungeness Spit.

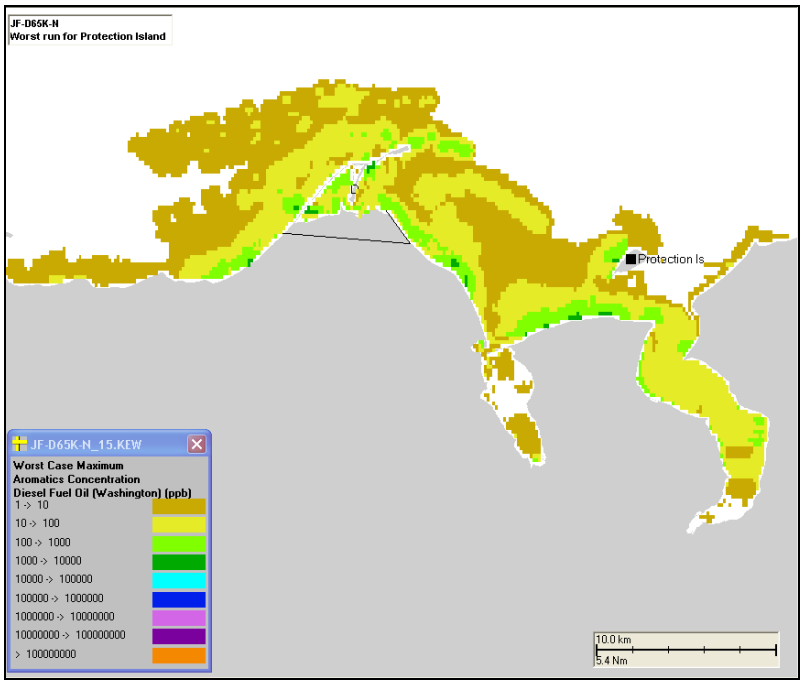


Figure X.E-6. Strait of Juan de Fuca – Diesel, No mechanical removal: Maximum water column exposure of dissolved aromatic concentration (ppb) at some time after the spill for the worst run for Protection Island.

X.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, 50th, and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.
- 5th, 50th, and 95th percentile runs based on water volume exceeding 1 ppb, which is the threshold for affecting fish and invertebrates.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table X.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 X.F-1. Strait of Juan de Fuca – Diesel, 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	2.58E-05	9,139.29	13,308.90	0.22	0.47
Seabirds	2.15E-05	-383.22	3,211.34	0.77	0.88
Wading birds	2.57E-05	-1.23	3.02	0.6827	0.8263
Shorebirds	2.03E-05	7.88	10.83	0.0953	0.3088
Raptors	4.07E-08	0.68	0.73	0.0485	0.2203
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	2.73E-08	2.92	8.52	0.4397	0.6631
Pinnipeds (seals)	9.14E-07	-2.42	152.31	0.7338	0.8566
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 types of wildlife.

Table X.F-2. Strait of Juan de Fuca – Diesel, No 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	13,709	814	0	9	0	0	1	-	14,529	14,528	0.90
50th Percentile	20,590	6,343	3	204	0	0	2	-	27,074	27,072	2.09
95th Percentile	37,575	19,992	17	1,099	0	0	5	-	58,546	58,541	5.03
Mean	22,645	7,995	6	364	0	0	2	-	31,013	31,010	2.45
Std Dev (SD)	7,560	6,075	7	421	0	0	1	-	13,853	13,852	1.31
Mean - 2SD	7,524	-	-	-	0	0	-	-	3,306	3,306	-
Mean + 2SD	37,766	20,145	19	1,206	0	0	5	-	58,720	58,714	5.07

X.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table IV.G-1. Strait of Juan de Fuca – Diesel, 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	6.20E+02	-15,527.95	9,327.51	0.3709	0.6090
Total large pelagic fish	1.78E+03	-45,457.03	24,703.73	0.4088	0.6394
Total demersal fish	2.80E+00	-58.04	140.30	0.0506	0.2249
Total demersal invertebrates	6.88E-02	22.71	35.27	0.0005	0.0225
Total mollusks	1.32E+02	-3,432.45	2,923.96	0.2134	0.4620

[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 X.G-2. Strait of Juan de Fuca – Diesel, 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	7.78	-	11.80	24.42	-	-	44
50th Percentile	11,289.45	31,459.62	63.19	25.68	2,270.45	11,412	56,521
95th Percentile	25,606.32	72,522.75	127.91	27.27	5,315.03	118,054	221,653
Mean	12,348.67	34,553.75	67.42	25.76	2,504.21	28,928	78,428
Std Dev (SD)	7,244.53	20,682.86	33.80	0.89	1,526.24	41,555	71,043
Mean - 2SD	-	-	-	23.98	-	-	24
Mean + 2SD	26,837.73	75,919.46	135.01	27.54	5,556.69	112,038	220,514

X.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 X.H-1. Strait of Juan de Fuca – Diesel, 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	7.8	11,289.4	25,606.3	12,348.7	-	26,837.7
Large pelagic fish	-	31,459.6	72,522.7	34,553.7	-	75,919.5
Demersal fish	11.8	63.2	127.9	67.4	-	135.0
Decapods	24.4	25.7	27.3	25.8	24.0	27.5
Molluscs	-	13,683	123,369	31,433	-	117,594
Birds:						
Waterfowl (# * kg each)	10,613	15,940	29,089	17,531	5,825	29,237
Seabirds (# * kg each)	761	5,931	18,692	7,476	-	18,835
Waders (# * kg each)	0	3	16	5	-	18
Shorebirds (# * kg each)	8	191	1,028	340	-	1,128
Raptors (# * kg each)	0.1	0.1	0.1	0.1	0.1	0.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	0.8	1.9	4.7	2.3	-	4.7
Cetaceans	0.0	0.0	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	44	56,521	221,653	78,428	24	220,514
Subtotal birds	11,383	22,065	48,826	25,353	5,825	49,219
Subtotal other wildlife	1	2	5	2	0	5
Total all species	11,428	78,588	270,484	103,783	5,849	269,738

Table X.H-2. Strait of Juan de Fuca – Diesel, 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)	17.5	153.3	386.1	176.3	110.3	7.0	397.0
Saltmarsh Area (acres)	43.1	378.7	954.1	435.6	272.7	17.4	981.0
Saltmarsh Cost (millions of 2004$)	8.1	71.0	178.8	81.6	51.1	3.2	183.8
Eelgrass Area (m^2)	10.9	95.8	241.3	110.2	69.0	4.4	248.1
Eelgrass Area (acres)	27.0	236.6	596.2	272.2	170.4	10.9	613.0
Eelgrass Cost (millions of 2004$)	3.2	28.2	71.2	32.5	20.3	1.3	73.2

X.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table X.I-1. Strait of Juan de Fuca – Diesel, 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.)	16.47	16.47	17.97	16.79	15.44	18.15
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	45.0	45.0	49.1	45.8	42.1	49.5

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 XI: Results of Alternative Response Scenarios for Strait of Juan de Fuca – Diesel

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

XI.A. Introduction..... 1
XI.B. Oil Fate Over Time 3
XI.C. Estimated Biological Impacts: Wildlife..... 43
XI.D. Estimated Biological Impacts: Fish and Invertebrates 47
XI.E. Estimated NRDA Costs: Habitat Restoration Costs 49
XI.F. Estimated NRDA Costs: Washington Compensation schedule 58

List of Figures

Figure XI.A-1 Sensitive sites for location: Strait of Juan de Fuca. 2
Figure XI.B-1 Strait of Juan de Fuca - Diesel: 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 XI.B-2 Strait of Juan de Fuca - Diesel: 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 XI.B-3 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). 6
Figure XI.B-4 Strait of Juan de Fuca - Diesel: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Dungeness Spit. 7
Figure XI.B-5 Strait of Juan de Fuca - Diesel: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit..... 8
Figure XI.B-6 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit. 9
Figure XI.B-7 Strait of Juan de Fuca - Diesel: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit.. 10
Figure XI.B-8 Strait of Juan de Fuca - Diesel: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island. 11
Figure XI.B-9 Strait of Juan de Fuca - Diesel: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. 12
Figure XI.B-10 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island. 13
Figure XI.B-11 Strait of Juan de Fuca - Diesel: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island. 14

List of Tables

Table XI.B-1 Strait of Juan de Fuca - Diesel, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 15
Table XI.B-2 Strait of Juan de Fuca - Diesel, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost)..... 17
Table XI.B-3 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 19
Table XI.B-4 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 21
Table XI.B-5 Strait of Juan de Fuca - Diesel, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 23
Table XI.B-6 Strait of Juan de Fuca - Diesel, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit..... 25
Table XI.B-7 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 27
Table XI.B-8 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 29
Table XI.B-9 Strait of Juan de Fuca - Diesel, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island. 31
Table XI.B-10 Strait of Juan de Fuca - Diesel, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island. 33
Table XI.B-11 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island..... 35
Table XI.B-12 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island..... 37
Table XI.B-13 Strait of Juan de Fuca - Diesel, 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..... 39
Table XI.B-14 Strait of Juan de Fuca - Diesel, 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..... 40
Table XI.B-15 Strait of Juan de Fuca - Diesel, 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. 41

Table XI.B-16 Strait of Juan de Fuca - Diesel, 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. 42
Table XI.C-1 Strait of Juan de Fuca - Diesel, no removal: Wildlife injury (as numbers lost). 43
Table XI.C-2 Strait of Juan de Fuca - Diesel, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table XI.C-3 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table XI.C-4 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table XI.D-1. Strait of Juan de Fuca - Diesel, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XI.D-2. Strait of Juan de Fuca - Diesel, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XI.D-3. Strait of Juan de Fuca - Diesel, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XI.D-4. Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XI.E-1. Strait of Juan de Fuca - Diesel, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 50
Table XI.E-2. Strait of Juan de Fuca - Diesel, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 51
Table XI.E-3. Strait of Juan de Fuca - Diesel, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 52
Table XI.E-4. Strait of Juan de Fuca - Diesel, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 53
Table XI.E-5. Strait of Juan de Fuca - Diesel, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 54
Table XI.E-6. Strait of Juan de Fuca - Diesel, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 55
Table XI.E-7. Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 56
Table XI.E-8. Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 57
Table XI.F-1. Strait of Juan de Fuca - Diesel, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XI.F-2. Strait of Juan de Fuca - Diesel, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XI.F-3. Strait of Juan de Fuca - Diesel, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58

Table XI.F-4. Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59

XI.A. INTRODUCTION

The results of the alternate response scenarios for the Strait of Juan de Fuca – Diesel 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Locations of the sensitive sites are shown in Figure XI.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.

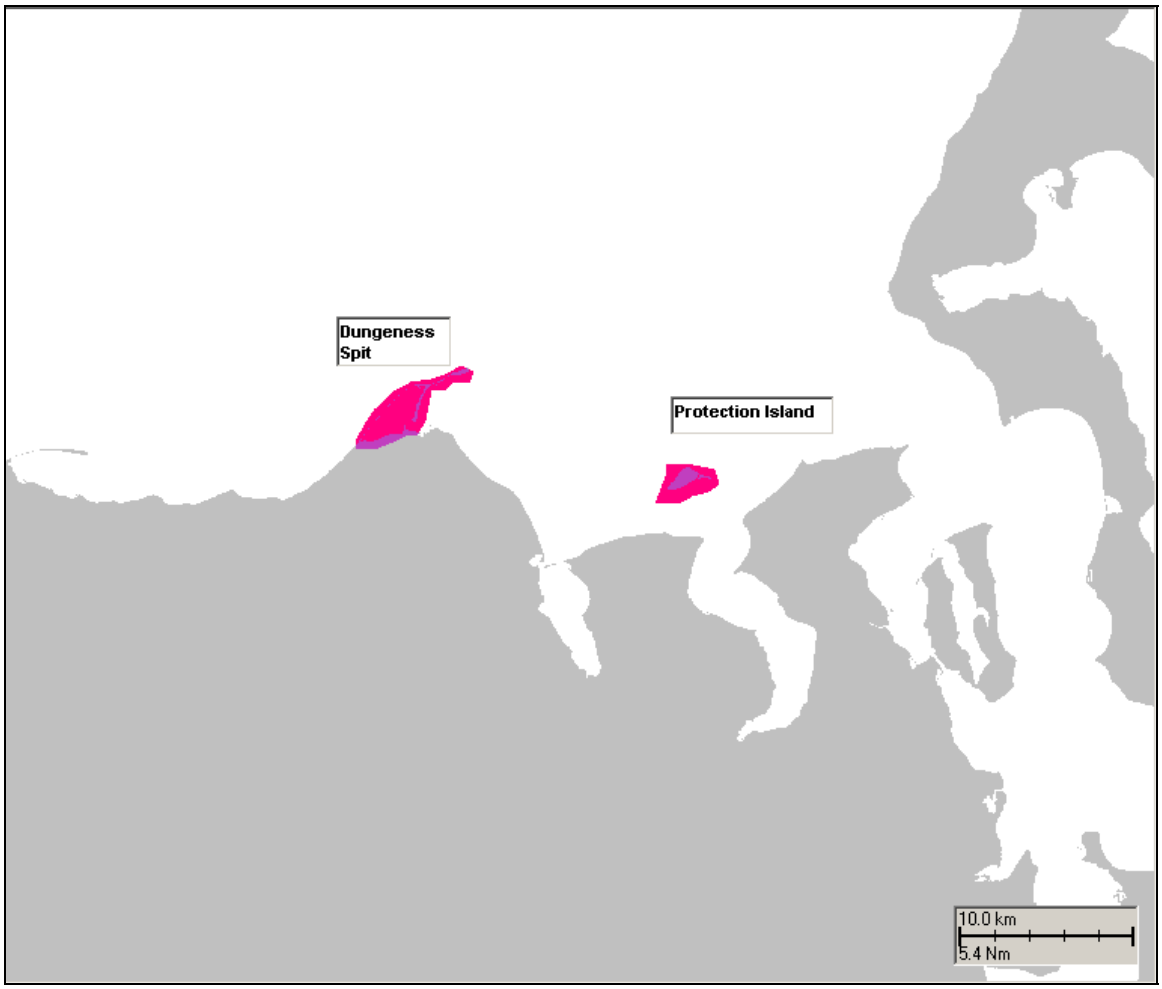
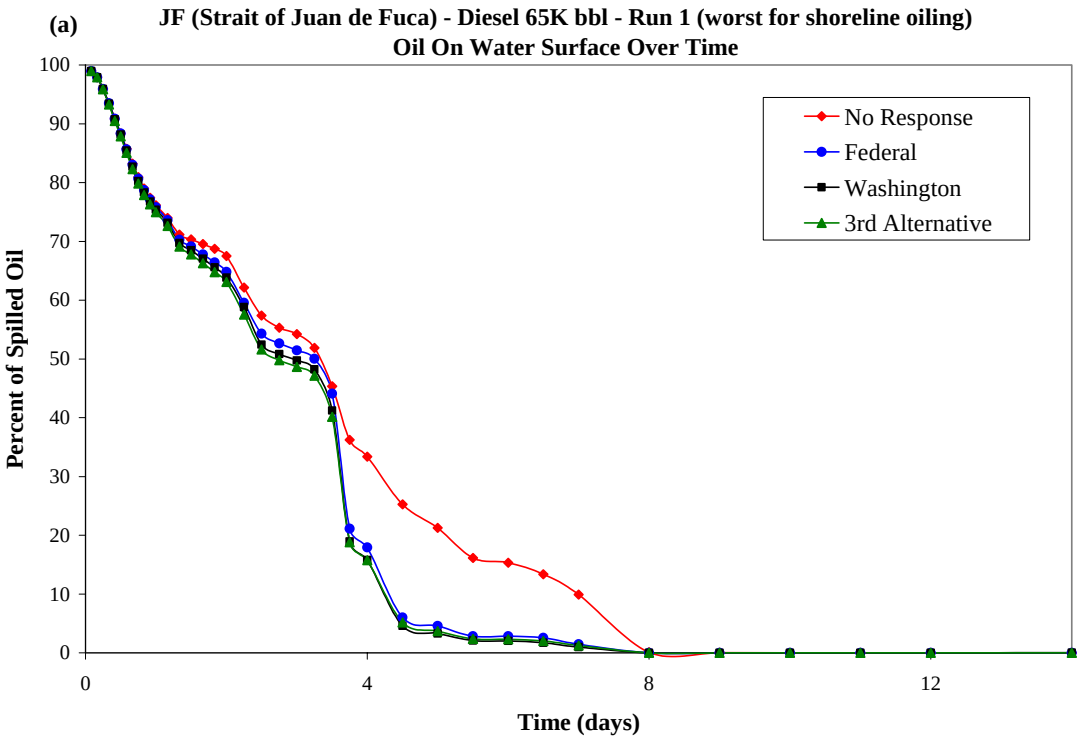


Figure XI.A-1 Sensitive sites for location: Strait of Juan de Fuca.

XI.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XI.B-1 to XI.B-12 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 XI.B-1 to XI.B-11 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 XI.B-13 to XI.B-16 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 Etkin 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.



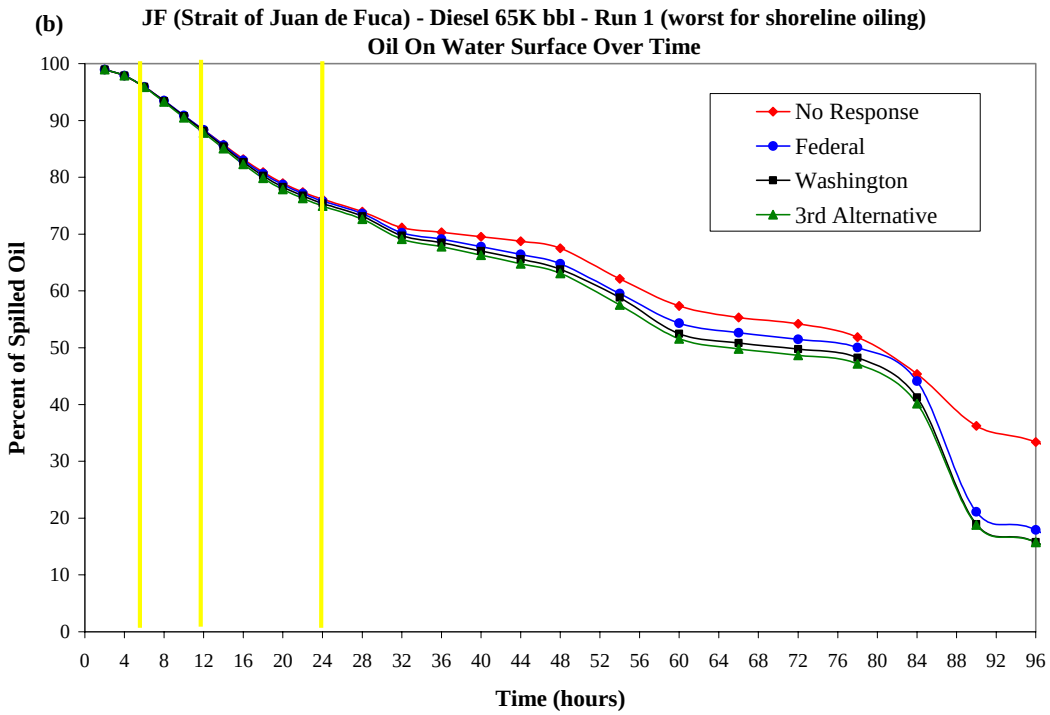


Figure XI.B-1 Strait of Juan de Fuca - Diesel: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.

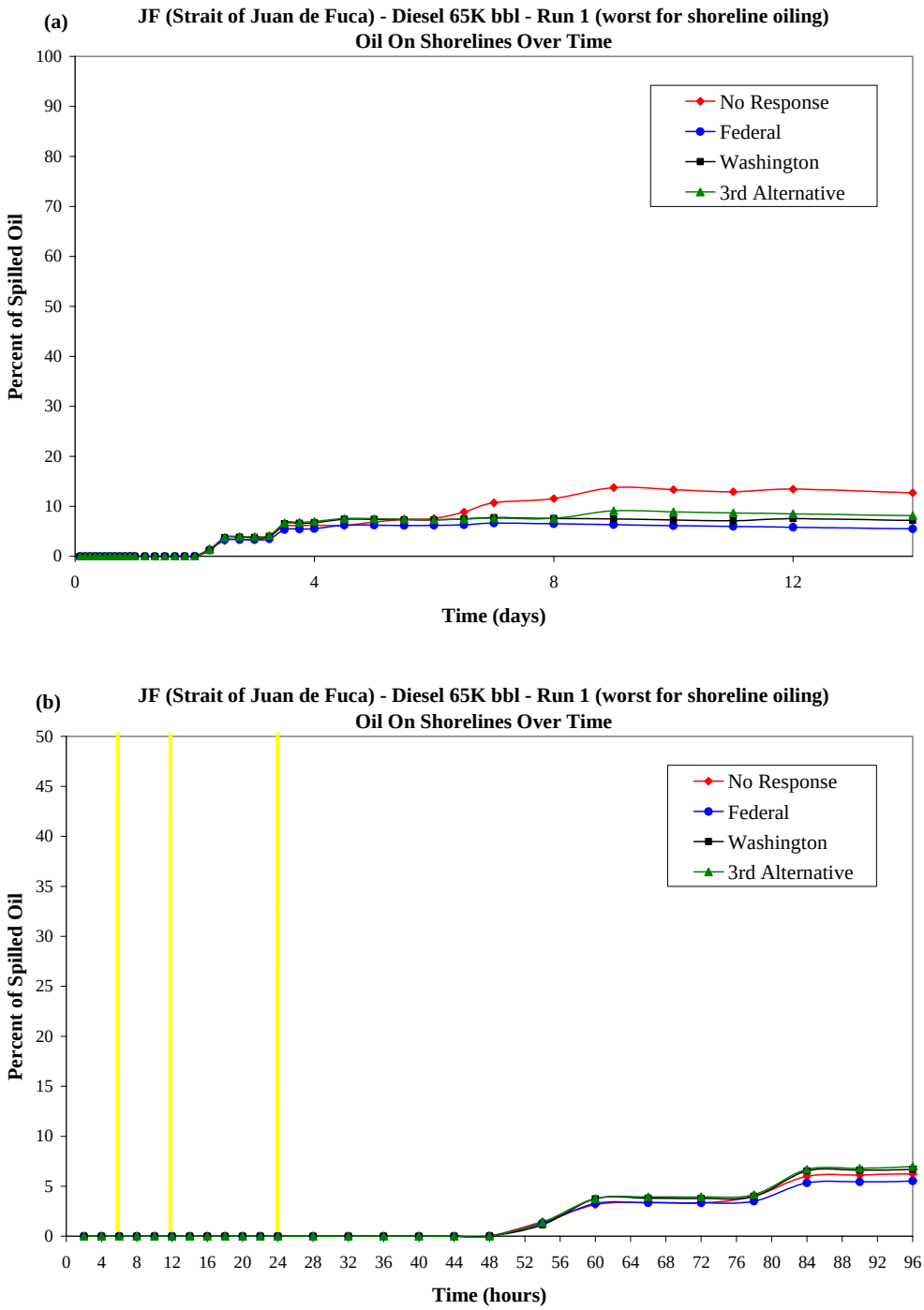
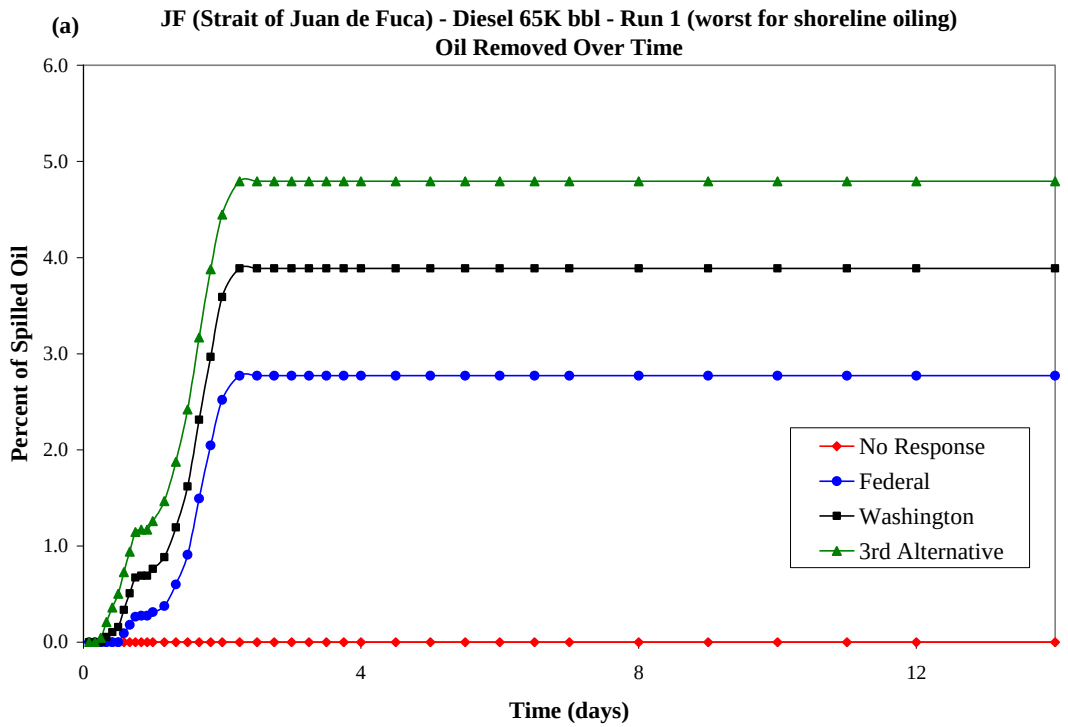


Figure XI.B-2 Strait of Juan de Fuca - Diesel: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



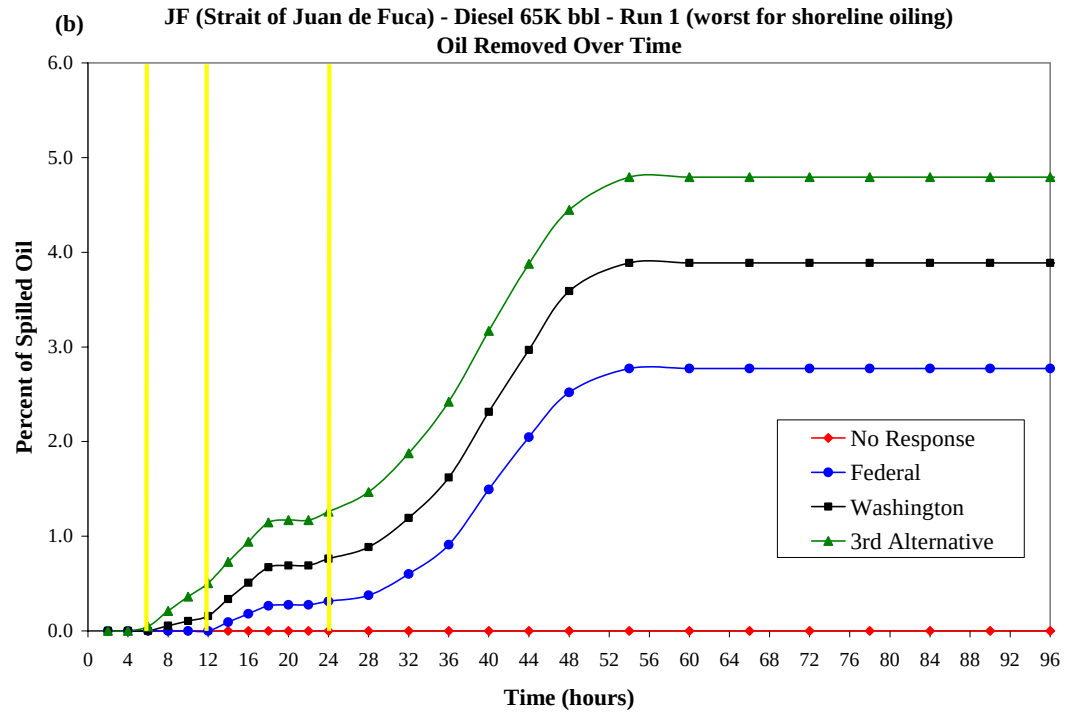
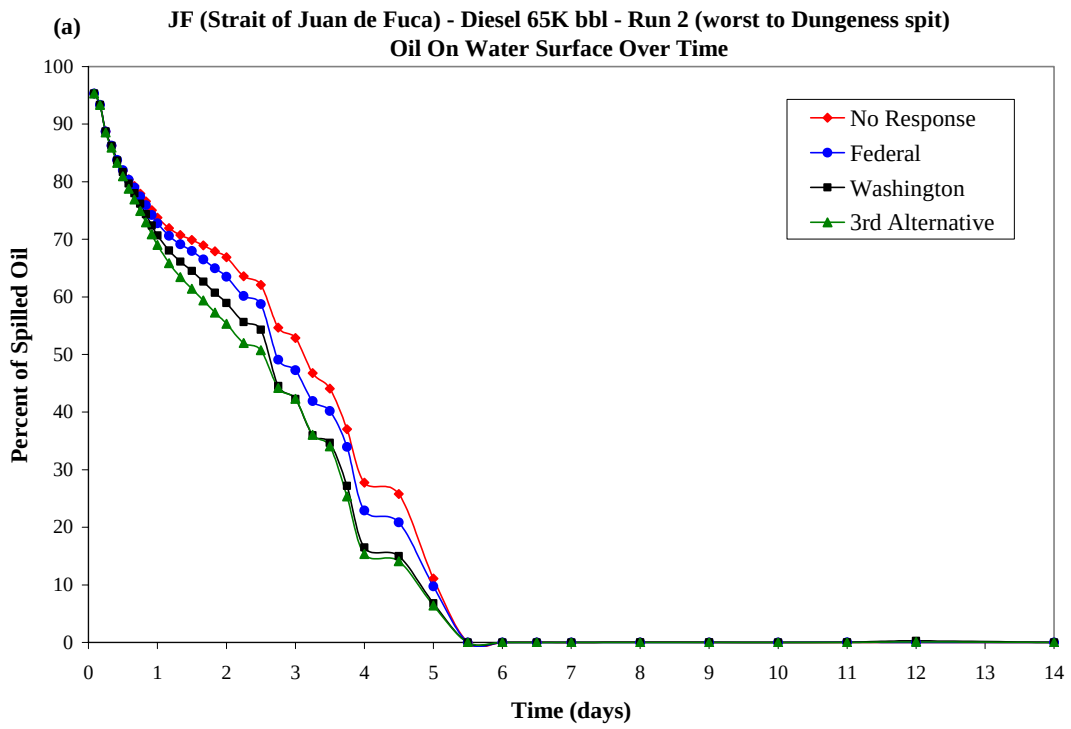


Figure XI.B-3 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



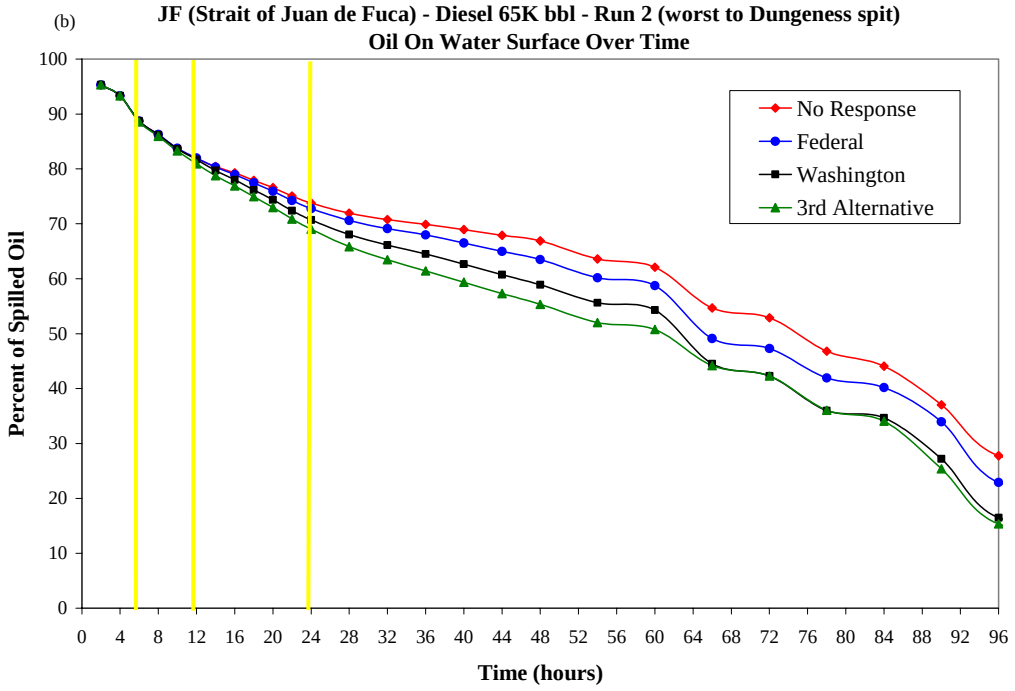
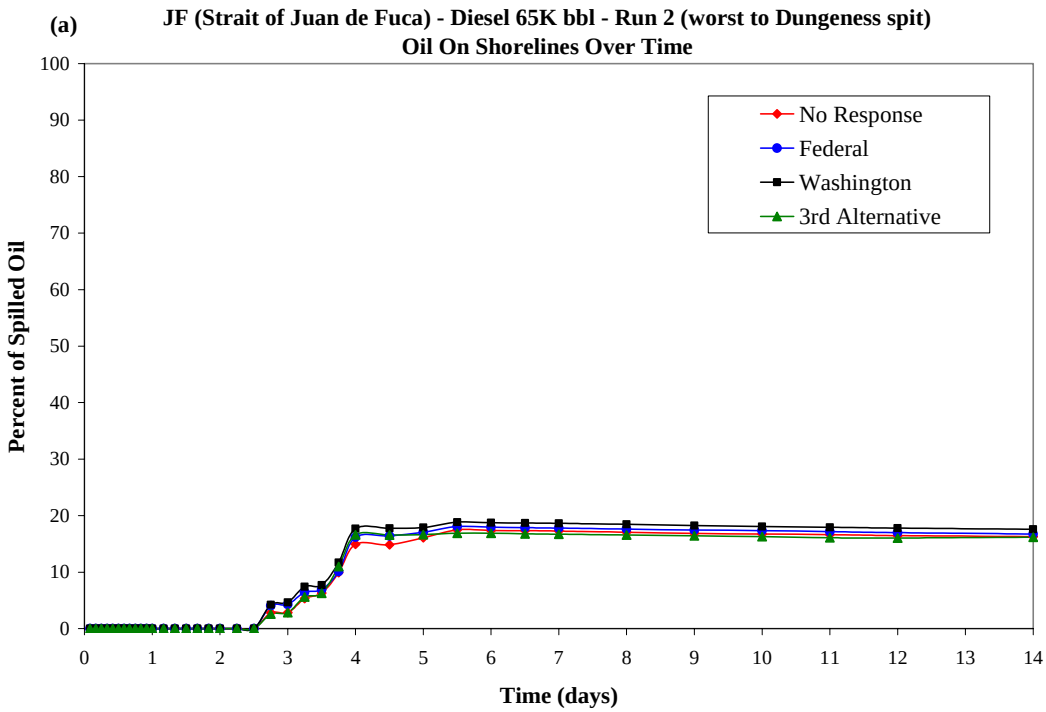


Figure XI.B-4 Strait of Juan de Fuca - Diesel: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a.



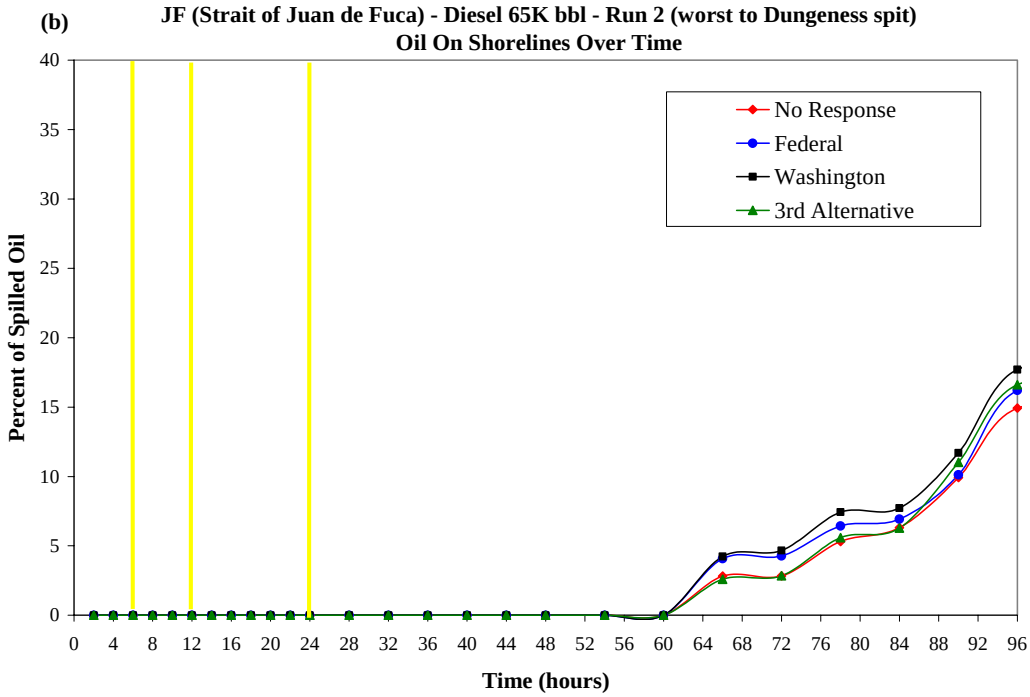
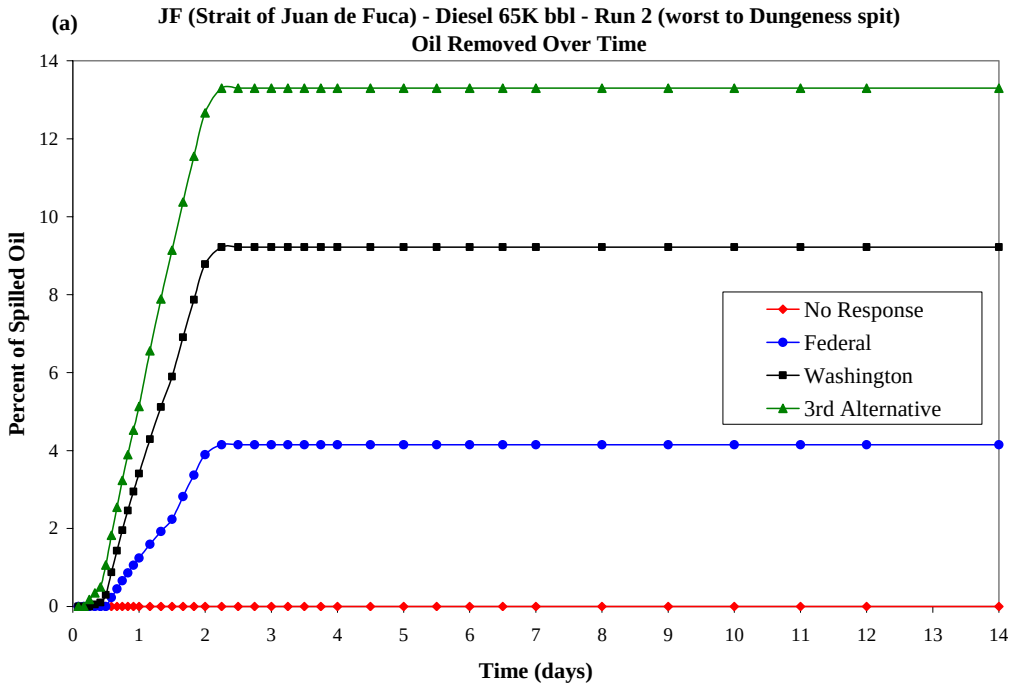


Figure XI.B-5 Strait of Juan de Fuca - Diesel: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



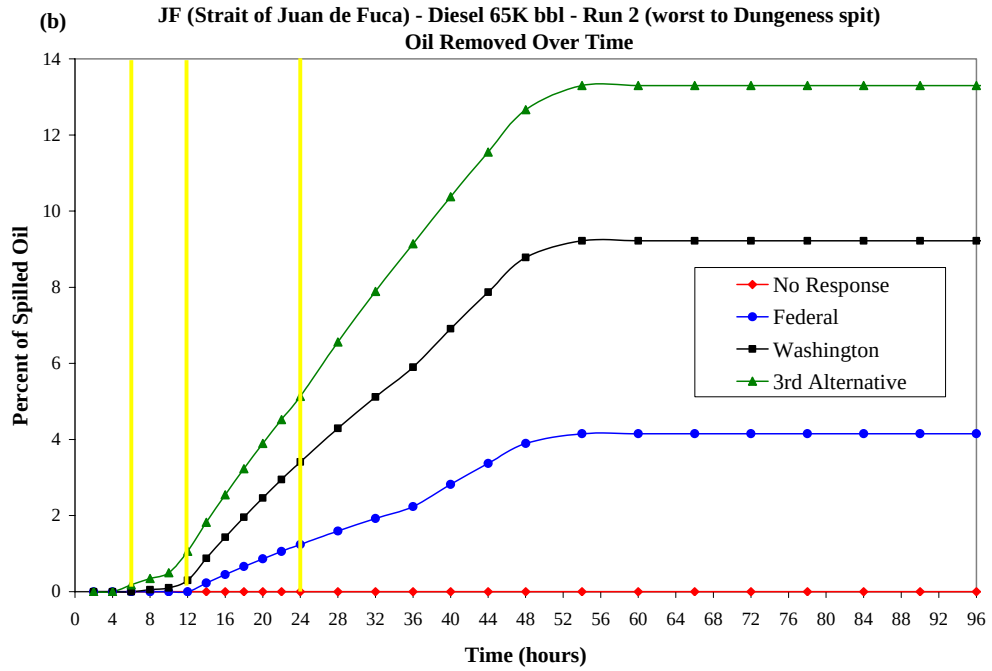
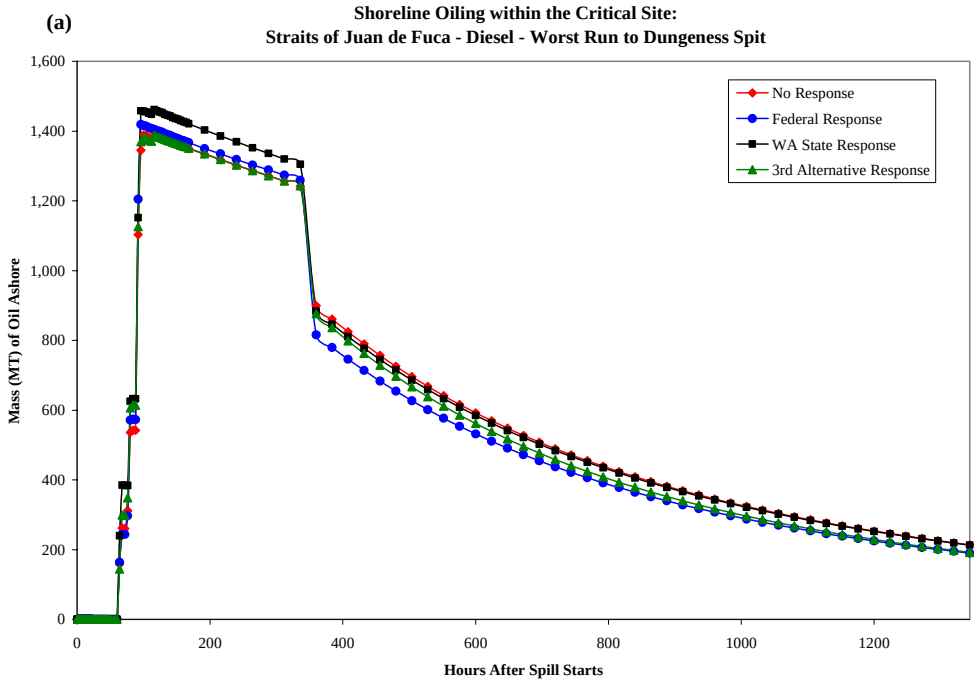


Figure XI.B-6 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a.



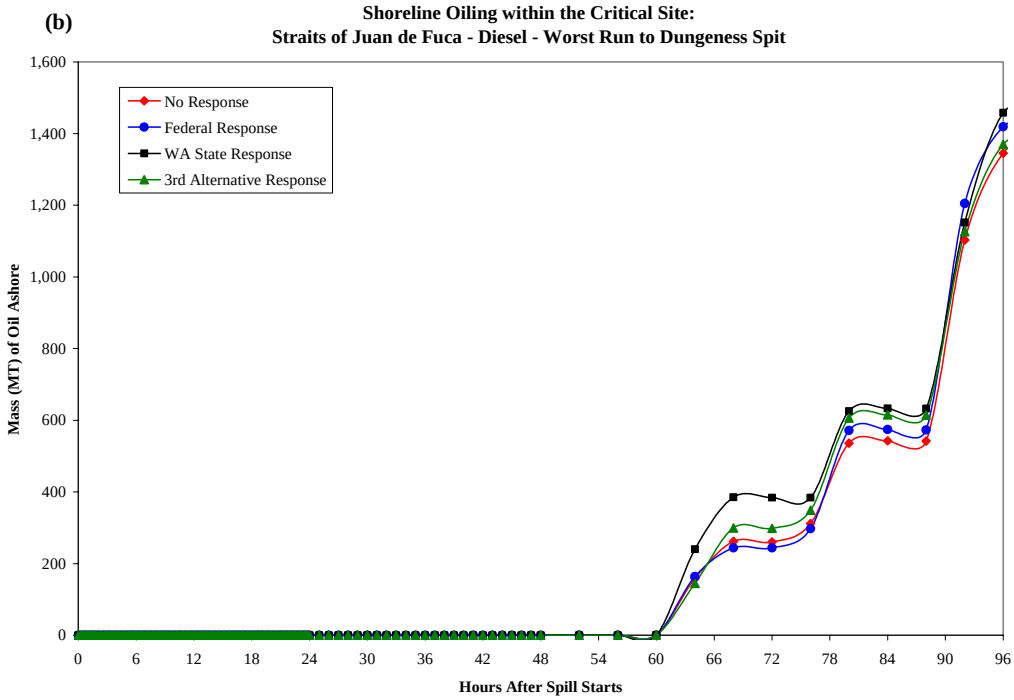


Figure XI.B-7 Strait of Juan de Fuca - Diesel: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

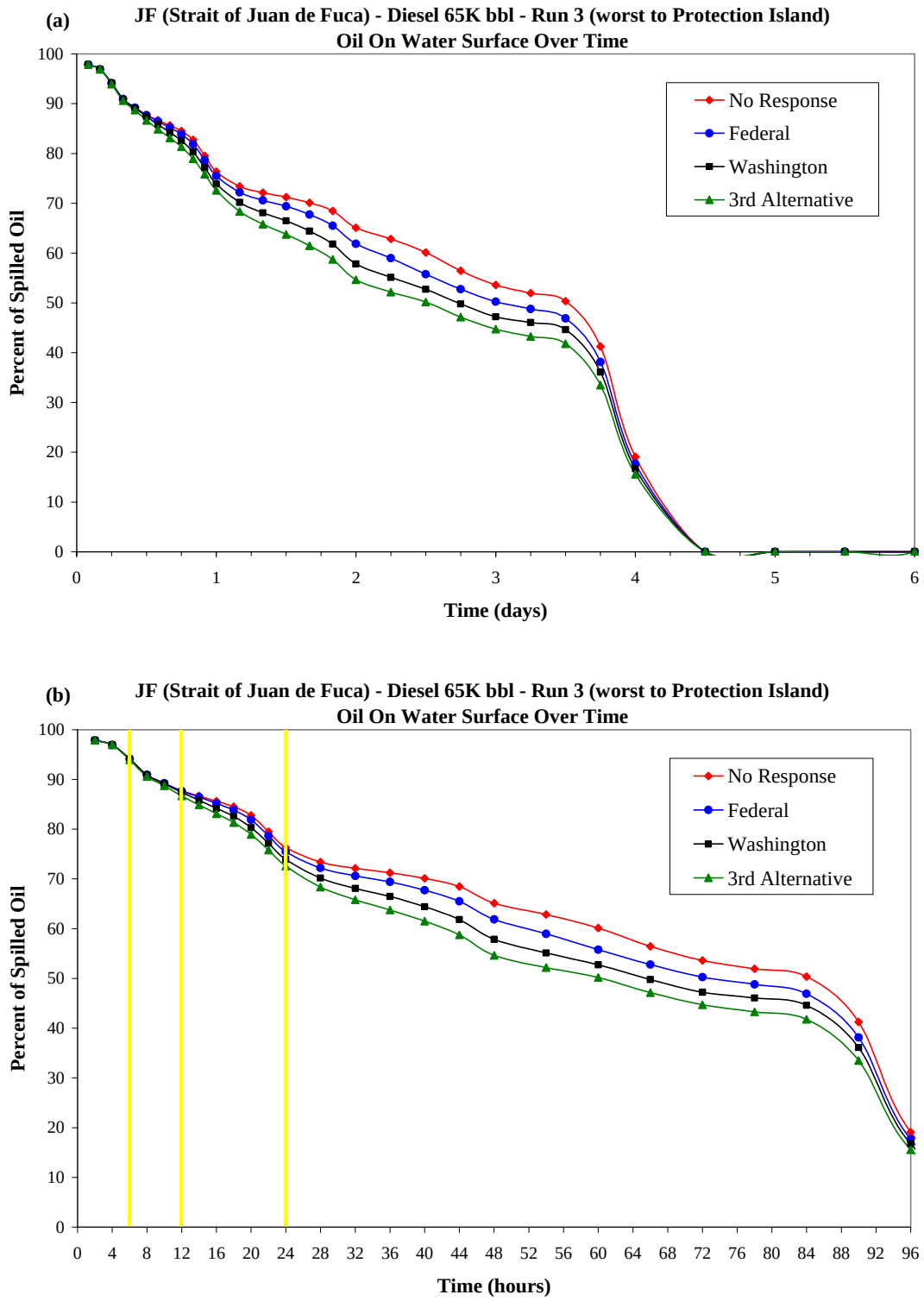
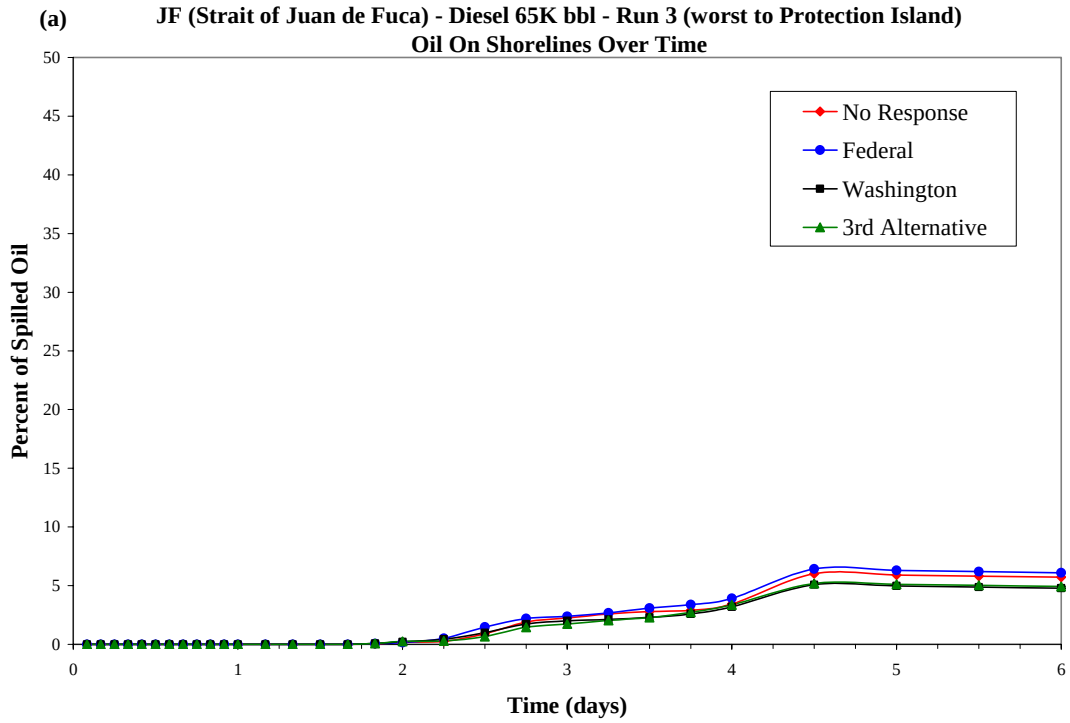


Figure XI.B-8 Strait of Juan de Fuca - Diesel: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island. This model was run for a total of 14 days. Part b of this figure is a subset of Part a.



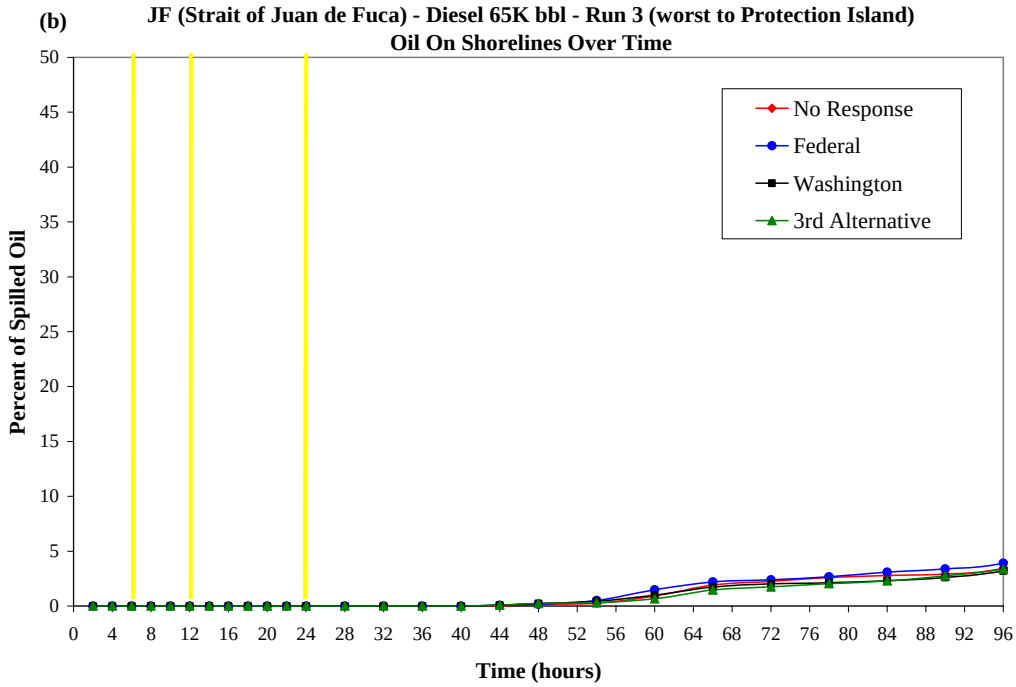


Figure XI.B-9 Strait of Juan de Fuca - Diesel: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. This model was run for a total of 14 days. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

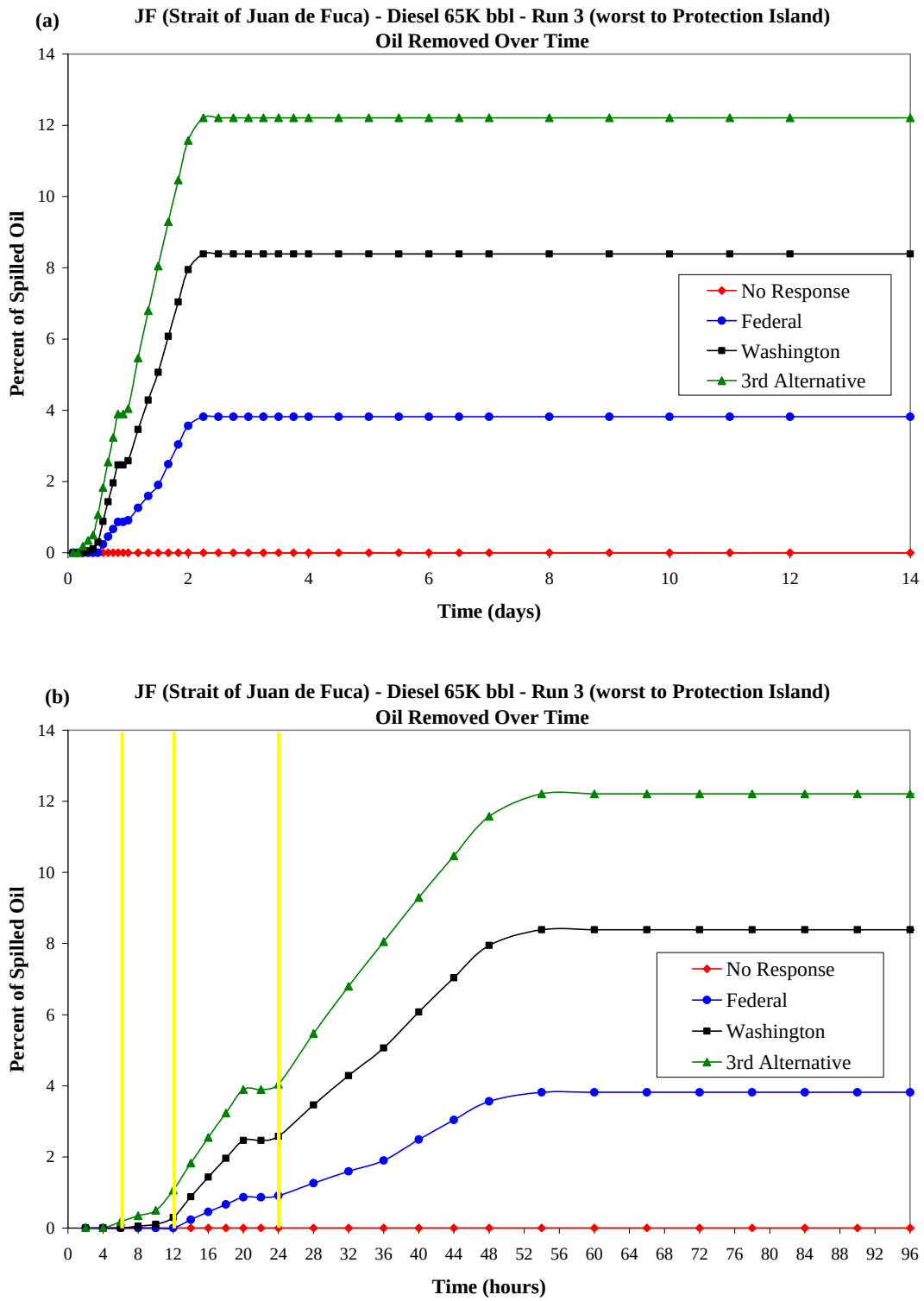


Figure XI.B-10 Strait of Juan de Fuca - Diesel: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a.

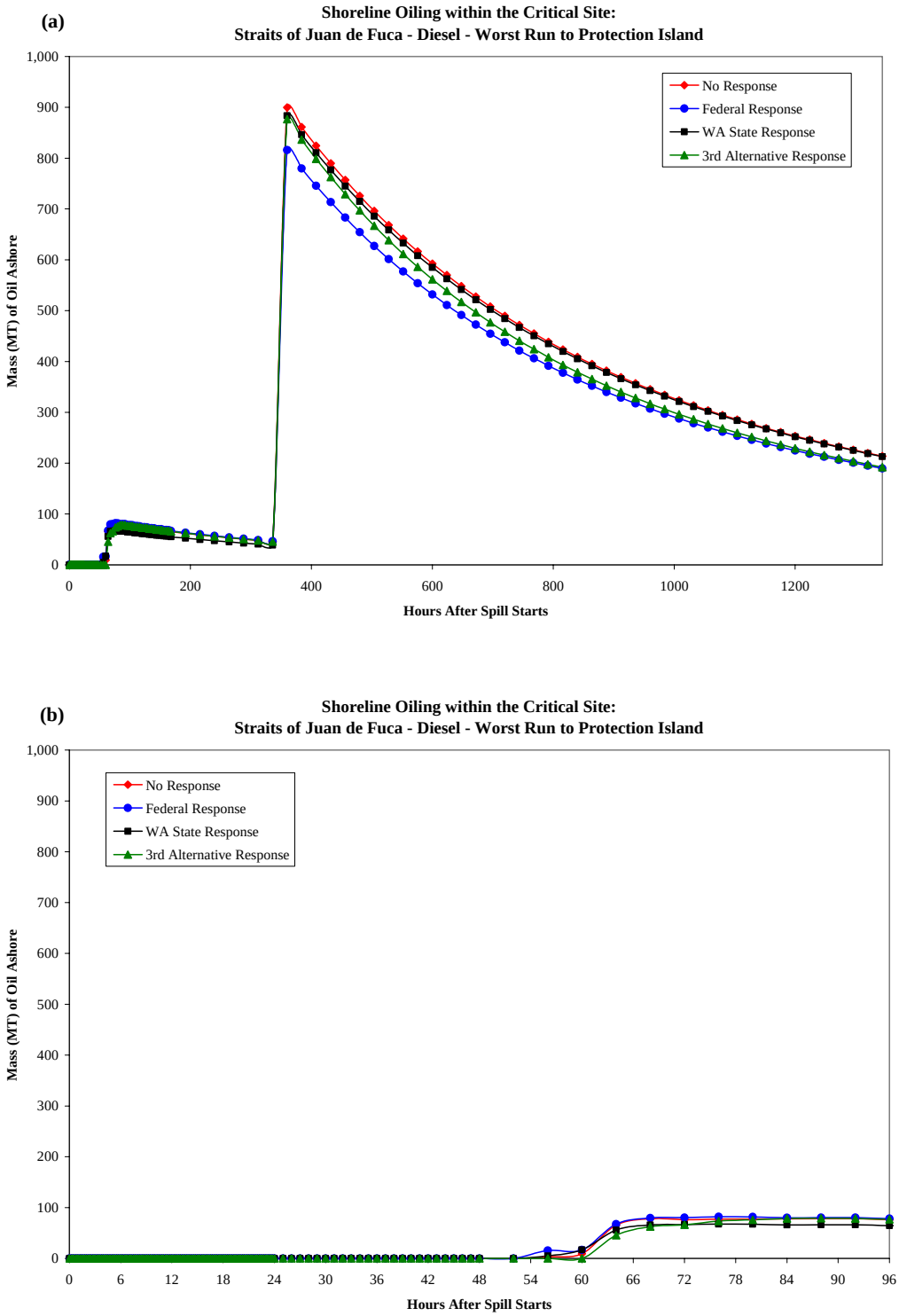


Figure XI.B-11 Strait of Juan de Fuca - Diesel: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

Table XI.B-1 Strait of Juan de Fuca - Diesel, 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	98.94	1.02	0.00	0.00	0.00	0.05	0.00	0.00	98.94
4	0.17	97.88	2.03	0.00	0.00	0.00	0.09	0.00	0.00	97.88
6	0.25	95.92	3.91	0.00	0.00	0.00	0.17	0.00	0.00	95.92
8	0.33	93.48	6.28	0.00	0.00	0.00	0.25	0.00	0.00	93.48
10	0.42	90.84	8.83	0.00	0.00	0.00	0.32	0.00	0.00	90.84
12	0.50	88.32	11.27	0.01	0.00	0.00	0.40	0.00	0.00	88.32
14	0.58	85.75	13.77	0.01	0.00	0.00	0.47	0.00	0.00	85.75
16	0.67	83.18	16.27	0.02	0.00	0.00	0.54	0.00	0.00	83.18
18	0.75	80.91	18.46	0.02	0.00	0.00	0.61	0.00	0.00	80.91
20	0.83	78.97	20.33	0.02	0.00	0.00	0.68	0.00	0.00	78.97
22	0.92	77.39	21.84	0.03	0.00	0.00	0.74	0.00	0.00	77.39
24	1.00	76.11	23.06	0.03	0.00	0.00	0.80	0.00	0.00	76.11
28	1.17	73.97	25.07	0.04	0.00	0.00	0.93	0.00	0.00	73.97
32	1.33	71.14	27.18	0.63	0.00	0.00	1.05	0.00	0.00	71.14
36	1.50	70.32	27.88	0.63	0.00	0.00	1.17	0.00	0.00	70.32
40	1.67	69.54	28.55	0.63	0.00	0.00	1.29	0.00	0.00	69.54
44	1.83	68.72	29.25	0.63	0.00	0.00	1.40	0.00	0.00	68.72
48	2.00	67.51	30.31	0.63	0.00	0.03	1.52	0.00	0.00	67.51
54	2.25	62.12	33.84	0.90	0.00	1.46	1.68	0.00	0.00	62.12
60	2.50	57.37	36.69	0.95	0.00	3.15	1.84	0.00	0.00	57.37
66	2.75	55.32	38.35	0.96	0.00	3.38	1.99	0.00	0.00	55.32
72	3.00	54.21	39.31	1.01	0.00	3.33	2.14	0.00	0.00	54.21
78	3.25	51.86	40.95	0.90	0.00	4.01	2.28	0.00	0.00	51.86
84	3.50	45.37	44.13	2.07	0.00	6.00	2.42	0.00	0.00	45.37
90	3.75	36.23	47.28	7.81	0.00	6.13	2.55	0.00	0.00	36.23

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	33.39	49.16	8.55	0.00	6.22	2.67	0.00	0.00	33.39
108	4.50	25.25	52.89	12.81	0.00	6.15	2.90	0.00	0.00	25.25
120	5.00	21.26	55.47	13.29	0.00	6.86	3.12	0.00	0.00	21.26
132	5.50	16.13	57.05	16.10	0.00	7.39	3.32	0.00	0.00	16.13
144	6.00	15.33	57.60	15.98	0.00	7.58	3.52	0.00	0.00	15.33
156	6.50	13.39	58.05	16.01	0.00	8.85	3.71	0.00	0.00	13.39
168	7.00	9.92	58.40	17.08	0.00	10.70	3.90	0.00	0.00	9.92
192	8.00	0.12	58.58	25.49	0.00	11.54	4.27	0.00	0.00	0.12
216	9.00	0.02	58.71	22.87	0.00	13.76	4.64	0.00	0.00	0.02
240	10.00	0.00	58.72	22.94	0.00	13.34	5.01	0.00	0.00	0.00
264	11.00	0.00	58.73	22.97	0.00	12.94	5.37	0.00	0.00	0.00
288	12.00	0.00	58.76	22.08	0.00	13.44	5.72	0.00	0.00	0.00
336	14.00	0.01	58.85	21.99	0.00	12.73	6.43	0.00	0.00	0.01
Maximum	14.00	99.14	58.85	25.49	0.00	13.76	6.43	0.00	0.00	99.14

Table XI.B-2 Strait of Juan de Fuca - Diesel, 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	98.94	1.02	0.00	0.00	0.00	0.05	0.00	0.00	98.94
4	0.17	97.88	2.03	0.00	0.00	0.00	0.09	0.00	0.00	97.88
6	0.25	95.92	3.91	0.00	0.00	0.00	0.17	0.00	0.00	95.92
8	0.33	93.48	6.27	0.00	0.00	0.00	0.25	0.00	0.00	93.48
10	0.42	90.84	8.83	0.00	0.00	0.00	0.32	0.00	0.00	90.84
12	0.50	88.33	11.27	0.01	0.00	0.00	0.40	0.00	0.00	88.33
14	0.58	85.66	13.77	0.01	0.00	0.00	0.47	0.09	0.00	85.66
16	0.67	83.00	16.27	0.01	0.00	0.00	0.54	0.18	0.00	83.00
18	0.75	80.65	18.46	0.02	0.00	0.00	0.61	0.27	0.00	80.65
20	0.83	78.70	20.33	0.02	0.00	0.00	0.67	0.28	0.00	78.70
22	0.92	77.12	21.83	0.03	0.00	0.00	0.74	0.28	0.00	77.12
24	1.00	75.80	23.05	0.03	0.00	0.00	0.80	0.31	0.00	75.80
28	1.17	73.60	25.06	0.04	0.00	0.00	0.93	0.38	0.00	73.60
32	1.33	70.25	27.17	0.93	0.00	0.00	1.05	0.60	0.00	70.25
36	1.50	69.13	27.86	0.93	0.00	0.00	1.17	0.91	0.00	69.13
40	1.67	67.77	28.53	0.92	0.00	0.00	1.28	1.49	0.00	67.77
44	1.83	66.41	29.22	0.92	0.00	0.00	1.40	2.05	0.00	66.41
48	2.00	64.79	30.25	0.92	0.00	0.02	1.51	2.52	0.00	64.79
54	2.25	59.53	33.55	1.19	0.00	1.29	1.67	2.77	0.00	59.53
60	2.50	54.29	36.60	1.24	0.00	3.28	1.82	2.77	0.00	54.29
66	2.75	52.64	38.05	1.25	0.00	3.34	1.96	2.77	0.00	52.64
72	3.00	51.46	39.02	1.30	0.00	3.34	2.10	2.77	0.00	51.46
78	3.25	50.02	40.16	1.30	0.00	3.50	2.24	2.77	0.00	50.02
84	3.50	44.11	43.19	2.22	0.00	5.33	2.38	2.77	0.00	44.11
90	3.75	21.12	46.68	21.48	0.00	5.45	2.50	2.77	0.00	21.12
96	4.00	17.92	48.65	22.51	0.00	5.53	2.62	2.77	0.00	17.92

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	6.02	51.01	31.12	0.00	6.25	2.84	2.77	0.00	6.02
120	5.00	4.57	51.68	31.70	0.00	6.23	3.05	2.77	0.00	4.57
132	5.50	2.84	51.91	33.04	0.00	6.17	3.26	2.77	0.00	2.84
144	6.00	2.83	52.02	32.72	0.00	6.18	3.47	2.77	0.00	2.83
156	6.50	2.56	52.05	32.62	0.00	6.32	3.68	2.77	0.00	2.56
168	7.00	1.45	52.07	33.15	0.00	6.67	3.89	2.77	0.00	1.45
192	8.00	0.01	52.08	34.31	0.00	6.52	4.30	2.77	0.00	0.01
216	9.00	0.00	52.10	34.09	0.00	6.34	4.71	2.77	0.00	0.00
240	10.00	0.02	52.11	33.85	0.00	6.14	5.11	2.77	0.00	0.02
264	11.00	0.00	52.14	33.60	0.00	5.98	5.51	2.77	0.00	0.00
288	12.00	0.00	52.14	33.37	0.01	5.81	5.90	2.77	0.00	0.00
336	14.00	0.00	52.18	32.88	0.00	5.48	6.68	2.77	0.00	0.00
Maximum	14.00	99.13	52.18	34.31	0.01	6.67	6.68	2.77	0.00	99.13

Table XI.B-3 Strait of Juan de Fuca - Diesel, 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	98.94	1.02	0.00	0.00	0.00	0.05	0.00	0.00	98.94
4	0.17	97.88	2.03	0.00	0.00	0.00	0.09	0.00	0.00	97.88
6	0.25	95.92	3.91	0.00	0.00	0.00	0.17	0.00	0.00	95.92
8	0.33	93.42	6.27	0.00	0.00	0.00	0.25	0.05	0.00	93.42
10	0.42	90.74	8.83	0.00	0.00	0.00	0.32	0.11	0.00	90.74
12	0.50	88.17	11.27	0.01	0.00	0.00	0.40	0.16	0.00	88.17
14	0.58	85.42	13.77	0.01	0.00	0.00	0.47	0.34	0.00	85.42
16	0.67	82.68	16.26	0.01	0.00	0.00	0.54	0.51	0.00	82.68
18	0.75	80.26	18.44	0.02	0.00	0.00	0.61	0.67	0.00	80.26
20	0.83	78.30	20.31	0.02	0.00	0.00	0.67	0.69	0.00	78.30
22	0.92	76.74	21.81	0.03	0.00	0.00	0.74	0.69	0.00	76.74
24	1.00	75.38	23.02	0.03	0.00	0.00	0.80	0.76	0.00	75.38
28	1.17	73.13	25.02	0.04	0.00	0.00	0.93	0.88	0.00	73.13
32	1.33	69.72	27.12	0.92	0.00	0.00	1.05	1.19	0.00	69.72
36	1.50	68.49	27.81	0.92	0.00	0.00	1.16	1.62	0.00	68.49
40	1.67	67.03	28.47	0.92	0.00	0.00	1.28	2.31	0.00	67.03
44	1.83	65.58	29.15	0.91	0.00	0.00	1.39	2.97	0.00	65.58
48	2.00	63.81	30.17	0.91	0.00	0.02	1.50	3.59	0.00	63.81
54	2.25	58.82	33.32	1.18	0.00	1.14	1.65	3.89	0.00	58.82
60	2.50	52.45	36.90	1.22	0.00	3.74	1.80	3.89	0.00	52.45
66	2.75	50.83	38.31	1.22	0.00	3.80	1.94	3.89	0.00	50.83
72	3.00	49.74	39.24	1.27	0.00	3.78	2.08	3.89	0.00	49.74
78	3.25	48.24	40.39	1.27	0.00	3.99	2.22	3.89	0.00	48.24
84	3.50	41.23	43.88	2.13	0.00	6.53	2.35	3.89	0.00	41.23
90	3.75	18.95	47.29	20.79	0.00	6.62	2.47	3.89	0.00	18.95

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
96	4.00	15.78	49.23	21.81	0.00	6.71	2.58	3.89	0.00	15.78
108	4.50	4.60	51.27	30.02	0.00	7.42	2.79	3.89	0.00	4.60
120	5.00	3.30	51.73	30.69	0.00	7.38	3.00	3.89	0.00	3.30
132	5.50	2.12	51.91	31.54	0.00	7.33	3.21	3.89	0.00	2.12
144	6.00	2.03	51.93	31.44	0.00	7.29	3.41	3.89	0.00	2.03
156	6.50	1.70	51.96	31.33	0.00	7.50	3.62	3.89	0.00	1.70
168	7.00	0.98	51.98	31.62	0.00	7.72	3.82	3.89	0.00	0.98
192	8.00	0.00	51.99	32.32	0.00	7.58	4.22	3.89	0.00	0.00
216	9.00	0.00	52.01	32.00	0.00	7.49	4.62	3.89	0.00	0.00
240	10.00	0.00	52.02	31.78	0.00	7.30	5.01	3.89	0.00	0.00
264	11.00	0.00	52.06	31.54	0.00	7.12	5.40	3.89	0.00	0.00
288	12.00	0.00	52.36	30.46	0.00	7.51	5.78	3.89	0.00	0.00
336	14.00	0.00	52.38	29.97	0.00	7.18	6.53	3.89	0.05	0.05
Maximum	14.00	99.13	52.38	32.32	0.00	7.72	6.53	3.89	0.05	99.13

Table XI.B-4 Strait of Juan de Fuca - Diesel, 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	98.94	1.02	0.00	0.00	0.00	0.05	0.00	0.00	98.94
4	0.17	97.88	2.03	0.00	0.00	0.00	0.09	0.00	0.00	97.88
6	0.25	95.87	3.91	0.00	0.00	0.00	0.17	0.05	0.00	95.87
8	0.33	93.27	6.27	0.00	0.00	0.00	0.25	0.21	0.00	93.27
10	0.42	90.49	8.83	0.00	0.00	0.00	0.32	0.36	0.00	90.49
12	0.50	87.83	11.26	0.01	0.00	0.00	0.40	0.50	0.00	87.83
14	0.58	85.04	13.75	0.01	0.00	0.00	0.47	0.73	0.00	85.04
16	0.67	82.27	16.23	0.01	0.00	0.00	0.54	0.94	0.00	82.27
18	0.75	79.82	18.41	0.02	0.00	0.00	0.61	1.15	0.00	79.82
20	0.83	77.86	20.27	0.02	0.00	0.00	0.67	1.17	0.00	77.86
22	0.92	76.30	21.76	0.03	0.00	0.00	0.74	1.17	0.00	76.30
24	1.00	74.94	22.97	0.03	0.00	0.00	0.80	1.26	0.00	74.94
28	1.17	72.61	24.96	0.04	0.00	0.00	0.92	1.47	0.00	72.61
32	1.33	69.12	27.05	0.92	0.00	0.00	1.04	1.88	0.00	69.12
36	1.50	67.78	27.73	0.91	0.00	0.00	1.16	2.42	0.00	67.78
40	1.67	66.27	28.38	0.91	0.00	0.00	1.27	3.17	0.00	66.27
44	1.83	64.77	29.06	0.91	0.00	0.00	1.38	3.88	0.00	64.77
48	2.00	63.09	30.06	0.91	0.00	0.01	1.49	4.45	0.00	63.09
54	2.25	57.54	33.45	1.18	0.00	1.39	1.64	4.79	0.00	57.54
60	2.50	51.58	36.83	1.23	0.00	3.77	1.79	4.79	0.00	51.58
66	2.75	49.78	38.32	1.23	0.00	3.94	1.93	4.79	0.00	49.78
72	3.00	48.66	39.26	1.29	0.00	3.93	2.06	4.79	0.00	48.66
78	3.25	47.15	40.42	1.28	0.00	4.16	2.20	4.79	0.00	47.15
84	3.50	40.15	43.89	2.15	0.00	6.69	2.32	4.79	0.00	40.15
90	3.75	18.82	47.12	20.03	0.00	6.80	2.44	4.79	0.00	18.82

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	15.75	48.96	20.99	0.00	6.96	2.55	4.79	0.00	15.75
108	4.50	5.17	50.99	28.72	0.00	7.56	2.76	4.79	0.00	5.17
120	5.00	3.70	51.48	29.55	0.00	7.51	2.97	4.79	0.00	3.70
132	5.50	2.37	51.66	30.59	0.00	7.42	3.17	4.79	0.00	2.37
144	6.00	2.31	51.68	30.50	0.00	7.33	3.37	4.79	0.00	2.31
156	6.50	2.04	51.70	30.42	0.00	7.47	3.57	4.79	0.00	2.04
168	7.00	1.25	51.71	30.84	0.00	7.64	3.77	4.79	0.00	1.25
192	8.00	0.01	51.71	31.71	0.00	7.60	4.17	4.79	0.00	0.01
216	9.00	0.00	52.67	28.87	0.00	9.10	4.56	4.79	0.00	0.00
240	10.00	0.00	52.68	28.71	0.00	8.88	4.93	4.79	0.00	0.00
264	11.00	0.00	52.83	28.37	0.00	8.69	5.31	4.79	0.00	0.00
288	12.00	0.00	52.84	28.18	0.01	8.49	5.68	4.79	0.00	0.00
336	14.00	0.00	52.91	27.77	0.00	8.11	6.42	4.79	0.00	0.00
Maximum	14.00	99.13	52.91	31.71	0.01	9.10	6.42	4.79	0.00	99.13

Table XI.B-5 Strait of Juan de Fuca - Diesel, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	95.26	3.53	1.16	0.00	0.00	0.05	0.00	0.00	95.26
4	0.17	93.33	5.07	1.52	0.00	0.00	0.08	0.00	0.00	93.33
6	0.25	88.71	8.71	2.43	0.00	0.00	0.16	0.00	0.00	88.71
8	0.33	86.23	11.05	2.48	0.00	0.00	0.24	0.00	0.00	86.23
10	0.42	83.68	13.52	2.49	0.00	0.00	0.31	0.00	0.00	83.68
12	0.50	81.87	15.27	2.48	0.00	0.00	0.38	0.00	0.00	81.87
14	0.58	80.43	16.65	2.47	0.00	0.00	0.45	0.00	0.00	80.43
16	0.67	79.27	17.74	2.47	0.00	0.00	0.52	0.00	0.00	79.27
18	0.75	77.93	19.03	2.46	0.00	0.00	0.59	0.00	0.00	77.93
20	0.83	76.58	20.31	2.46	0.00	0.00	0.65	0.00	0.00	76.58
22	0.92	75.06	21.76	2.46	0.00	0.00	0.72	0.00	0.00	75.06
24	1.00	73.77	22.98	2.47	0.00	0.00	0.78	0.00	0.00	73.77
28	1.17	71.92	24.71	2.47	0.00	0.00	0.91	0.00	0.00	71.92
32	1.33	70.76	25.75	2.46	0.00	0.00	1.03	0.00	0.00	70.76
36	1.50	69.89	26.52	2.44	0.00	0.00	1.15	0.00	0.00	69.89
40	1.67	68.96	27.34	2.43	0.00	0.00	1.27	0.00	0.00	68.96
44	1.83	67.90	28.29	2.42	0.00	0.00	1.39	0.00	0.00	67.90
48	2.00	66.87	29.20	2.42	0.00	0.00	1.51	0.00	0.00	66.87
54	2.25	63.60	31.34	3.38	0.00	0.00	1.68	0.00	0.00	63.60
60	2.50	62.08	32.73	3.34	0.00	0.00	1.84	0.00	0.00	62.08
66	2.75	54.67	37.02	3.50	0.00	2.81	2.00	0.00	0.00	54.67
72	3.00	52.88	38.62	3.51	0.00	2.84	2.15	0.00	0.00	52.88
78	3.25	46.79	42.10	3.50	0.00	5.31	2.29	0.00	0.00	46.79
84	3.50	44.07	43.69	3.50	0.00	6.30	2.43	0.00	0.00	44.07
90	3.75	37.05	46.98	3.48	0.00	9.93	2.56	0.00	0.00	37.05
96	4.00	27.75	51.17	3.46	0.00	14.93	2.68	0.00	0.00	27.75

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	25.78	52.98	3.48	0.00	14.85	2.91	0.00	0.00	25.78
120	5.00	11.11	55.72	13.97	0.00	16.08	3.12	0.00	0.00	11.11
132	5.50	0.00	56.92	22.28	0.00	17.48	3.32	0.00	0.00	0.00
144	6.00	0.00	56.95	22.15	0.00	17.37	3.52	0.00	0.00	0.00
156	6.50	0.04	57.00	21.88	0.00	17.35	3.72	0.00	0.00	0.04
168	7.00	0.00	57.04	21.77	0.00	17.28	3.91	0.00	0.00	0.00
192	8.00	0.03	57.05	21.57	0.00	17.05	4.30	0.00	0.00	0.03
216	9.00	0.00	57.09	21.37	0.00	16.85	4.69	0.00	0.00	0.00
240	10.00	0.00	57.17	21.03	0.00	16.73	5.07	0.00	0.00	0.00
264	11.00	0.01	57.24	20.67	0.00	16.63	5.44	0.00	0.00	0.01
288	12.00	0.00	57.28	20.43	0.00	16.48	5.81	0.00	0.00	0.00
336	14.00	0.00	57.42	19.75	0.00	16.29	6.54	0.00	0.00	0.00
Maximum	14.00	96.58	57.42	22.28	0.00	17.48	6.54	0.00	0.00	96.58

Table XI.B-6 Strait of Juan de Fuca - Diesel, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	95.31	3.50	1.14	0.00	0.00	0.05	0.00	0.00	95.31
4	0.17	93.33	5.07	1.52	0.00	0.00	0.08	0.00	0.00	93.33
6	0.25	88.72	8.70	2.42	0.00	0.00	0.16	0.00	0.00	88.72
8	0.33	86.27	11.03	2.46	0.00	0.00	0.24	0.00	0.00	86.27
10	0.42	83.76	13.46	2.46	0.00	0.00	0.31	0.00	0.00	83.76
12	0.50	81.98	15.18	2.46	0.00	0.00	0.38	0.00	0.00	81.98
14	0.58	80.33	16.54	2.45	0.00	0.00	0.45	0.23	0.00	80.33
16	0.67	78.97	17.61	2.44	0.00	0.00	0.52	0.45	0.00	78.97
18	0.75	77.44	18.87	2.43	0.00	0.00	0.59	0.66	0.00	77.44
20	0.83	75.92	20.13	2.43	0.00	0.00	0.65	0.86	0.00	75.92
22	0.92	74.22	21.56	2.44	0.00	0.00	0.72	1.06	0.00	74.22
24	1.00	72.77	22.76	2.45	0.00	0.00	0.78	1.24	0.00	72.77
28	1.17	70.60	24.46	2.44	0.00	0.00	0.90	1.60	0.00	70.60
32	1.33	69.14	25.48	2.43	0.00	0.00	1.02	1.93	0.00	69.14
36	1.50	67.98	26.22	2.42	0.00	0.00	1.14	2.24	0.00	67.98
40	1.67	66.51	27.00	2.41	0.00	0.00	1.26	2.82	0.00	66.51
44	1.83	64.96	27.90	2.40	0.00	0.00	1.37	3.37	0.00	64.96
48	2.00	63.48	28.76	2.38	0.00	0.00	1.48	3.90	0.00	63.48
54	2.25	60.17	30.74	3.30	0.00	0.00	1.64	4.15	0.00	60.17
60	2.50	58.75	32.01	3.29	0.00	0.00	1.80	4.15	0.00	58.75
66	2.75	49.10	37.31	3.41	0.00	4.08	1.95	4.15	0.00	49.10
72	3.00	47.27	39.02	3.20	0.00	4.28	2.09	4.15	0.00	47.27
78	3.25	41.92	42.07	3.21	0.00	6.44	2.22	4.15	0.00	41.92
84	3.50	40.18	43.19	3.21	0.00	6.92	2.35	4.15	0.00	40.18
90	3.75	33.94	46.13	3.19	0.00	10.12	2.47	4.15	0.00	33.94
96	4.00	22.91	50.96	3.19	0.00	16.20	2.58	4.15	0.00	22.91

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	20.85	52.61	3.22	0.00	16.39	2.79	4.15	0.00	20.85
120	5.00	9.72	54.77	11.32	0.00	17.05	2.99	4.15	0.00	9.72
132	5.50	0.00	55.83	18.76	0.00	18.09	3.17	4.15	0.00	0.00
144	6.00	0.00	55.85	18.67	0.00	17.97	3.36	4.15	0.00	0.00
156	6.50	0.00	55.90	18.53	0.00	17.88	3.54	4.15	0.00	0.00
168	7.00	0.00	55.94	18.38	0.00	17.81	3.72	4.15	0.00	0.00
192	8.00	0.00	55.99	18.14	0.00	17.64	4.08	4.15	0.00	0.00
216	9.00	0.00	56.04	17.92	0.00	17.45	4.44	4.15	0.00	0.00
240	10.00	0.00	56.10	17.63	0.00	17.33	4.79	4.15	0.00	0.00
264	11.00	0.02	56.15	17.36	0.00	17.18	5.14	4.15	0.00	0.02
288	12.00	0.00	56.18	17.18	0.00	17.01	5.48	4.15	0.00	0.00
336	14.00	0.00	56.27	16.69	0.00	16.73	6.16	4.15	0.00	0.00
Maximum	14.00	96.52	56.27	18.76	0.00	18.09	6.16	4.15	0.00	96.52

Table XI.B-7 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	95.31	3.50	1.14	0.00	0.00	0.05	0.00	0.00	95.31
4	0.17	93.33	5.07	1.52	0.00	0.00	0.08	0.00	0.00	93.33
6	0.25	88.72	8.70	2.42	0.00	0.00	0.16	0.00	0.00	88.72
8	0.33	86.22	11.03	2.46	0.00	0.00	0.24	0.05	0.00	86.22
10	0.42	83.66	13.46	2.46	0.00	0.00	0.31	0.11	0.00	83.66
12	0.50	81.68	15.18	2.46	0.00	0.00	0.38	0.30	0.00	81.68
14	0.58	79.69	16.54	2.45	0.00	0.00	0.45	0.88	0.00	79.69
16	0.67	78.01	17.61	2.44	0.00	0.00	0.52	1.43	0.00	78.01
18	0.75	76.17	18.86	2.42	0.00	0.00	0.58	1.96	0.00	76.17
20	0.83	74.36	20.10	2.42	0.00	0.00	0.65	2.46	0.00	74.36
22	0.92	72.40	21.52	2.43	0.00	0.00	0.71	2.95	0.00	72.40
24	1.00	70.69	22.69	2.43	0.00	0.00	0.77	3.41	0.00	70.69
28	1.17	68.03	24.35	2.43	0.00	0.00	0.89	4.30	0.00	68.03
32	1.33	66.11	25.34	2.43	0.00	0.00	1.01	5.12	0.00	66.11
36	1.50	64.51	26.05	2.42	0.00	0.00	1.12	5.90	0.00	64.51
40	1.67	62.65	26.80	2.41	0.00	0.00	1.23	6.91	0.00	62.65
44	1.83	60.73	27.65	2.40	0.00	0.00	1.34	7.87	0.00	60.73
48	2.00	58.92	28.46	2.40	0.00	0.00	1.44	8.78	0.00	58.92
54	2.25	55.64	30.32	3.24	0.00	0.00	1.59	9.22	0.00	55.64
60	2.50	54.30	31.51	3.23	0.00	0.00	1.74	9.22	0.00	54.30
66	2.75	44.52	36.80	3.35	0.00	4.24	1.87	9.22	0.00	44.52
72	3.00	42.28	38.46	3.37	0.00	4.66	2.00	9.22	0.00	42.28
78	3.25	35.98	41.87	3.38	0.00	7.42	2.12	9.22	0.00	35.98
84	3.50	34.67	42.78	3.37	0.00	7.72	2.24	9.22	0.00	34.67
90	3.75	27.20	46.16	3.36	0.00	11.70	2.35	9.22	0.00	27.20

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	16.49	50.78	3.35	0.00	17.71	2.45	9.22	0.00	16.49
108	4.50	15.00	52.02	3.36	0.00	17.77	2.63	9.22	0.00	15.00
120	5.00	6.79	53.55	9.71	0.00	17.92	2.81	9.22	0.00	6.79
132	5.50	0.00	54.34	14.61	0.00	18.85	2.98	9.22	0.00	0.00
144	6.00	0.00	54.37	14.52	0.00	18.73	3.15	9.22	0.00	0.00
156	6.50	0.00	54.41	14.35	0.00	18.70	3.31	9.22	0.00	0.00
168	7.00	0.00	54.44	14.23	0.00	18.64	3.48	9.22	0.00	0.00
192	8.00	0.02	54.47	14.01	0.00	18.47	3.80	9.22	0.00	0.02
216	9.00	0.02	54.49	13.87	0.00	18.27	4.13	9.22	0.00	0.02
240	10.00	0.00	54.51	13.74	0.00	18.07	4.45	9.22	0.00	0.00
264	11.00	0.03	54.56	13.48	0.00	17.95	4.76	9.22	0.00	0.03
288	12.00	0.29	54.79	12.83	0.00	17.80	5.08	9.22	0.00	0.29
336	14.00	0.00	54.97	12.53	0.00	17.59	5.69	9.22	0.00	0.00
Maximum	14.00	96.52	54.97	14.61	0.00	18.85	5.69	9.22	0.00	96.52

Table XI.B-8 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	95.31	3.50	1.14	0.00	0.00	0.05	0.00	0.00	95.31
4	0.17	93.33	5.07	1.52	0.00	0.00	0.08	0.00	0.00	93.33
6	0.25	88.54	8.70	2.42	0.00	0.00	0.16	0.18	0.00	88.54
8	0.33	85.93	11.03	2.46	0.00	0.00	0.24	0.35	0.00	85.93
10	0.42	83.28	13.45	2.46	0.00	0.00	0.31	0.50	0.00	83.28
12	0.50	80.93	15.17	2.45	0.00	0.00	0.38	1.07	0.00	80.93
14	0.58	78.76	16.52	2.45	0.00	0.00	0.45	1.83	0.00	78.76
16	0.67	76.92	17.58	2.44	0.00	0.00	0.51	2.55	0.00	76.92
18	0.75	74.92	18.83	2.43	0.00	0.00	0.58	3.24	0.00	74.92
20	0.83	72.97	20.06	2.43	0.00	0.00	0.64	3.89	0.00	72.97
22	0.92	70.86	21.47	2.44	0.00	0.00	0.71	4.53	0.00	70.86
24	1.00	69.03	22.63	2.44	0.00	0.00	0.77	5.13	0.00	69.03
28	1.17	65.86	24.26	2.44	0.00	0.00	0.88	6.56	0.00	65.86
32	1.33	63.46	25.23	2.42	0.00	0.00	0.99	7.89	0.00	63.46
36	1.50	61.44	25.93	2.39	0.00	0.00	1.10	9.14	0.00	61.44
40	1.67	59.37	26.65	2.39	0.00	0.00	1.21	10.38	0.00	59.37
44	1.83	57.29	27.47	2.38	0.00	0.00	1.31	11.55	0.00	57.29
48	2.00	55.32	28.22	2.38	0.00	0.00	1.41	12.67	0.00	55.32
54	2.25	52.00	29.99	3.16	0.00	0.00	1.55	13.30	0.00	52.00
60	2.50	50.74	31.11	3.16	0.00	0.00	1.68	13.30	0.00	50.74
66	2.75	44.18	34.89	3.23	0.00	2.59	1.81	13.30	0.00	44.18
72	3.00	42.29	36.39	3.24	0.00	2.84	1.94	13.30	0.00	42.29
78	3.25	36.05	39.76	3.24	0.00	5.60	2.05	13.30	0.00	36.05
84	3.50	34.07	40.95	3.24	0.00	6.28	2.16	13.30	0.00	34.07
90	3.75	25.37	44.83	3.22	0.00	11.01	2.27	13.30	0.00	25.37

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	15.36	49.14	3.23	0.00	16.61	2.36	13.30	0.00	15.36
108	4.50	14.12	50.27	3.21	0.00	16.57	2.54	13.30	0.00	14.12
120	5.00	6.40	51.72	9.23	0.00	16.66	2.70	13.30	0.00	6.40
132	5.50	0.00	52.31	14.64	0.00	16.90	2.86	13.30	0.00	0.00
144	6.00	0.00	52.43	14.36	0.00	16.89	3.02	13.30	0.00	0.00
156	6.50	0.00	52.45	14.28	0.00	16.80	3.17	13.30	0.00	0.00
168	7.00	0.00	52.48	14.18	0.00	16.71	3.33	13.30	0.00	0.00
192	8.00	0.00	52.53	13.96	0.00	16.58	3.64	13.30	0.00	0.00
216	9.00	0.00	52.58	13.75	0.00	16.43	3.94	13.30	0.00	0.00
240	10.00	0.00	52.61	13.57	0.00	16.29	4.24	13.30	0.00	0.00
264	11.00	0.00	52.62	13.46	0.00	16.09	4.54	13.30	0.00	0.00
288	12.00	0.09	52.84	12.89	0.00	16.04	4.83	13.30	0.00	0.09
336	14.00	0.00	53.00	12.09	0.00	16.20	5.40	13.30	0.00	0.00
Maximum	14.00	96.52	53.00	14.64	0.00	16.90	5.40	13.30	0.00	96.52

Table XI.B-9 Strait of Juan de Fuca - Diesel, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	97.87	2.02	0.06	0.00	0.00	0.05	0.00	0.00	97.87
4	0.17	96.94	2.94	0.03	0.00	0.00	0.09	0.00	0.00	96.94
6	0.25	94.13	5.66	0.04	0.00	0.00	0.17	0.00	0.00	94.13
8	0.33	90.95	8.59	0.21	0.00	0.00	0.24	0.00	0.00	90.95
10	0.42	89.22	10.26	0.21	0.00	0.00	0.32	0.00	0.00	89.22
12	0.50	87.71	11.69	0.21	0.00	0.00	0.39	0.00	0.00	87.71
14	0.58	86.69	12.64	0.21	0.00	0.00	0.46	0.00	0.00	86.69
16	0.67	85.64	13.62	0.20	0.00	0.00	0.54	0.00	0.00	85.64
18	0.75	84.52	14.66	0.20	0.00	0.00	0.61	0.00	0.00	84.52
20	0.83	82.75	16.36	0.21	0.00	0.00	0.68	0.00	0.00	82.75
22	0.92	79.53	18.92	0.80	0.00	0.00	0.75	0.00	0.00	79.53
24	1.00	76.35	21.23	1.61	0.00	0.00	0.81	0.00	0.00	76.35
28	1.17	73.41	23.75	1.90	0.00	0.00	0.94	0.00	0.00	73.41
32	1.33	72.13	24.93	1.88	0.00	0.00	1.06	0.00	0.00	72.13
36	1.50	71.23	25.72	1.87	0.00	0.00	1.19	0.00	0.00	71.23
40	1.67	70.12	26.71	1.86	0.00	0.00	1.31	0.00	0.00	70.12
44	1.83	68.48	28.20	1.87	0.00	0.03	1.42	0.00	0.00	68.48
48	2.00	65.10	30.11	3.08	0.00	0.16	1.54	0.00	0.00	65.10
54	2.25	62.84	31.88	3.32	0.00	0.26	1.71	0.00	0.00	62.84
60	2.50	60.12	33.78	3.32	0.00	0.91	1.87	0.00	0.00	60.12
66	2.75	56.45	36.28	3.33	0.00	1.91	2.03	0.00	0.00	56.45
72	3.00	53.60	38.36	3.61	0.00	2.25	2.18	0.00	0.00	53.60
78	3.25	51.94	39.53	3.60	0.00	2.60	2.33	0.00	0.00	51.94
84	3.50	50.36	40.75	3.62	0.00	2.80	2.47	0.00	0.00	50.36
90	3.75	41.23	43.45	9.80	0.00	2.91	2.61	0.00	0.00	41.23
96	4.00	19.09	47.56	27.17	0.00	3.44	2.74	0.00	0.00	19.09

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	0.00	50.32	40.68	0.00	6.02	2.98	0.00	0.00	0.00
120	5.00	0.00	50.37	40.51	0.00	5.91	3.21	0.00	0.00	0.00
132	5.50	0.05	50.47	40.23	0.00	5.81	3.44	0.00	0.00	0.05
144	6.00	0.02	50.49	40.10	0.00	5.72	3.67	0.00	0.00	0.02
156	6.50	0.00	50.54	39.94	0.00	5.63	3.90	0.00	0.00	0.00
168	7.00	0.00	50.55	39.79	0.00	5.53	4.13	0.00	0.00	0.00
192	8.00	0.00	50.72	39.38	0.00	5.32	4.58	0.00	0.00	0.00
216	9.00	0.00	50.78	39.01	0.00	5.18	5.02	0.00	0.00	0.00
240	10.00	0.00	50.88	38.65	0.00	5.01	5.46	0.00	0.00	0.00
264	11.00	0.00	50.95	38.27	0.00	4.89	5.89	0.00	0.00	0.00
288	12.00	0.08	50.99	37.82	0.00	4.79	6.32	0.00	0.00	0.08
336	14.00	0.00	51.10	37.24	0.00	4.49	7.17	0.00	0.00	0.00
Maximum	14.00	98.45	51.10	40.68	0.00	6.02	7.17	0.00	0.00	98.45

Table XI.B-10 Strait of Juan de Fuca - Diesel, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	97.87	2.02	0.06	0.00	0.00	0.05	0.00	0.00	97.87
4	0.17	96.94	2.94	0.03	0.00	0.00	0.09	0.00	0.00	96.94
6	0.25	94.14	5.66	0.04	0.00	0.00	0.17	0.00	0.00	94.14
8	0.33	90.96	8.59	0.21	0.00	0.00	0.24	0.00	0.00	90.96
10	0.42	89.22	10.25	0.21	0.00	0.00	0.32	0.00	0.00	89.22
12	0.50	87.71	11.69	0.21	0.00	0.00	0.39	0.00	0.00	87.71
14	0.58	86.46	12.64	0.21	0.00	0.00	0.46	0.23	0.00	86.46
16	0.67	85.19	13.62	0.21	0.00	0.00	0.54	0.45	0.00	85.19
18	0.75	83.86	14.66	0.21	0.00	0.00	0.61	0.66	0.00	83.86
20	0.83	81.89	16.36	0.21	0.00	0.00	0.68	0.86	0.00	81.89
22	0.92	78.69	18.91	0.79	0.00	0.00	0.74	0.86	0.00	78.69
24	1.00	75.47	21.21	1.60	0.00	0.00	0.81	0.91	0.00	75.47
28	1.17	72.20	23.72	1.88	0.00	0.00	0.93	1.26	0.00	72.20
32	1.33	70.60	24.88	1.88	0.00	0.00	1.06	1.59	0.00	70.60
36	1.50	69.40	25.65	1.87	0.00	0.00	1.18	1.90	0.00	69.40
40	1.67	67.73	26.62	1.87	0.00	0.00	1.29	2.49	0.00	67.73
44	1.83	65.49	28.11	1.88	0.00	0.07	1.41	3.04	0.00	65.49
48	2.00	61.88	29.90	2.98	0.00	0.15	1.52	3.56	0.00	61.88
54	2.25	58.96	31.84	3.19	0.00	0.51	1.68	3.82	0.00	58.96
60	2.50	55.77	34.04	3.06	0.00	1.48	1.83	3.82	0.00	55.77
66	2.75	52.77	36.18	3.06	0.00	2.20	1.98	3.82	0.00	52.77
72	3.00	50.26	38.05	3.36	0.00	2.40	2.12	3.82	0.00	50.26
78	3.25	48.79	39.11	3.35	0.00	2.67	2.26	3.82	0.00	48.79
84	3.50	46.90	40.43	3.37	0.00	3.09	2.40	3.82	0.00	46.90
90	3.75	38.13	43.08	9.08	0.00	3.38	2.53	3.82	0.00	38.13
96	4.00	17.67	46.96	25.00	0.00	3.91	2.65	3.82	0.00	17.67

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	0.00	49.67	37.21	0.00	6.43	2.87	3.82	0.00	0.00
120	5.00	0.00	49.73	37.06	0.00	6.31	3.09	3.82	0.00	0.00
132	5.50	0.04	49.78	36.86	0.00	6.20	3.30	3.82	0.00	0.04
144	6.00	0.01	49.81	36.74	0.00	6.10	3.52	3.82	0.00	0.01
156	6.50	0.00	49.84	36.62	0.00	6.00	3.73	3.82	0.00	0.00
168	7.00	0.00	49.85	36.50	0.00	5.89	3.94	3.82	0.00	0.00
192	8.00	0.00	49.87	36.26	0.00	5.69	4.37	3.82	0.00	0.00
216	9.00	0.00	50.00	35.91	0.00	5.50	4.78	3.82	0.00	0.00
240	10.00	0.00	50.04	35.62	0.00	5.33	5.19	3.82	0.00	0.00
264	11.00	0.00	50.06	35.35	0.00	5.15	5.60	3.82	0.03	0.03
288	12.00	0.26	50.13	34.72	0.00	5.05	6.00	3.82	0.03	0.28
336	14.00	0.00	51.61	32.84	0.00	4.92	6.78	3.82	0.03	0.03
Maximum	14.00	98.45	51.61	37.21	0.00	6.43	6.78	3.82	0.03	98.45

Table XI.B-11 Strait of Juan de Fuca - Diesel, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	97.87	2.02	0.06	0.00	0.00	0.05	0.00	0.00	97.87
4	0.17	96.94	2.94	0.03	0.00	0.00	0.09	0.00	0.00	96.94
6	0.25	94.14	5.66	0.04	0.00	0.00	0.17	0.00	0.00	94.14
8	0.33	90.90	8.59	0.21	0.00	0.00	0.24	0.05	0.00	90.90
10	0.42	89.12	10.25	0.21	0.00	0.00	0.32	0.11	0.00	89.12
12	0.50	87.42	11.68	0.21	0.00	0.00	0.39	0.30	0.00	87.42
14	0.58	85.82	12.63	0.21	0.00	0.00	0.46	0.88	0.00	85.82
16	0.67	84.21	13.61	0.21	0.00	0.00	0.54	1.43	0.00	84.21
18	0.75	82.58	14.64	0.21	0.00	0.00	0.60	1.96	0.00	82.58
20	0.83	80.33	16.33	0.21	0.00	0.00	0.67	2.46	0.00	80.33
22	0.92	77.16	18.85	0.79	0.00	0.00	0.74	2.46	0.00	77.16
24	1.00	73.92	21.13	1.56	0.00	0.00	0.80	2.58	0.00	73.92
28	1.17	70.17	23.60	1.84	0.00	0.00	0.93	3.46	0.00	70.17
32	1.33	68.10	24.73	1.84	0.00	0.00	1.04	4.29	0.00	68.10
36	1.50	66.47	25.48	1.82	0.00	0.00	1.16	5.06	0.00	66.47
40	1.67	64.42	26.42	1.82	0.00	0.00	1.27	6.08	0.00	64.42
44	1.83	61.82	27.86	1.82	0.00	0.08	1.38	7.04	0.00	61.82
48	2.00	57.83	29.61	2.90	0.00	0.23	1.48	7.95	0.00	57.83
54	2.25	55.12	31.31	3.11	0.00	0.44	1.63	8.39	0.00	55.12
60	2.50	52.73	33.00	3.12	0.00	0.99	1.78	8.39	0.00	52.73
66	2.75	49.78	35.12	3.07	0.00	1.73	1.92	8.39	0.00	49.78
72	3.00	47.22	36.99	3.33	0.00	2.02	2.05	8.39	0.00	47.22
78	3.25	46.05	37.93	3.32	0.00	2.14	2.18	8.39	0.00	46.05
84	3.50	44.62	39.04	3.34	0.00	2.31	2.31	8.39	0.00	44.62
90	3.75	36.11	41.60	8.87	0.00	2.60	2.43	8.39	0.00	36.11

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	16.69	45.44	23.75	0.00	3.20	2.54	8.39	0.00	16.69
108	4.50	0.00	47.72	36.05	0.00	5.09	2.75	8.39	0.00	0.00
120	5.00	0.00	47.75	35.92	0.00	4.99	2.96	8.39	0.00	0.00
132	5.50	0.00	47.77	35.79	0.00	4.89	3.16	8.39	0.00	0.00
144	6.00	0.00	47.82	35.64	0.00	4.79	3.36	8.39	0.00	0.00
156	6.50	0.00	47.87	35.43	0.00	4.75	3.56	8.39	0.00	0.00
168	7.00	0.00	47.89	35.31	0.00	4.65	3.77	8.39	0.00	0.00
192	8.00	0.00	47.92	35.05	0.00	4.47	4.16	8.39	0.00	0.00
216	9.00	0.00	47.95	34.80	0.00	4.31	4.56	8.39	0.00	0.00
240	10.00	5.11	48.94	28.43	0.00	4.19	4.94	8.39	0.00	5.11
264	11.00	0.00	49.69	32.51	0.00	4.11	5.31	8.39	0.00	0.00
288	12.00	0.06	49.73	32.13	0.00	4.01	5.67	8.39	0.00	0.07
336	14.00	0.00	49.80	31.60	0.00	3.82	6.39	8.39	0.00	0.00
Maximum	14.00	98.45	49.80	36.05	0.00	5.09	6.39	8.39	0.00	98.45

Table XI.B-12 Strait of Juan de Fuca - Diesel, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	97.87	2.02	0.06	0.00	0.00	0.05	0.00	0.00	97.87
4	0.17	96.94	2.94	0.03	0.00	0.00	0.09	0.00	0.00	96.94
6	0.25	93.96	5.66	0.04	0.00	0.00	0.17	0.18	0.00	93.96
8	0.33	90.61	8.59	0.21	0.00	0.00	0.24	0.35	0.00	90.61
10	0.42	88.73	10.24	0.21	0.00	0.00	0.32	0.50	0.00	88.73
12	0.50	86.67	11.67	0.21	0.00	0.00	0.39	1.07	0.00	86.67
14	0.58	84.89	12.61	0.21	0.00	0.00	0.46	1.83	0.00	84.89
16	0.67	83.13	13.58	0.21	0.00	0.00	0.53	2.55	0.00	83.13
18	0.75	81.35	14.61	0.20	0.00	0.00	0.60	3.24	0.00	81.35
20	0.83	78.96	16.27	0.21	0.00	0.00	0.67	3.89	0.00	78.96
22	0.92	75.83	18.77	0.77	0.00	0.00	0.73	3.89	0.00	75.83
24	1.00	72.59	21.04	1.53	0.00	0.00	0.80	4.05	0.00	72.59
28	1.17	68.35	23.47	1.80	0.00	0.00	0.92	5.47	0.00	68.35
32	1.33	65.83	24.58	1.75	0.00	0.00	1.03	6.80	0.00	65.83
36	1.50	63.74	25.31	1.75	0.00	0.00	1.14	8.05	0.00	63.74
40	1.67	61.50	26.21	1.74	0.00	0.00	1.25	9.29	0.00	61.50
44	1.83	58.75	27.60	1.75	0.00	0.09	1.35	10.46	0.00	58.75
48	2.00	54.64	29.30	2.77	0.00	0.25	1.45	11.58	0.00	54.64
54	2.25	52.18	30.76	2.97	0.00	0.29	1.59	12.21	0.00	52.18
60	2.50	50.19	32.24	2.97	0.00	0.67	1.73	12.21	0.00	50.19
66	2.75	47.15	34.34	2.98	0.00	1.46	1.86	12.21	0.00	47.15
72	3.00	44.71	36.15	3.20	0.00	1.74	1.99	12.21	0.00	44.71
78	3.25	43.27	37.18	3.20	0.00	2.04	2.11	12.21	0.00	43.27
84	3.50	41.78	38.28	3.22	0.00	2.28	2.23	12.21	0.00	41.78
90	3.75	33.47	40.84	8.40	0.00	2.74	2.34	12.21	0.00	33.47

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	15.57	44.28	22.12	0.00	3.37	2.45	12.21	0.00	15.57
108	4.50	0.00	46.40	33.55	0.00	5.20	2.65	12.21	0.00	0.00
120	5.00	0.00	46.47	33.35	0.00	5.12	2.84	12.21	0.00	0.00
132	5.50	0.00	46.51	33.22	0.00	5.03	3.03	12.21	0.00	0.00
144	6.00	0.00	46.54	33.09	0.00	4.94	3.22	12.21	0.00	0.00
156	6.50	9.41	46.62	23.46	0.00	4.89	3.41	12.21	0.00	9.41
168	7.00	5.77	47.37	26.24	0.00	4.81	3.60	12.21	0.00	5.77
192	8.00	0.35	48.26	30.57	0.00	4.65	3.96	12.21	0.00	0.35
216	9.00	0.00	48.31	30.64	0.00	4.52	4.31	12.21	0.00	0.00
240	10.00	0.00	48.33	30.44	0.00	4.36	4.66	12.21	0.00	0.00
264	11.00	0.00	48.35	30.22	0.00	4.22	5.01	12.21	0.00	0.00
288	12.00	0.01	48.36	29.99	0.00	4.08	5.35	12.21	0.00	0.01
336	14.00	0.00	48.48	29.25	0.00	4.03	6.02	12.21	0.00	0.00
Maximum	14.00	98.45	48.48	33.55	0.00	5.20	6.02	12.21	0.00	98.45

Table XI.B-13 Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	587	325	170
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	552	288	166
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	2,451	1,564	685
Shoreline length (km) oiled by > 100 g/m^2	1,767	1,054	322
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	2,034,600	1,016,100	481,760
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	416,800	548,040	203,140
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	36	25	9

Table XI.B-14 Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	541	303	174
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	506	273	172
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,057	1,521	746
Shoreline length (km) oiled by > 100 g/m^2	674	941	336
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	884,670	1,046,700	551,420
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	172,350	474,440	194,130
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	15	25	10

Table XI.B-15 Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	535	267	166
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	469	238	164
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,051	1,638	583
Shoreline length (km) oiled by > 100 g/m^2	701	1,011	286
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	808,820	1,142,300	428,250
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	242,010	495,470	154,700
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	15	27	7

Table XI.B-16 Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	544	263	155
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	494	230	154
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,276	1,204	569
Shoreline length (km) oiled by > 100 g/m^2	949	896	339
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	1,027,900	749,120	430,320
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	248,580	454,730	138,750
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	18	18	8

XI.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 XI.C-1 Strait of Juan de Fuca - Diesel, 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)	31,065	14,760	36	2,265	0	0	4	-	48,130	48,126	4
Worst run for Dungeness Spit	21,260	6,882	21	1,293	0	0	2	-	29,457	29,455	2
Worst run for Protection Island	16,735	3,246	5	341	0	0	1	-	20,328	20,327	1

Table XI.C-2 Strait of Juan de Fuca - Diesel, 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)	29,341	13,376	13	822	0	0	4	-	43,556	43,552	4
Worst run for Dungeness Spit	20,706	6,437	18	1,153	0	0	2	-	28,316	28,314	2
Worst run for Protection Island	16,937	3,409	6	359	0	0	1	-	20,712	20,711	1

Table XI.C-3 Strait of Juan de Fuca - Diesel, 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)	27,970	12,274	14	855	0	0	3	-	41,116	41,113	3
Worst run for Dungeness Spit	19,398	5,386	20	1,239	0	0	2	-	26,045	26,043	2
Worst run for Protection Island	16,639	3,169	5	297	0	0	1	-	20,112	20,111	1

Table XI.C-4 Strait of Juan de Fuca - Diesel, 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)	28,902	13,023	18	1,163	0	0	4	-	43,110	43,107	4
Worst run for Dungeness Spit	19,117	5,160	17	1,053	0	0	2	-	25,349	25,347	2
Worst run for Protection Island	16,271	2,873	6	406	0	0	1	-	19,557	19,556	1

XI.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 XI.D-1. Strait of Juan de Fuca - Diesel, 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)	282	-	13	24	-	257,862	258,182
Worst run for Dungeness Spit	-	-	4	24	-	163,169	163,197
Worst run for Protection Island	9,707	26,921	56	26	1,934	22,824	61,467

Table XI.D-2. Strait of Juan de Fuca - Diesel, 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)	5,758	15,594	38	25	1,094	81,099	103,608
Worst run for Dungeness Spit	-	-	-	24	-	142,773	142,797
Worst run for Protection Island	7,557	20,755	46	25	1,477	22,824	52,684

Table XI.D-3. Strait of Juan de Fuca - Diesel, 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)	4,523	12,053	33	25	832	87,412	104,878
Worst run for Dungeness Spit	-	-	-	24	-	156,369	156,393
Worst run for Protection Island	6,838	18,692	43	25	1,324	16,511	43,433

Table XI.D-4. Strait of Juan de Fuca - Diesel, 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)	4,142	10,959	31	25	750	129,661	145,568
Worst run for Dungeness Spit	-	-	-	24	-	137,917	137,941
Worst run for Protection Island	5,282	14,230	36	25	993	29,138	49,704

XI.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 XI.E-1. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	282	-	9,707
Large pelagic fish	-	-	26,921
Demersal fish	13	4.4	56
Decapods	25	24	26
Molluscs	257,862	163,169	24,758
Birds:			
Waterfowl (# * kg each)	24,049	16,459	12,955
Seabirds (# * kg each)	13,801	6,434	3,035
Waders (# * kg each)	34	19	5
Shorebirds (# * kg each)	2,118	1,209	319
Raptors (# * kg each)	0.1	0.2	0.2
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	3.6	2.1	1.3
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	258,182	163,197	61,467
Subtotal birds	40,002	24,121	16,314
Subtotal other wildlife	4	2	1
Total all species	298,187	187,321	77,783

Table XI.E-2. Strait of Juan de Fuca - Diesel, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	146	80	120
Saltmarsh Area (acres)	362	198	296
Saltmarsh Cost (millions of 2004$)	67.8	37.1	55.5
Eelgrass Area (m2)	92	50	75
Eelgrass Area (acres)	226	124	185
Eelgrass Cost (millions of 2004$)	27.0	14.8	22.1

Table XI.E-3. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	5,758	-	7,557
Large pelagic fish	15,594	-	20,755
Demersal fish	38	-	46
Decapods	25	24	25
Molluscs	82,193	142,773	24,301
Birds:			
Waterfowl (# * kg each)	22,715	16,030	13,112
Seabirds (# * kg each)	12,506	6,018	3,187
Waders (# * kg each)	12	17	5
Shorebirds (# * kg each)	769	1,078	336
Raptors (# * kg each)	0.1	0.2	0.2
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	3.4	2.0	1.4
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	103,608	142,797	52,684
Subtotal birds	36,002	23,143	16,641
Subtotal other wildlife	3	2	1
Total all species	139,614	165,942	69,326

Table XI.E-4. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	162	74	102
Saltmarsh Area (acres)	400	184	252
Saltmarsh Cost (millions of 2004$)	74.9	34.4	47.2
Eelgrass Area (m2)	101	47	64
Eelgrass Area (acres)	250	115	158
Eelgrass Cost (millions of 2004$)	29.8	13.7	18.8

Table XI.E-5. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	4,523	-	6,838
Large pelagic fish	12,053	-	18,692
Demersal fish	33	-	43
Decapods	25	24	25
Molluscs	88,243	156,369	17,835
Birds:			
Waterfowl (# * kg each)	21,653	15,017	12,882
Seabirds (# * kg each)	11,476	5,036	2,963
Waders (# * kg each)	13	18	4
Shorebirds (# * kg each)	800	1,159	278
Raptors (# * kg each)	0.1	0.1	0.2
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	3.1	1.8	1.3
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	104,878	156,393	43,433
Subtotal birds	33,942	21,230	16,127
Subtotal other wildlife	3	2	1
Total all species	138,823	177,625	59,562

Table XI.E-6. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	144	69	93
Saltmarsh Area (acres)	356	170	230
Saltmarsh Cost (millions of 2004$)	66.7	31.9	43.2
Eelgrass Area (m2)	90	43	58
Eelgrass Area (acres)	223	107	144
Eelgrass Cost (millions of 2004$)	26.6	12.7	17.2

Table XI.E-7. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	4,142	-	5,282
Large pelagic fish	10,959	-	14,230
Demersal fish	40	-	36
Decapods	25	24	25
Molluscs	130,411	137,917	30,131
Birds:			
Waterfowl (# * kg each)	22,375	14,800	12,596
Seabirds (# * kg each)	12,176	4,825	2,686
Waders (# * kg each)	17	16	6
Shorebirds (# * kg each)	1,088	985	379
Raptors (# * kg each)	0.1	0.1	0.2
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	3.3	1.7	1.3
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	145,568	137,941	49,704
Subtotal birds	35,656	20,625	15,668
Subtotal other wildlife	3	2	1
Total all species	181,227	158,567	65,373

Table XI.E-8. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	151	65	79
Saltmarsh Area (acres)	374	161	196
Saltmarsh Cost (millions of 2004$)	70.1	30.1	36.6
Eelgrass Area (m2)	95	41	50
Eelgrass Area (acres)	234	100	122
Eelgrass Cost (millions of 2004$)	27.9	12.0	14.6

XI.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 XI.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XI.F-1. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	16.47	17.25	17.28
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	45.0	47.1	47.2

Table XI.F-2. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	17.97	17.24	17.28
% Removed by 24 hours	0.31	1.24	0.91
Compensation (millions $)	48.9	46.5	46.8

Table XI.F-3. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	17.97	17.23	16.53
% Removed by 24 hours	0.76	3.41	2.58
Compensation (millions $)	48.7	45.4	44.0

Table XI.F-4. Strait of Juan de Fuca - Diesel, 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 Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	17.97	16.48	16.52
% Removed by 24 hours	1.26	5.13	4.05
Compensation (millions $)	48.4	42.7	43.3

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 XII: Model Inputs for Strait of Juan de Fuca – 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

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 7
XII.C.1. Basis of Current Data 7
XII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 8
XII.D: Oil Properties 11
XII.E: Inputs to the SIMAP Physical Fates Model 14

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.C.1-1 Grid used for the hydrodynamic model-generated current data. 7
Figure XII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC). 8
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. 9
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. 9
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. 10
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. 10
Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit. 17
Figure XII.E-2 Wind Station Locations. 21

List of Tables

Table XII.D-1. Oil properties for Alaskan North Slope crude oil assumed in the modeling. 11
Table XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil. ... 12
Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios..... 14
Table XII.E-2. Time, date and location inputs for each of the 100 stochastic runs..... 18
Table XII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 20
Table XII.E-4. Water temperature by month of the year (from French et al., 1996b)..... 20
Table XII.E-5. Wind data sources and records used..... 21

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 was 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

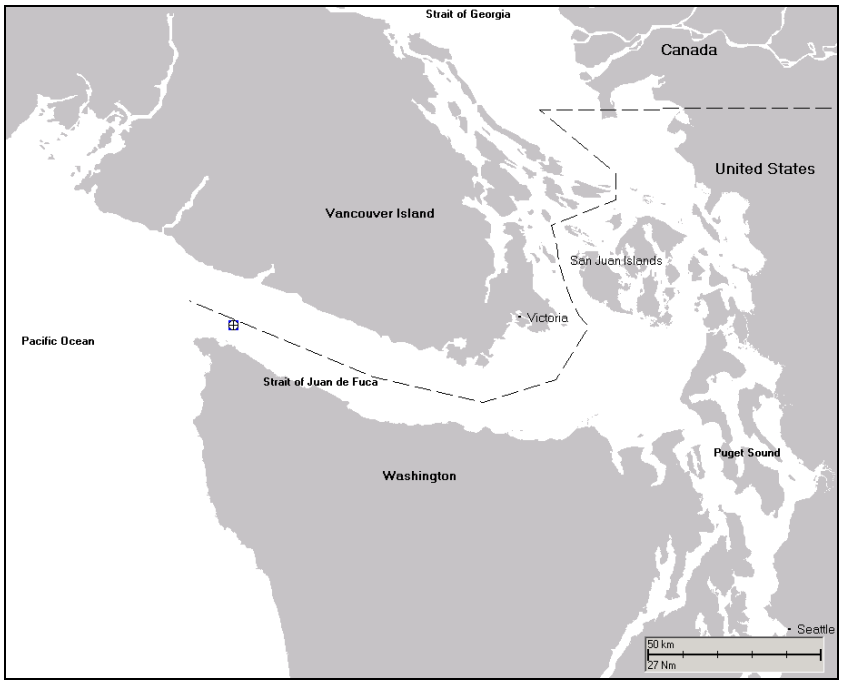


Figure XII.B.1-1 Map of the vicinity of the potential spill locations.

XII.B.2. Gridded Habitat Mapping

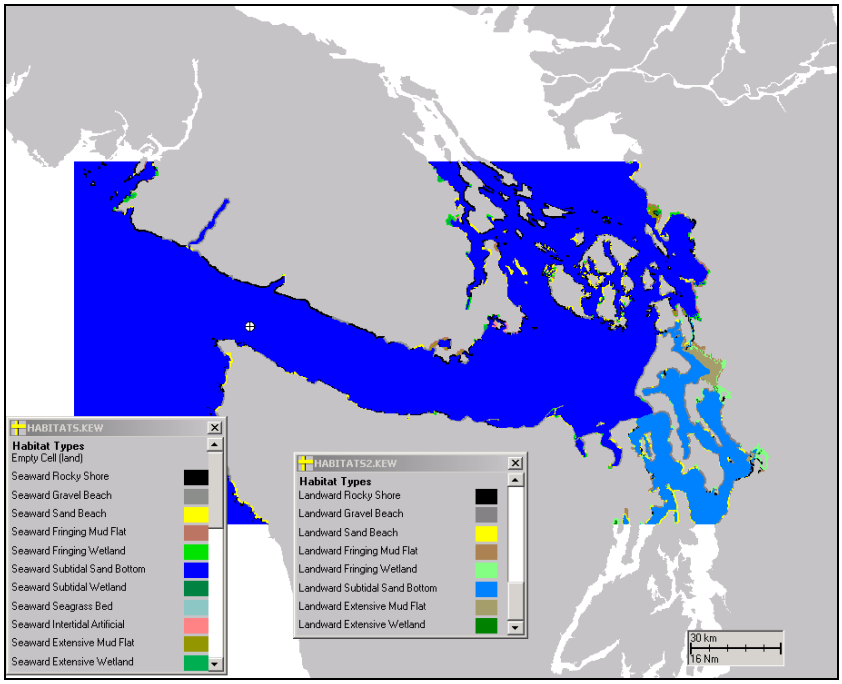


Figure XII.B.2-1 Habitat grid used for modeling the potential spills.

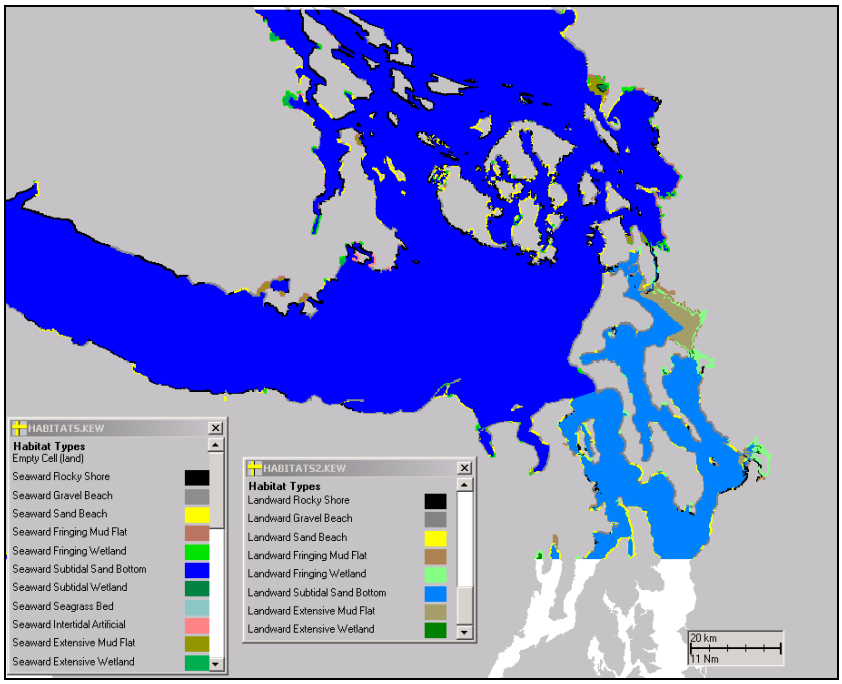


Figure XII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XII.B-3. Gridded Depth Data

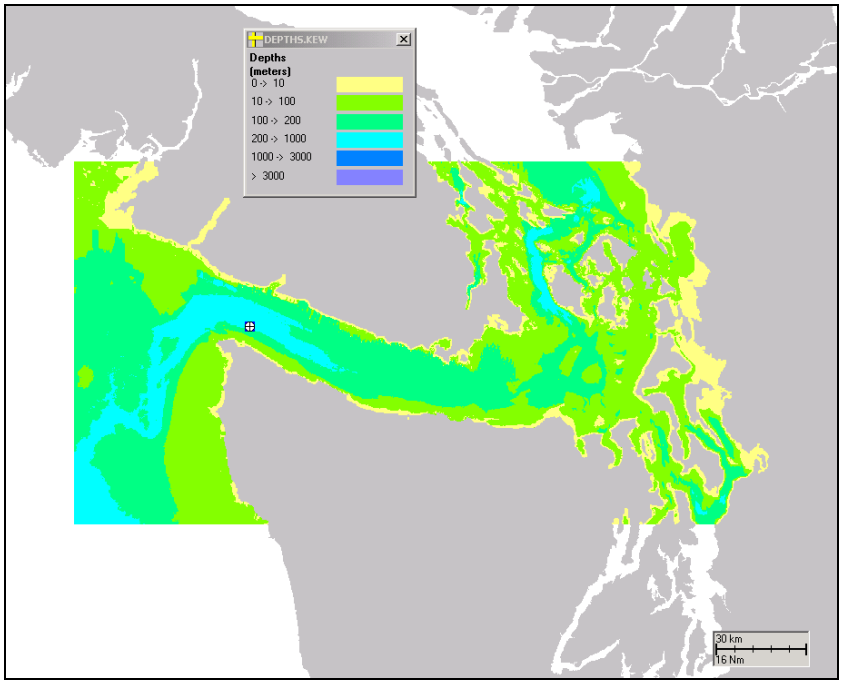


Figure XII.B.3-1 Depth grid used for modeling the potential spills.

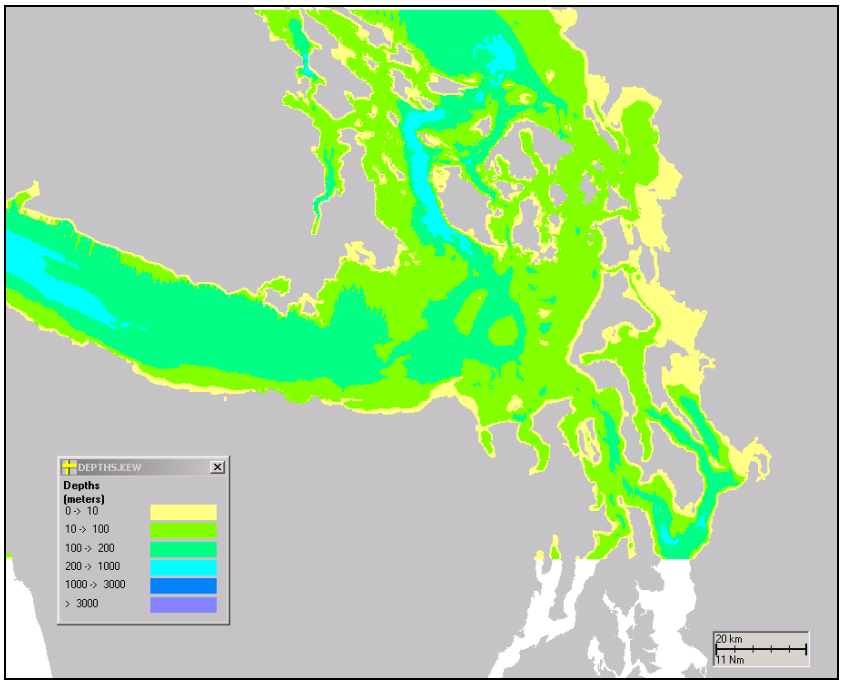


Figure XII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XII.B-4. Areas Where Response Actions Assumed

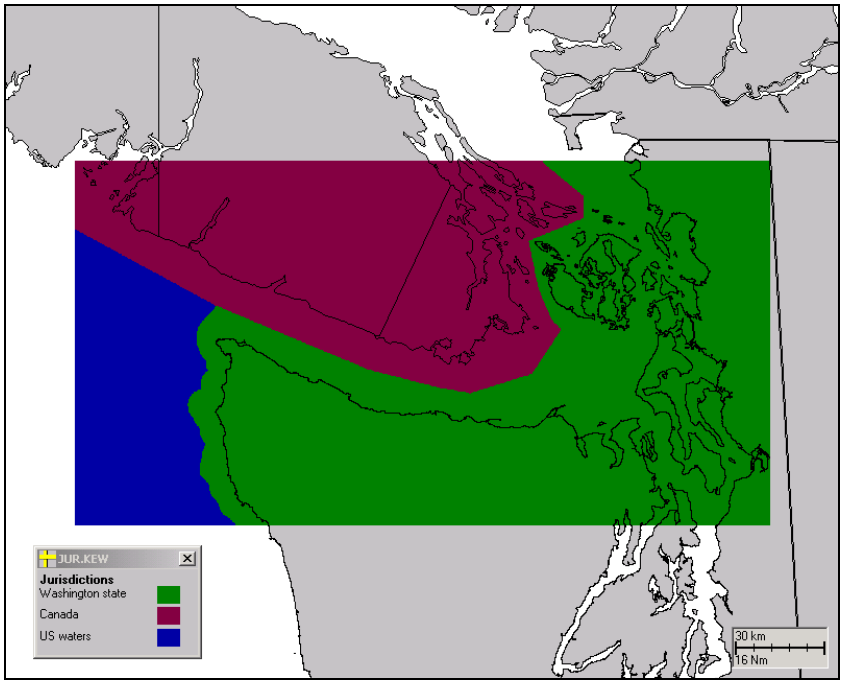


Figure XII.B.4-1 Jurisdictions in the area of the potential spills.

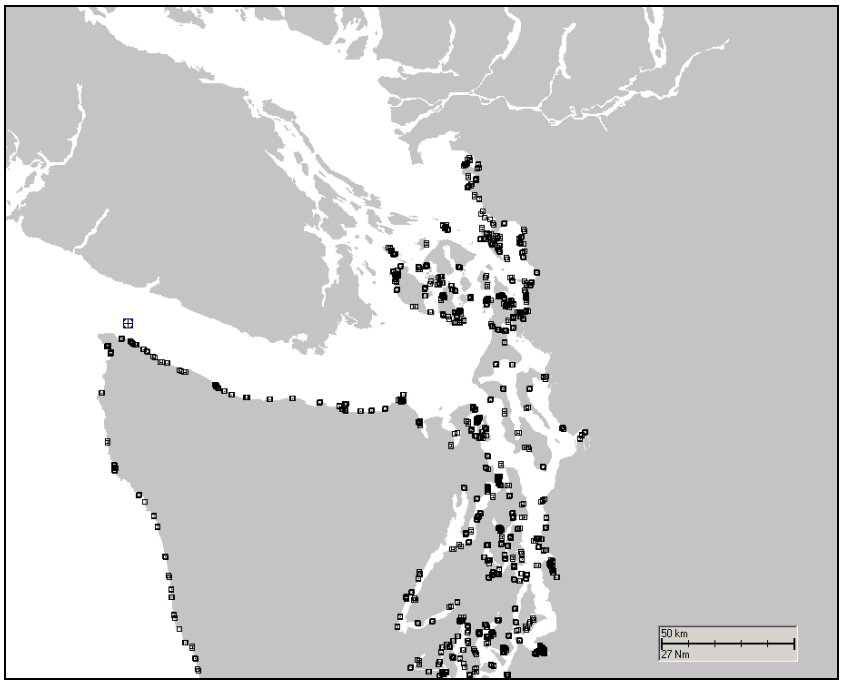


Figure XII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

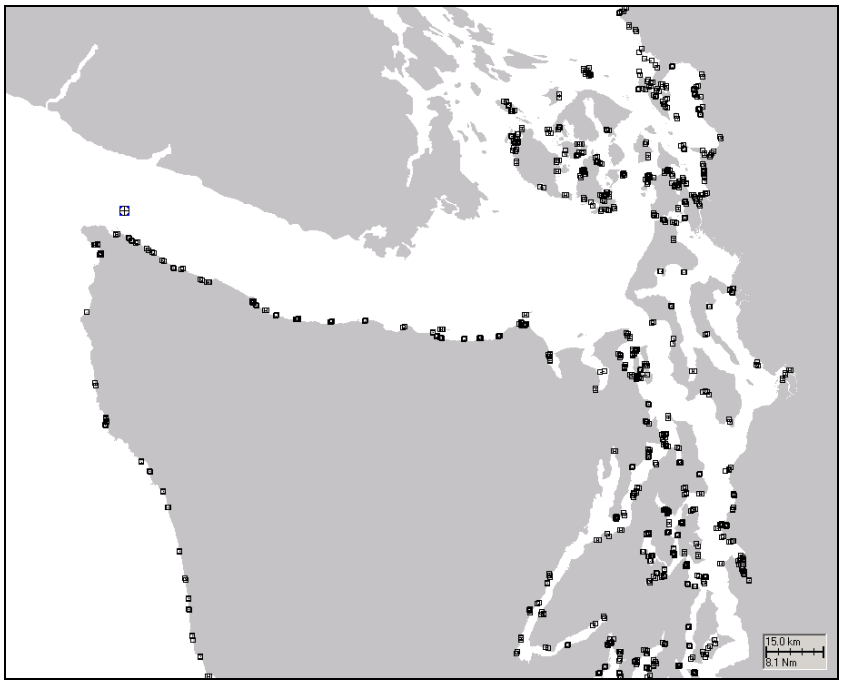


Figure XII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

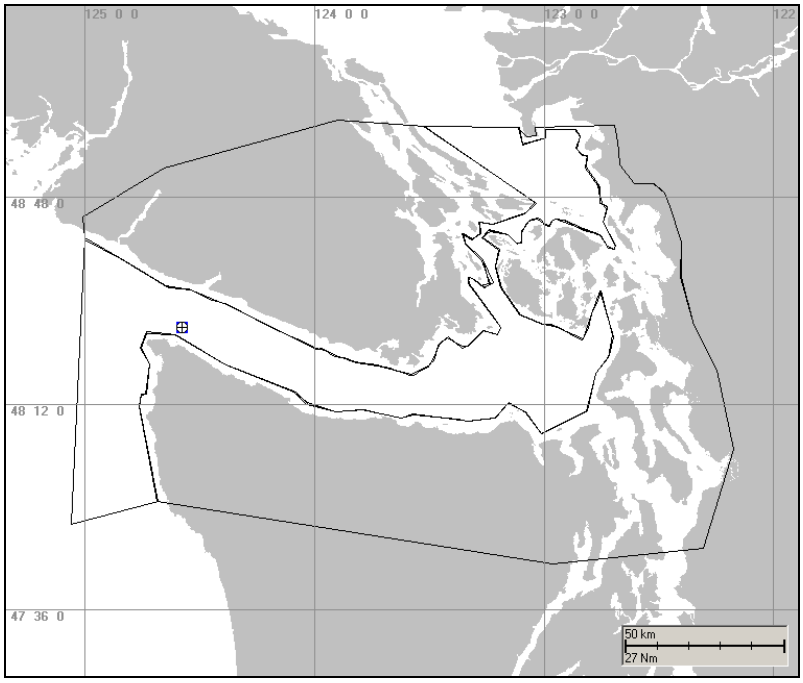


Figure XII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

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).

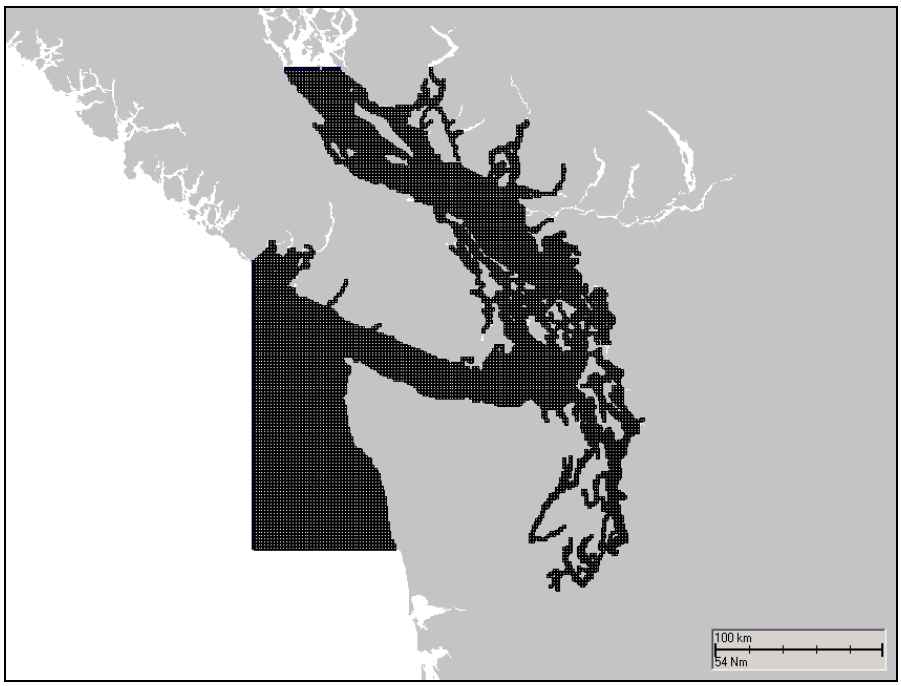


Figure XII.C.1-1 Grid used for the hydrodynamic model-generated current data.

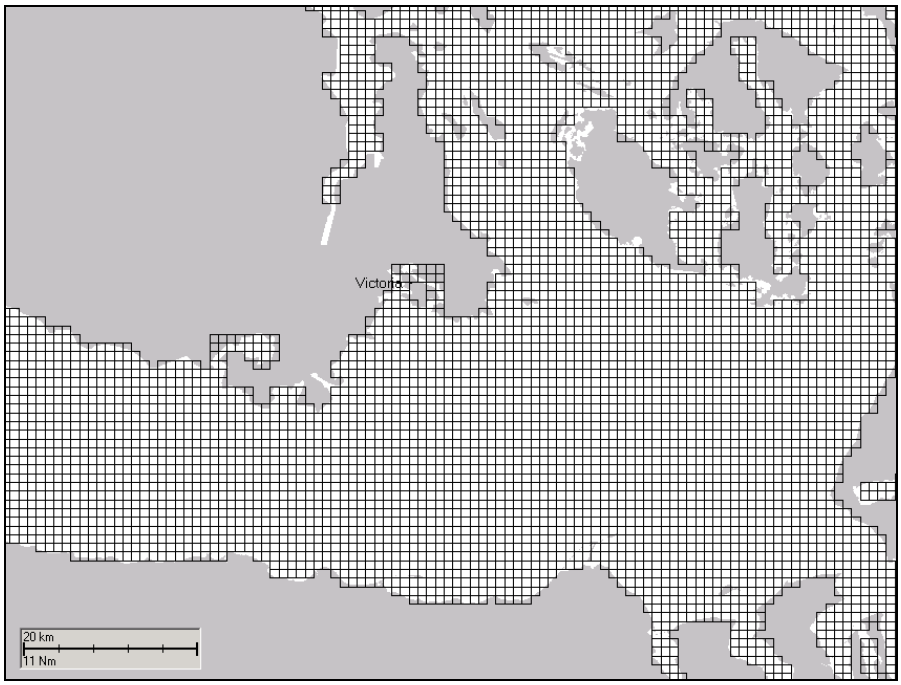


Figure XII.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Victoria, BC).

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.

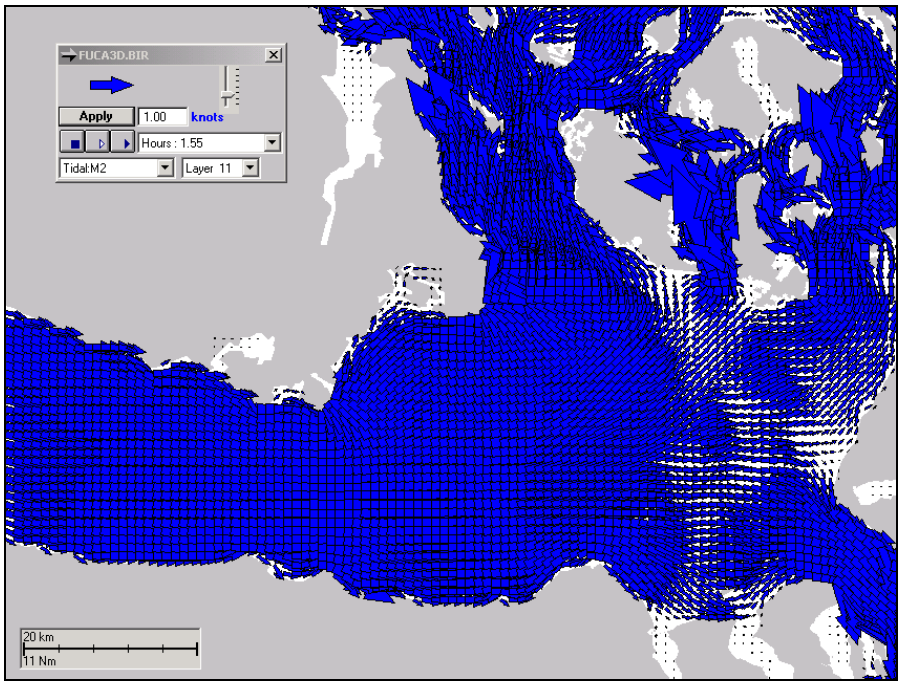


Figure XII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Victoria, BC.

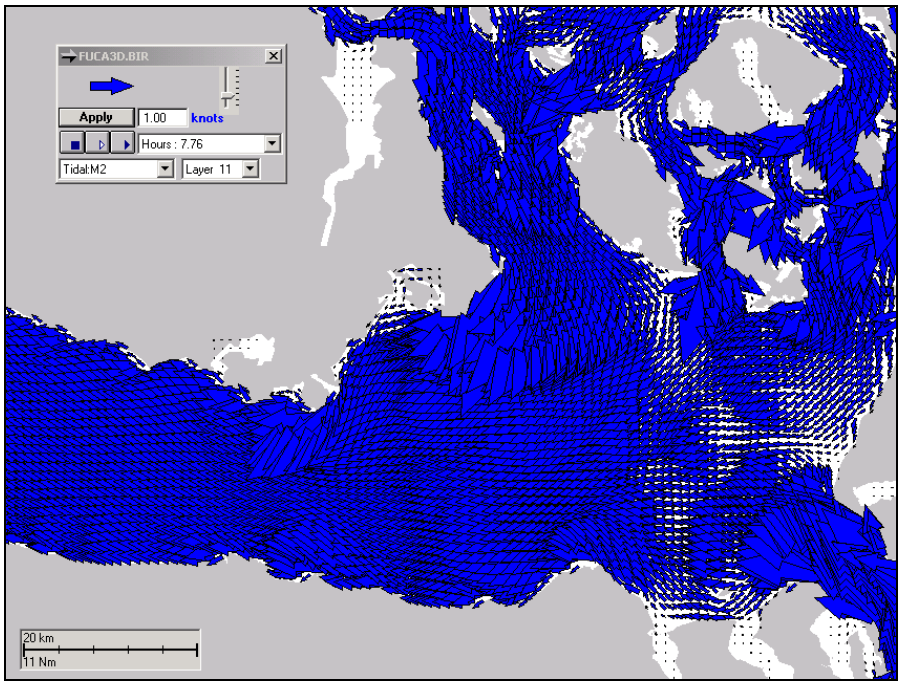


Figure XII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Victoria, BC.

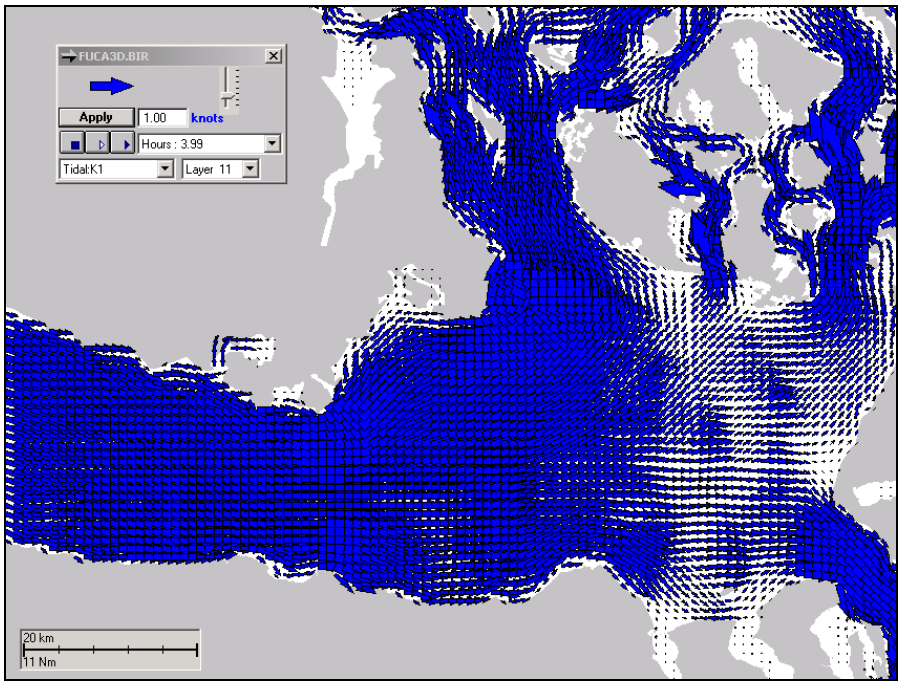


Figure XII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Victoria, BC.

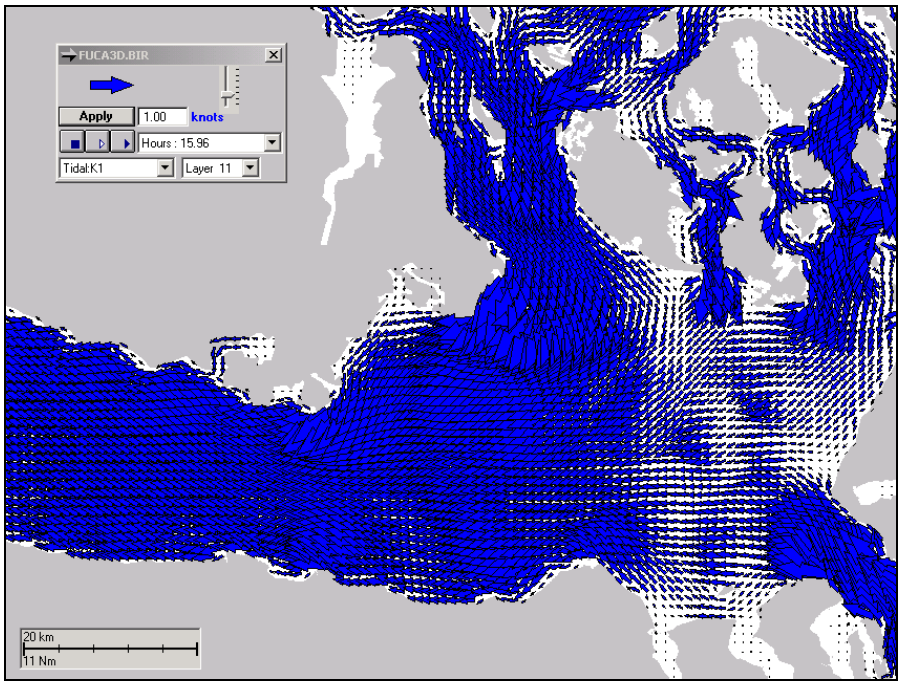


Figure XII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Victoria, BC.

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]; 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 XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil.

Aromatic	Log(K_{ow})*	Concentration (mg/kg)
benzene	2.13	0.0
Toluene	2.69	0.0
Ethylbenzene	3.13	0.0
o-Xylene	3.15	0.0
p-Xylene	3.18	0.0
m-Xylene	3.2	0.0
Xylenes	3.18	0.0
styrene	3.05	0.0
methylstyrenes	3.35	0.0
1,2,3-Trimethylbenzene	3.55	0.0
1,2,4-Trimethylbenzene	3.6	0.0
1,3,4-Trimethylbenzene	3.6	0.0
1,3,5-Trimethylbenzene	3.58	0.0
Trimethylbenzenes	3.58	0.0
n-propylbenzene	3.69	0.0
iso-propylbenzene	3.63	0.0
ethyl-methylbenzenes	3.63	0.0
iso-propyl-4-methylbenzene	4.10	0.0
butylbenzenes	4.12	0.0
tetramethylbenzenes	4.01	0.0
tetralin	3.83	0.0
diphenylmethane	4.14	0.0
naphthalene	3.37	650
C1-naphthalenes	3.87	1,300
C2-naphthalenes	4.37	1,800
C3-naphthalenes	5.00	1,400
C4-naphthalenes	5.55	850
biphenyls	3.9	180
acenaphthylene	4.07	0.0
acenaphthene	3.92	0.0
dibenzofuran	4.31	0.0
Fluorene	4.18	82
C1-fluorenes	4.97	220
C2-fluorenes	5.20	260
C3-fluorenes	5.50	280

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XII.D-2. Aromatic concentrations (mg/kg) for Alaskan North Slope crude oil (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	200
C1-dibenzothiophene	4.86	360
C2-dibenzothiophene	5.50	540
C3-dibenzothiophene	5.73	460
phenanthrene	4.57	230
anthracene	4.54	0.0
C1-phenanthrenes/anthracenes	5.14	430
C2-phenanthrenes/anthracenes	5.25	490
C3-phenanthrenes/anthracenes	6.00	380
C4-phenanthrenes/anthracenes	6.51	260
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total log(K_{ow})$\leq$5.6	-	9,272

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XII.E: INPUTS TO THE SIMAP PHYSICAL FATES MODEL

This section summarizes the model input data for the scenarios run and the sources for that information. The approach and sources applicable to all modeled locations are described in Volume I, Section 3 of this technical report. Specifics to this model location are below. Thus, the reader should refer to Volume I, Section 3 for background and the context within which these data are used.

The model grid and cell size were set to provide the maximum resolution (minimum cell size) possible within the memory constraints of the model, while also providing sufficient geographic coverage to encompass the maximum extent of oiling possible for the scenario. Test runs (randomizing weather conditions) were made to estimate the maximum extent of surface oiling and the grid size was set to cover that area.

Table XII.E-1. Inputs to the Fates Model for Stochastic Scenarios

Name	Description	Units	Source(s) of Information	Value(s)
Spill Site	Location of the spill site	-	Washington DOE	Neah Bay to Port Angeles
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XII.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XII.E-1)
Depth of release	Depth below the water surface of the release or 0 for surface release	m	Washington DOE	0 m
Start time and date	Randomized over selected months of the year	Date, hr,min	(randomized)	Jan-Dec
Spill duration	Hours over which the release occurs	Hours	(assumed)	4 hours
Total spill amount	Total volume (or weight) released (maximum if range)	bbl	Washington DOE	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 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	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table 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

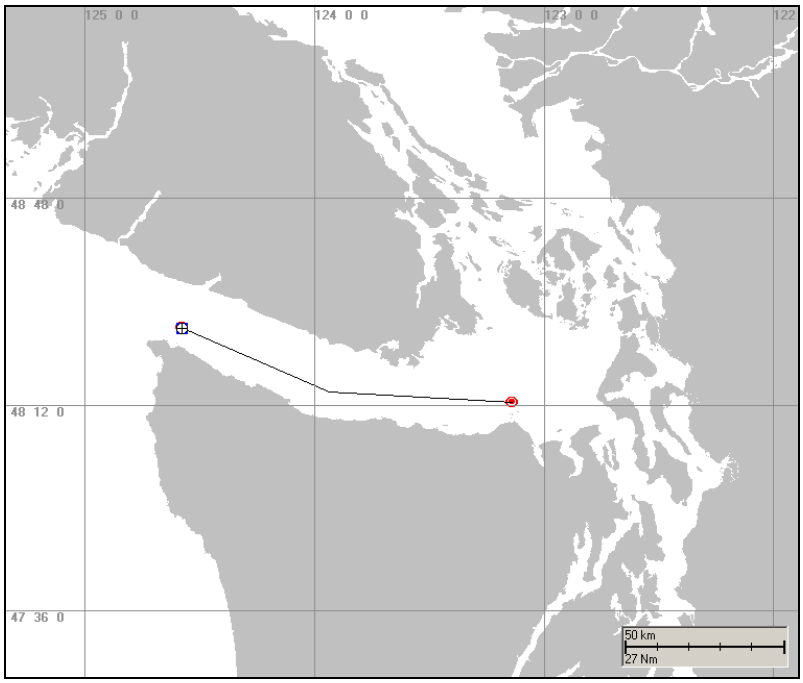


Figure VI.E-1. Varied range of spill site, shipping lane from Neah Bay to Dungeness Spit.

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

51	1999	10	1	8	48.23933	123.7417
52	1994	7	14	11	48.30342	124.1492
53	1997	2	22	2	48.22571	123.398
54	1995	7	22	4	48.30444	124.1526
55	2000	7	12	2	48.35349	124.321
56	2003	8	2	9	48.23631	123.6794
57	2003	6	4	2	48.31524	124.1895
58	1994	5	9	16	48.22585	123.4085
59	2002	7	12	7	48.31285	124.1813
60	1992	10	17	15	48.23282	123.6075
61	2001	6	19	18	48.2461	123.8811
62	2000	12	28	6	48.31212	124.1788
63	1994	7	13	4	48.27587	124.0569
64	2001	9	19	13	48.32818	124.234
65	2001	5	14	9	48.40291	124.4908
66	1992	10	12	17	48.22641	123.4526
67	1997	3	26	6	48.24678	123.8952
68	2000	3	14	12	48.42311	124.5603
69	1999	11	14	5	48.22632	123.446
70	2003	6	1	16	48.22619	123.4355
71	1996	2	25	17	48.24295	123.8163
72	2002	12	12	21	48.2308	123.566
73	1993	12	10	2	48.23368	123.6252
74	2000	8	21	5	48.38988	124.4461
75	1995	10	6	17	48.33747	124.2659
76	1999	2	19	2	48.22788	123.5057
77	2001	8	16	23	48.24784	123.9169
78	1995	1	19	14	48.22746	123.4971
79	1997	3	25	23	48.35339	124.3206
80	1995	1	2	7	48.38132	124.4166
81	1997	5	21	6	48.22599	123.4203
82	1995	12	9	10	48.24007	123.7569
83	1996	2	12	19	48.33024	124.2411
84	1992	5	9	21	48.3934	124.4581
85	1994	6	12	16	48.22598	123.4189
86	1992	11	20	19	48.23587	123.6703
87	2001	4	23	14	48.30344	124.1492
88	2003	3	21	6	48.22577	123.402
89	1994	12	10	15	48.23475	123.6472
90	2003	7	23	19	48.31435	124.1864
91	1993	4	13	13	48.28667	124.0931
92	1997	2	17	17	48.29125	124.1084
93	1999	4	14	11	48.22659	123.4668
94	1994	9	24	12	48.3381	124.2681
95	2003	2	16	4	48.31399	124.1852
96	1998	7	29	17	48.3829	124.4221
97	1999	8	29	17	48.23931	123.7412
98	1997	1	7	11	48.35633	124.3307
99	1998	12	28	11	48.24231	123.8029
100	1998	7	5	14	48.31825	124.1998

Table XII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	S1_S2-COARSE.HAB
Grid W edge	125° 23.40180'W
Grid S edge	47° 48.72180' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^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)	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 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.

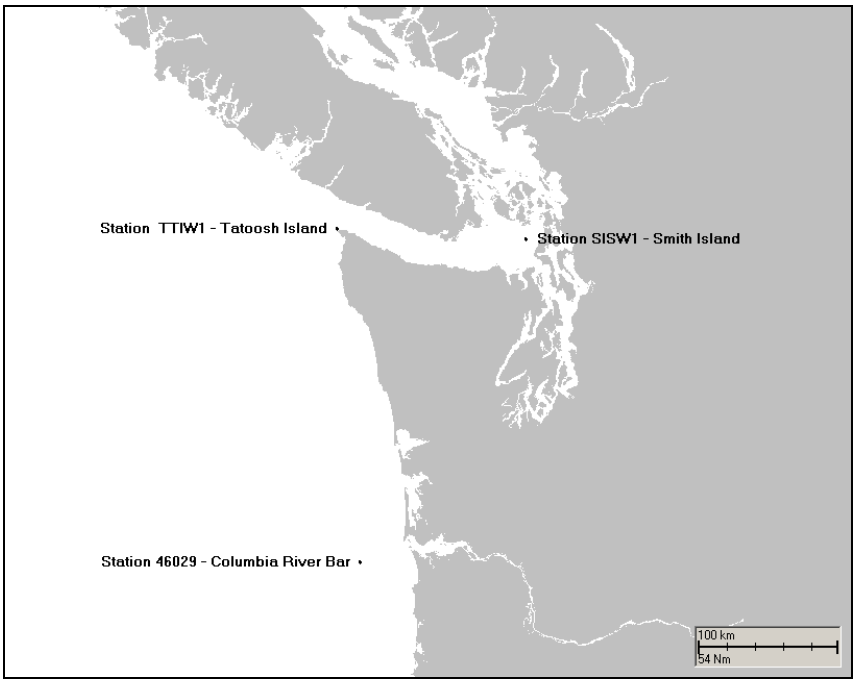


Figure XII.E-2 Wind Station Locations.

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 XIII: Model Results for Runs Assuming No Response for Strait of Juan de Fuca – 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

XIII.A. Introduction 1
XIII.B. Maps of Exposure Probability and Time First Exposed 1
XIII.C. Statistics for All Model Runs 3
XIII.D. Shoreline Areas Exposed by Shore Type 6
XIII.E. Exposure for Representative Individual Model Runs 8
XIII.F. Estimated Biological Impacts: Wildlife 11
XIII.G. Estimated Biological Impacts: Fish and Invertebrates 14
XIII.H. Estimated NRDA Costs: Habitat Restoration Costs 16
XIII.I. Estimated NRDA Costs: Washington Compensation schedule 19

List of Figures

Figure XIII.B-1. Strait of Juan de Fuca – 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 XIII.B-2. Strait of Juan de Fuca – 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 XIII.C-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 5
Figure XIII.C-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%). 5
Figure XIII.E-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 9
Figure XIII.E-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit. 9
Figure XIII.E-3. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island. 10

List of Tables

Table XIII.C-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 4
Table XIII.D-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 6
Table XIII.D-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 6
Table XIII.D-3. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 7
Table XIII.D-4. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 7
Table XIII.F-1. Strait of Juan de Fuca – 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..... 12
Table XIII.F-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Wildlife injury (as numbers lost)..... 13
Table IV.G-1. Strait of Juan de Fuca – 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. 15
Table XIII.G-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 15
Table XIII.H-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration..... 17
Table XIII.H-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 18
Table XIII.I-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 19

XIII.A. INTRODUCTION

The results of the stochastic scenario for the Strait of Juan de Fuca – 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).

XIII.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)

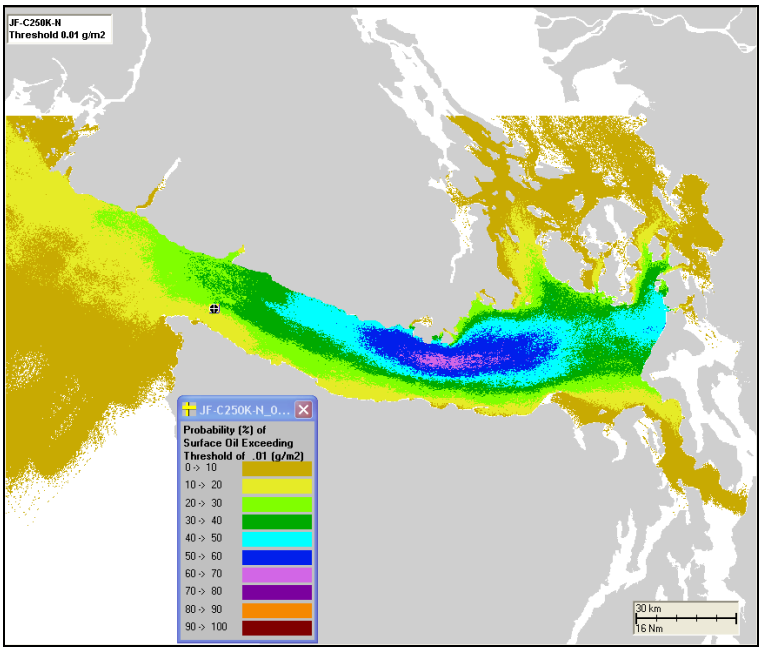


Figure XIII.B-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

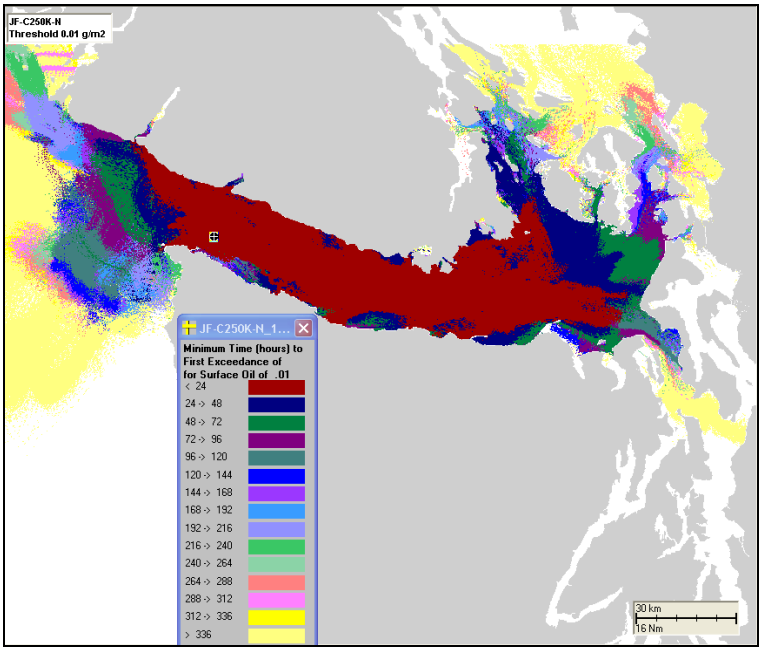


Figure XIII.B-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed on the Straits of Juan de Fuca using crude oil, maximum water column exposure of dissolved aromatic concentration never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

XIII.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 XIII.C-1. Strait of Juan de Fuca – 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)	1,023	846	2,716	0	783	2,537	4,380
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	917	809	2,535	0	669	2,440	4,246
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	81,200	56,903	195,007	0	64,736	190,917	290,686
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	81,185	56,904	194,993	0	64,721	190,912	290,686
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	80,542	56,990	194,523	0	63,642	190,606	290,535
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	73,555	55,536	184,626	0	56,984	187,285	287,921
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	30,989	14,918	60,824	0	29,481	58,447	76,802
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	9,256	2,565	14,386	0	9,055	12,998	16,558
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 (%)	18.15	7.27	32.69	0	18.63	29.94	32.38
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	12.7540	5.1137	22.9814	0	14.0207	20.1168	21.5251
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	1.46	1.18	3.82	0	1.05	4.13	5.17

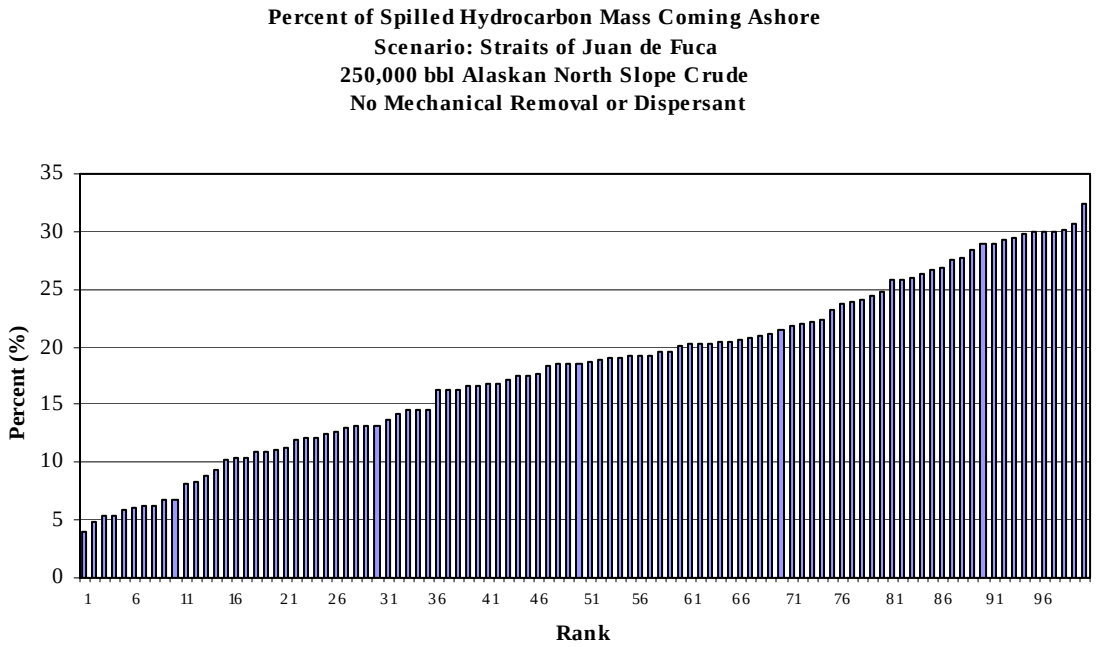


Figure XIII.C-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

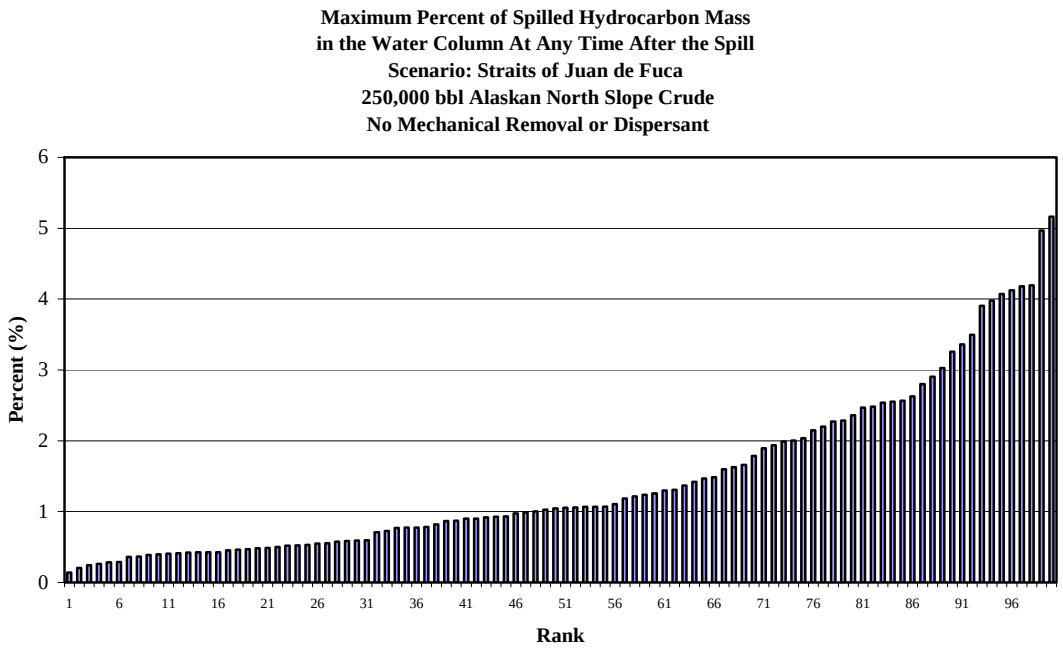


Figure XIII.C-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

XIII.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 XIII.D-1. Strait of Juan de Fuca – 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	2,325,460	782,353	554,611	594,224	157,709	236,563	0
95th	5,278,190	962,593	875,288	1,011,029	1,458,807	946,253	24,220
Maximum	6,239,653	1,100,589	1,436,473	1,250,410	2,089,643	2,207,924	39,427
Mean	2,441,489	390,404	473,022	362,787	612,699	600,870	1,707
Std. Dev.	1,395,886	234,669	237,484	250,580	595,032	574,482	5,592
Mean + 2 Std. Dev.	5,233,261	859,742	947,990	863,947	1,802,763	1,749,834	12,891

Table XIII.D-2. Strait of Juan de Fuca – 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	2,066,551	184,745	484,956	95,752	946,253	354,845	0
95th	4,299,447	368,364	695,236	594,224	1,143,389	1,498,234	0
Maximum	5,484,901	1,082,565	1,368,132	994,132	1,774,225	1,931,934	38,864
Mean	2,160,129	379,917	447,736	316,178	521,228	494,023	1,048
Std. Dev.	1,172,947	228,749	224,851	209,573	510,284	495,860	4,531
Mean + 2 Std. Dev.	4,506,023	837,415	897,438	735,324	1,541,796	1,485,743	10,110

Table XIII.D-3. Strait of Juan de Fuca – 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	1,542,731	196,573	413,986	183,055	118,282	630,835	0
95th	2,963,991	728,844	328,560	250,645	630,835	1,025,107	0
Maximum	3,840,406	979,490	1,050,083	597,040	1,261,670	1,458,807	34,921
Mean	1,626,191	341,959	382,155	226,453	339,468	335,525	631
Std. Dev.	786,019	202,773	181,837	137,943	360,699	382,363	3,773
Mean + 2 Std. Dev.	3,198,229	747,505	745,829	502,339	1,060,866	1,100,251	8,177

Table XIII.D-4. Strait of Juan de Fuca – 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	993,002	5,069	343,017	14,081	0	630,835	0
95th	1,421,632	316,545	126,167	42,243	394,272	512,553	29,852
Maximum	1,630,974	787,422	582,210	301,337	670,262	827,971	29,852
Mean	938,935	272,781	282,522	93,893	136,024	153,372	344
Std. Dev.	344,398	159,584	128,001	70,943	191,305	218,042	3,002
Mean + 2 Std. Dev.	1,627,731	591,949	538,524	235,779	518,634	589,456	6,348

XIII.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

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.

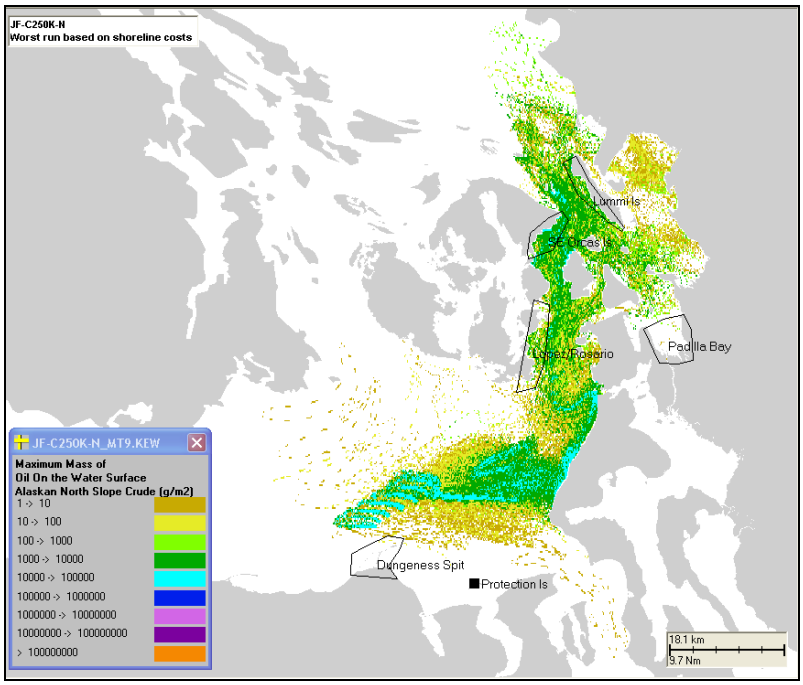


Figure XIII.E-1. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

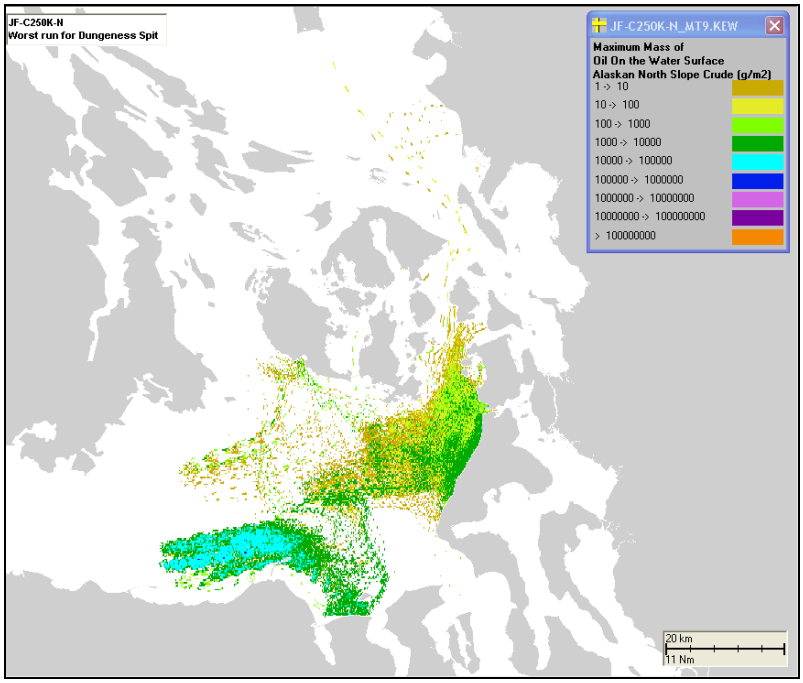


Figure XIII.E-2. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Dungeness Spit.

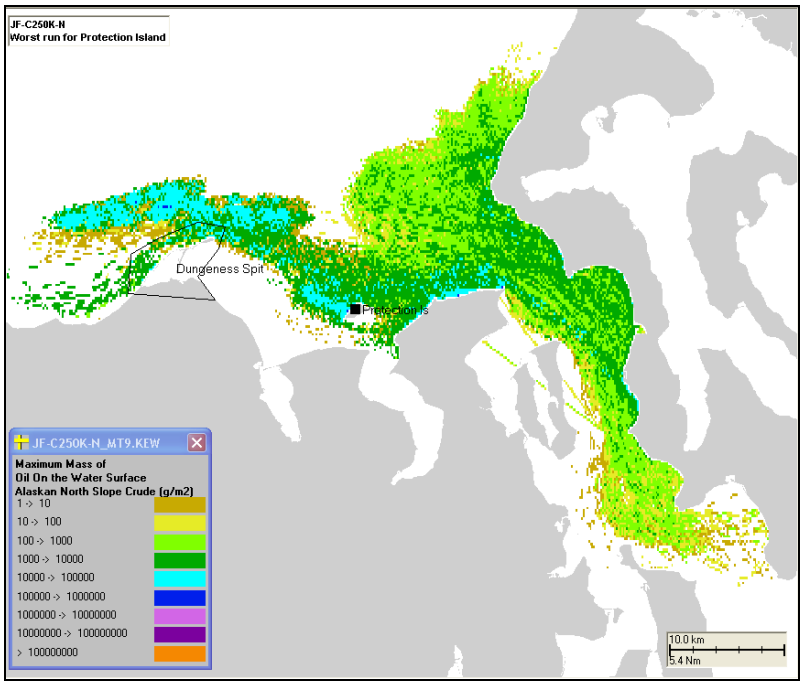


Figure XIII.E-3. Strait of Juan de Fuca – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Protection Island.

XIII.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table XIII.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 XIII.F-1. Strait of Juan de Fuca – 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	4.44E-05	15,814.86	19,745.59	0.7085	0.8418
Seabirds	1.59E-05	9,093.68	10,651.37	0.5178	0.7196
Wading birds	4.50E-05	-6.22	59.65	0.5890	0.7675
Shorebirds	6.38E-05	12.59	97.38	0.5198	0.7210
Raptors	8.35E-07	4.28	5.02	0.9853	0.9926
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	5.78E-08	-15.50	20.55	0.8025	0.8958
Pinnipeds (seals)	1.75E-06	-704.25	845.73	0.6732	0.8205
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 XIII.F-2. Strait of Juan de Fuca – 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	19,252	22,347	12	709	1	0	3	-	45,610	45,608	2.95
50th Percentile	115,943	31,791	54	3,395	1	0	14	-	153,820	153,806	14.44
95th Percentile	278,416	47,661	157	9,987	13	0	34	-	328,276	328,242	33.74
Mean	126,652	32,832	66	4,186	3	0	16	-	163,755	163,739	15.71
Std Dev (SD)	78,868	7,713	46	2,899	5	0	9	-	87,514	87,505	9.38
Mean - 2SD	-	17,407	-	-	-	-	-	-	-	-	-
Mean + 2SD	284,388	48,257	157	9,984	14	0	34	-	338,784	338,749	34.47

XIII.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table IV.G-1. Strait of Juan de Fuca – 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	1.10E+03	1,351.34	2,772.45	0.2674	0.5171
Total large pelagic fish	4.96E+03	697.34	8,897.53	0.4198	0.6480
Total demersal fish	9.97E+00	33.52	43.17	0.1104	0.3322
Total demersal invertebrates	3.08E+00	14.20	23.44	0.0386	0.1966
Total mollusks	1.43E+03	1,482.89	4,516.16	0.1886	0.4343

[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 XIII.G-2. Strait of Juan de Fuca – 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	1,664.95	2,114.51	36.37	15.08	1,890.59	12,141	17,862
50th Percentile	2,502.72	5,900.35	43.97	17.43	2,979.73	159,528	170,972
95th Percentile	5,825.08	20,913.91	74.13	26.75	7,298.92	403,740	437,878
Mean	2,956.55	7,951.18	48.09	18.71	3,569.72	174,703	189,247
Std Dev (SD)	1,293.25	5,844.14	11.74	3.63	1,681.28	117,105	125,939
Mean - 2SD	370.04	-	24.61	11.45	207.17	-	613
Mean + 2SD	5,543.06	19,639.46	71.57	25.96	6,932.28	408,913	441,125

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 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 XIII.H-1. Strait of Juan de Fuca – 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	1,664.9	2,502.7	5,825.1	2,956.5	370.0	5,543.1
Large pelagic fish	2,114.5	5,900.3	20,913.9	7,951.2	-	19,639.5
Demersal fish	36.4	44.0	74.1	48.1	24.6	71.6
Decapods	15.1	17.4	26.8	18.7	11.4	26.0
Molluscs	14,031	162,507	411,039	178,272	207	415,845
Birds:						
Waterfowl (# * kg each)	14,648	88,214	211,828	96,361	-	216,372
Seabirds (# * kg each)	24,432	34,759	52,110	35,896	19,031	52,761
Waders (# * kg each)	13	59	172	72	-	172
Shorebirds (# * kg each)	775	3,712	10,919	4,577	-	10,916
Raptors (# * kg each)	1.0	1.5	14.6	3.3	-	15.0
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	3.2	15.7	36.8	17.1	-	37.6
Cetaceans	0.0	0.0	0.1	0.1	-	0.1
Totals:						
Subtotal fish and invertebrates	17,862	170,972	437,878	189,247	613	441,125
Subtotal birds	39,869	126,744	275,043	136,910	19,031	280,236
Subtotal other wildlife	3	16	37	17	-	38
Total all species	57,734	297,732	712,958	326,174	19,644	721,399

Table XIII.H-2. Strait of Juan de Fuca – 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)	174.5	359.5	699.6	385.6	160.1	114.8	705.8
Saltmarsh Area (acres)	431.2	888.4	1,728.8	952.7	395.6	283.8	1,744.0
Saltmarsh Cost (millions of 2004$)	80.8	166.5	323.9	178.5	74.1	53.2	326.8
Eelgrass Area (m^2)	109.0	224.7	437.2	240.9	100.1	71.8	441.1
Eelgrass Area (acres)	269.5	555.1	1,080.3	595.4	247.2	177.3	1,089.8
Eelgrass Cost (millions of 2004$)	32.2	66.3	129.0	71.1	29.5	21.2	130.1

XIII.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XIII.I-1. Strait of Juan de Fuca – 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.)	20.79	22.69	25.55	22.64	19.84	25.44
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	218	238	268	238	208	267

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 XIV: Results of Alternative Response Scenarios for Strait of Juan de Fuca – 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

XIV.A. Introduction 1
XIV.B. Oil Fate Over Time 3
XIV.C. Estimated Biological Impacts: Wildlife 43
XIV.D. Estimated Biological Impacts: Fish and Invertebrates 47
XIV.E. Estimated NRDA Costs: Habitat Restoration Costs 49
XIV.F. Estimated NRDA Costs: Washington Compensation schedule 58

List of Figures

Figure XIV.A-1 Sensitive sites for location: Strait of Juan de Fuca. 2
Figure XIV.B-1 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 for the 99th percentile run (based on shore cost)..... 4
Figure XIV.B-2 Strait of Juan de Fuca - 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 XIV.B-3 Strait of Juan de Fuca - 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 XIV.B-4 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 for Dungeness Spit..... 7
Figure XIV.B-5 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit..... 8
Figure XIV.B-6 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit..... 9
Figure XIV.B-7 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit. 10
Figure XIV.B-8 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island..... 11
Figure XIV.B-9 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. 12
Figure XIV.B-10 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island..... 13
Figure XIV.B-11 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island..... 14

List of Tables

Table XIV.B-1 Strait of Juan de Fuca - 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). 15
Table XIV.B-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 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.) 17
Table XIV.B-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 99th percentile run (based on shore cost). 19
Table XIV.B-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 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.) 21
Table XIV.B-5 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit. 23
Table XIV.B-6 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit 25
Table XIV.B-7 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 worst run for Dungeness Spit 27
Table XIV.B-8 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 worst run for Dungeness Spit 29
Table XIV.B-9 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island. 31
Table XIV.B-10 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection Island. 33
Table XIV.B-11 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 worst run for Protection Island. 35
Table XIV.B-12 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 worst run for Protection Island. 37
Table XIV.B-13 Strait of Juan de Fuca - 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. 39

Table XIV.B-14 Strait of Juan de Fuca - 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. 40
Table XIV.B-15 Strait of Juan de Fuca - 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. 41
Table XIV.B-16 Strait of Juan de Fuca - 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. 42
Table XIV.C-1 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost). 43
Table XIV.C-2 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table XIV.C-3 Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table XIV.C-4 Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table XIV.D-1. Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XIV.D-2. Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XIV.D-3. Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
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). 48
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. 50
Table XIV.E-2. Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 51
Table XIV.E-3. Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 52
Table XIV.E-4. Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 53
Table XIV.E-5. 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. 54
Table XIV.E-6. Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 55

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. 56
Table XIV.E-8. Strait of Juan de Fuca - Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 57
Table XIV.F-1. Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XIV.F-2. Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XIV.F-3. Strait of Juan de Fuca - Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
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. 59

XIV.A. INTRODUCTION

The results of the alternate response scenarios for the Strait of Juan de Fuca – 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Dungeness Spit; and
3. the worst case run for impacts at Protection Island.

Locations of the sensitive sites are shown in Figure XIV.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.

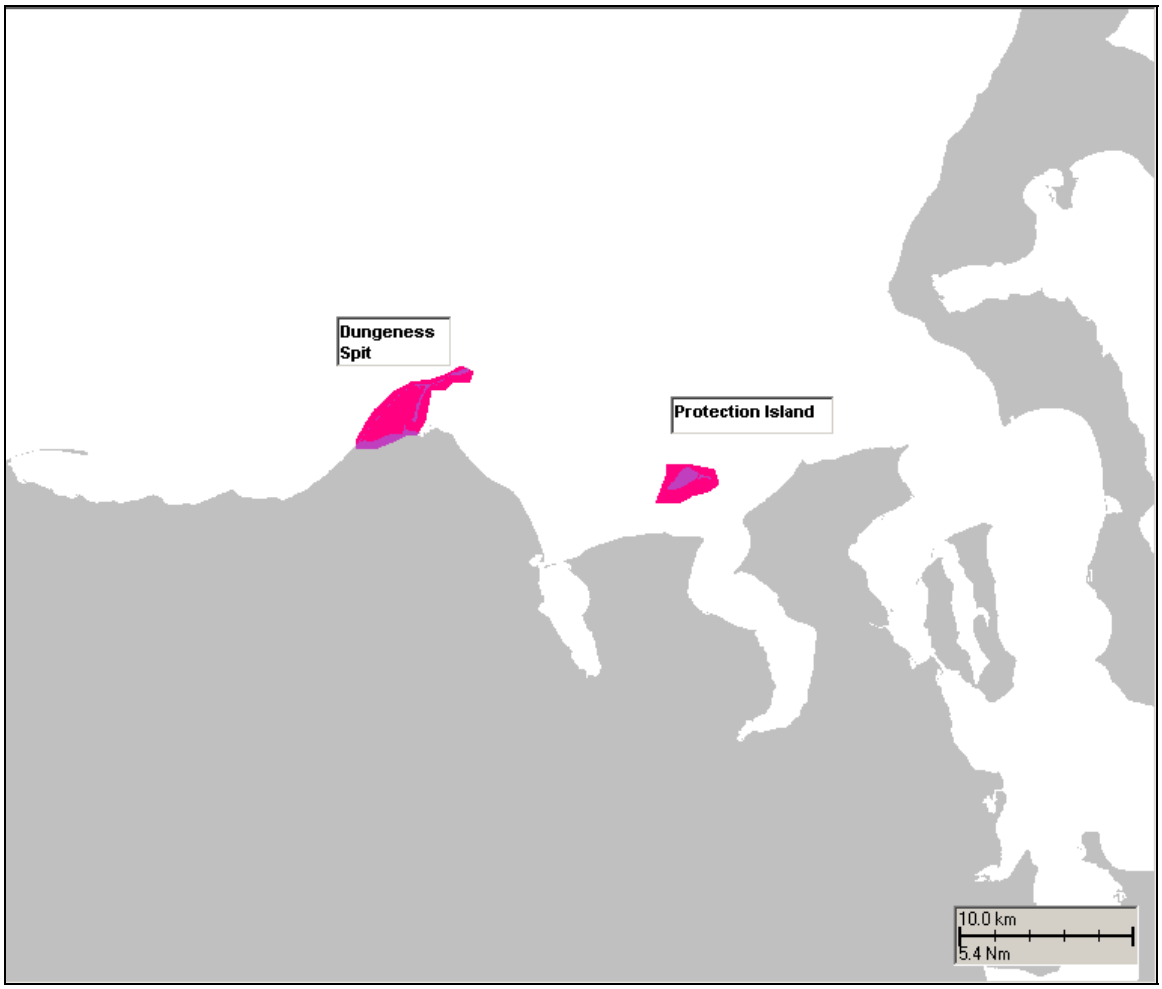
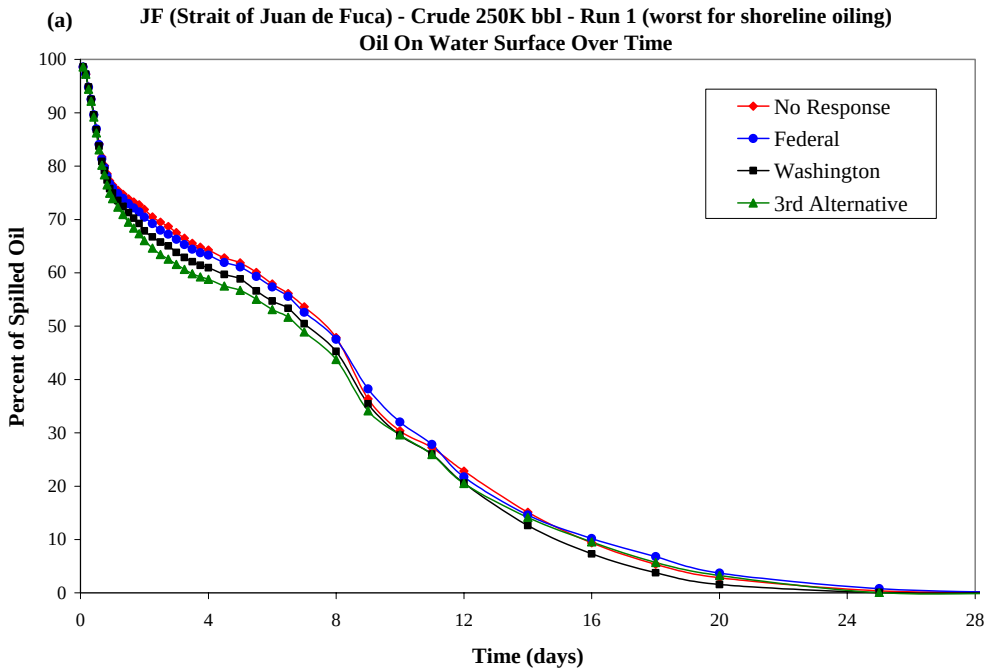


Figure XIV.A-1 Sensitive sites for location: Strait of Juan de Fuca.

XIV.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XIV.B-1 to XIV.B-12 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 XIV.B-1 to XIV.B-11 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 XIV.B-13 to XIV.B-16 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 Etkin 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.



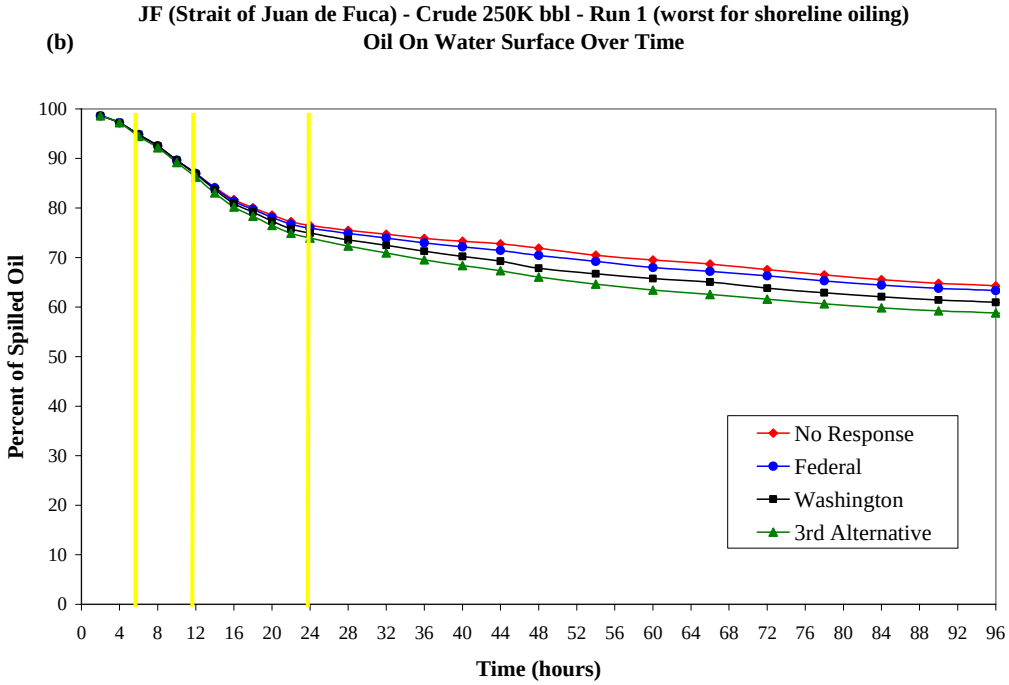
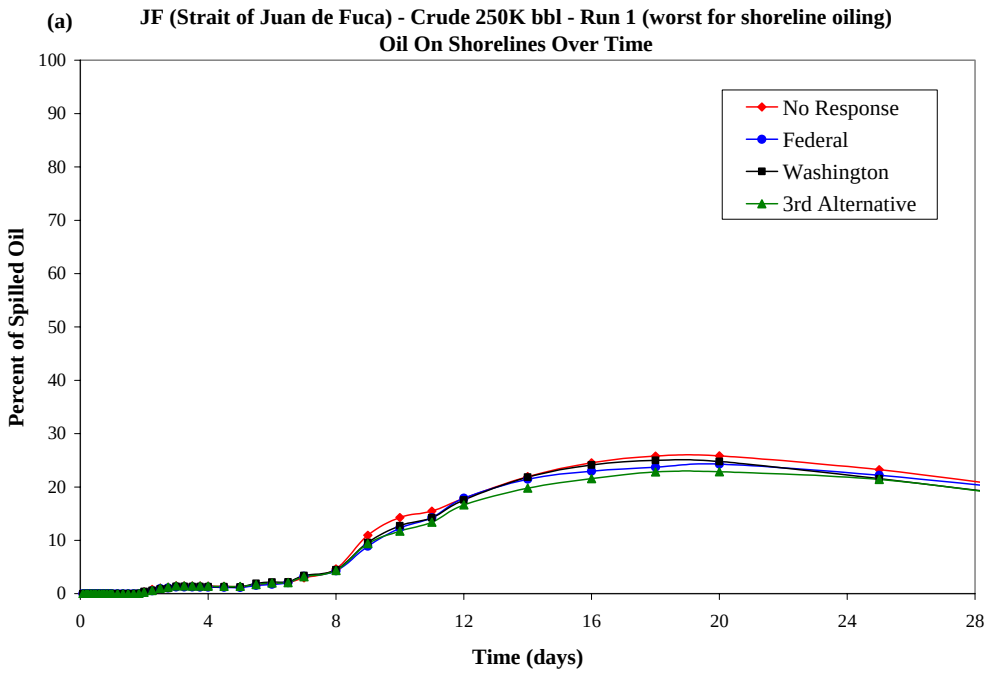


Figure XIV.B-1 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.



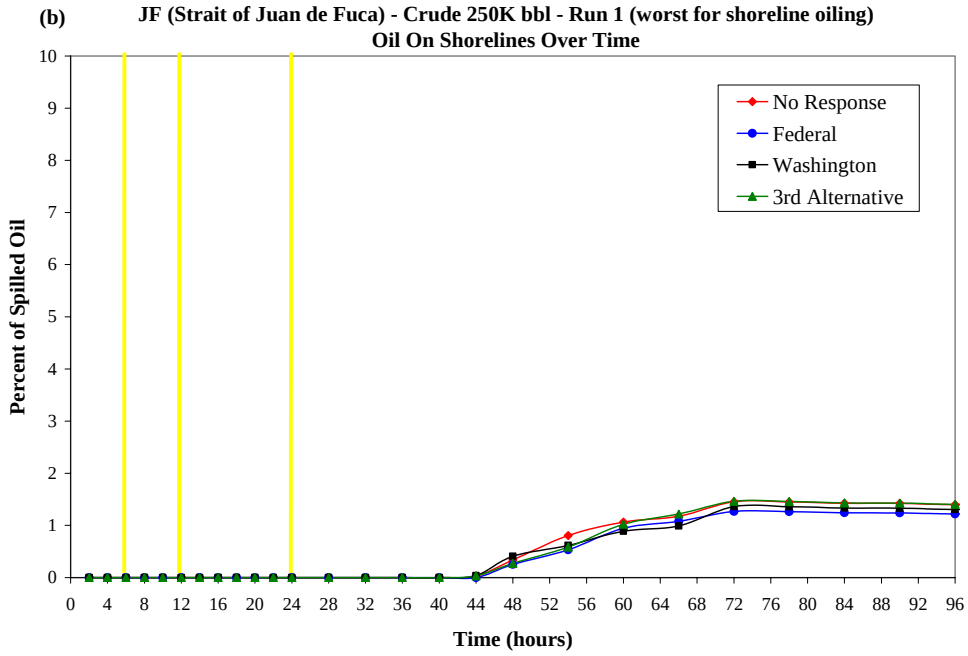


Figure XIV.B-2 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.

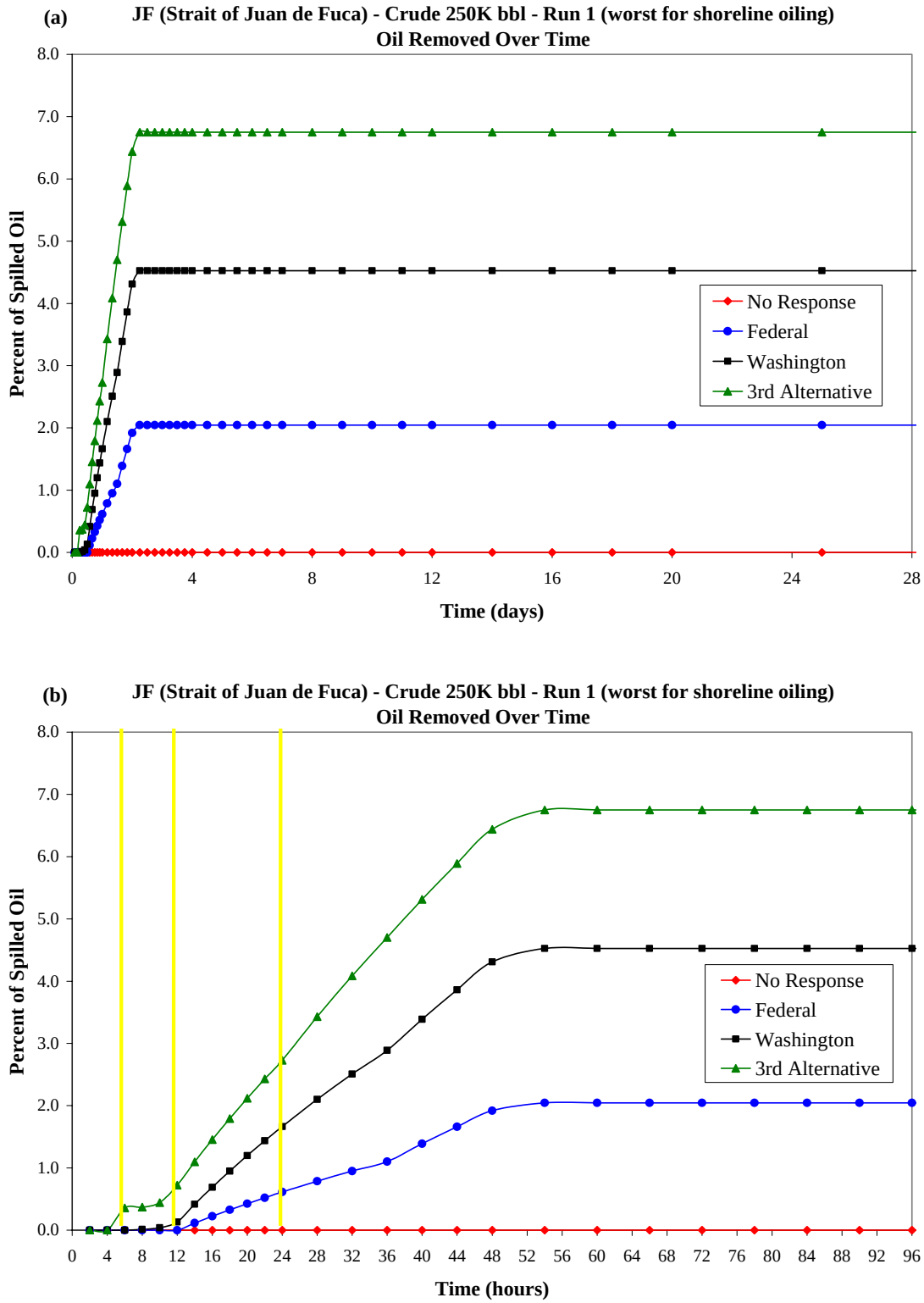
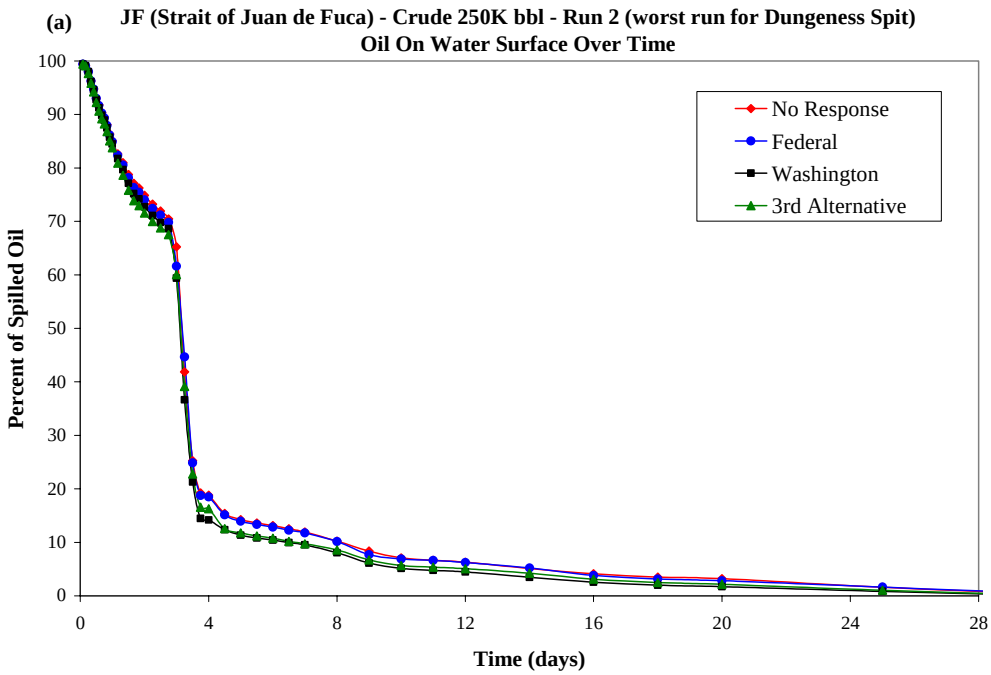


Figure XIV.B-3 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



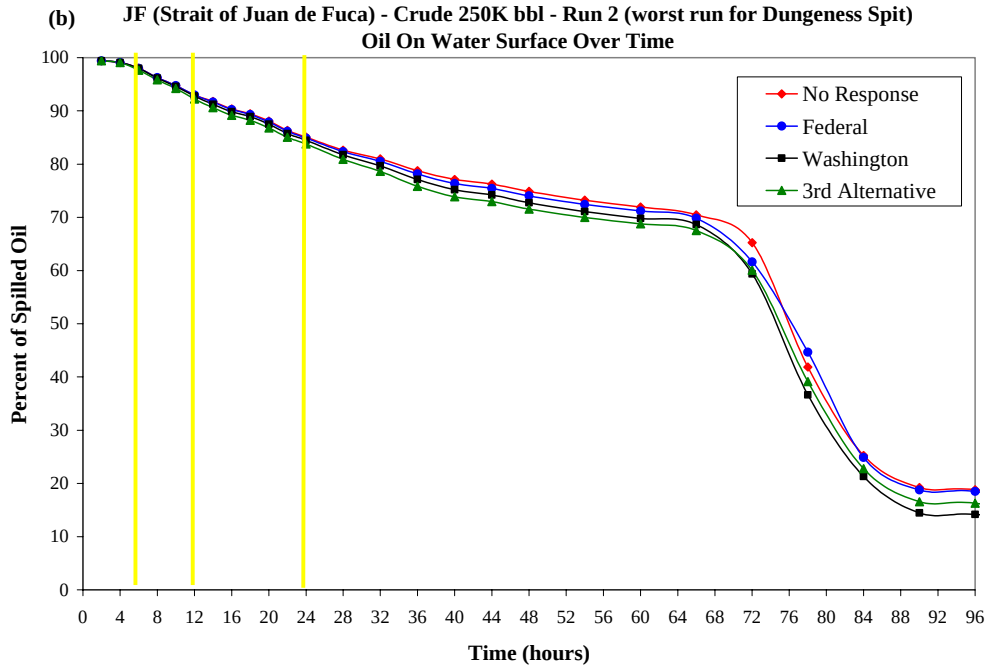


Figure XIV.B-4 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.

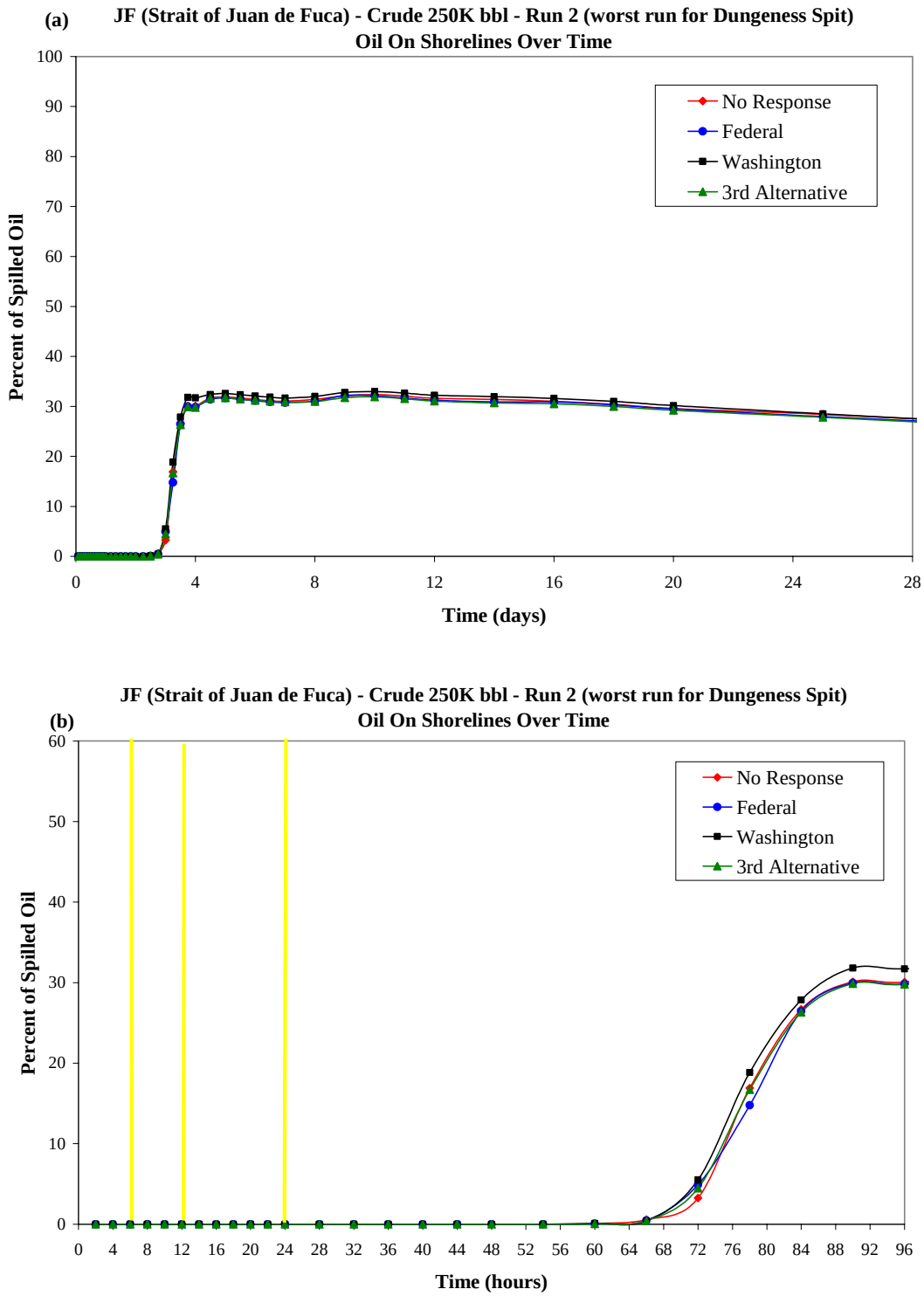
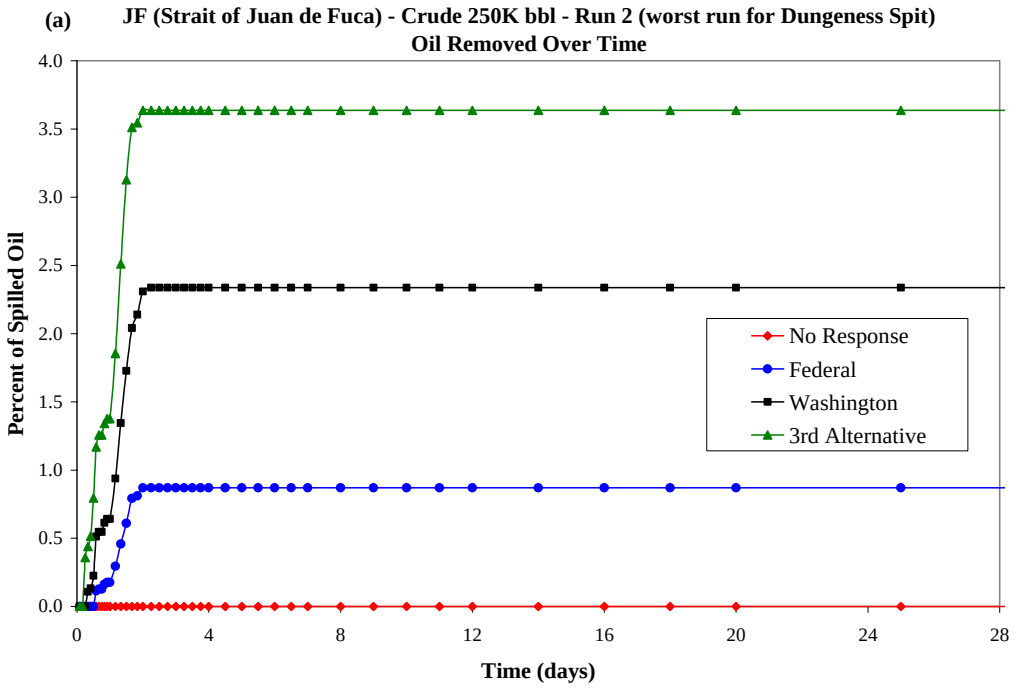


Figure XIV.B-5 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.



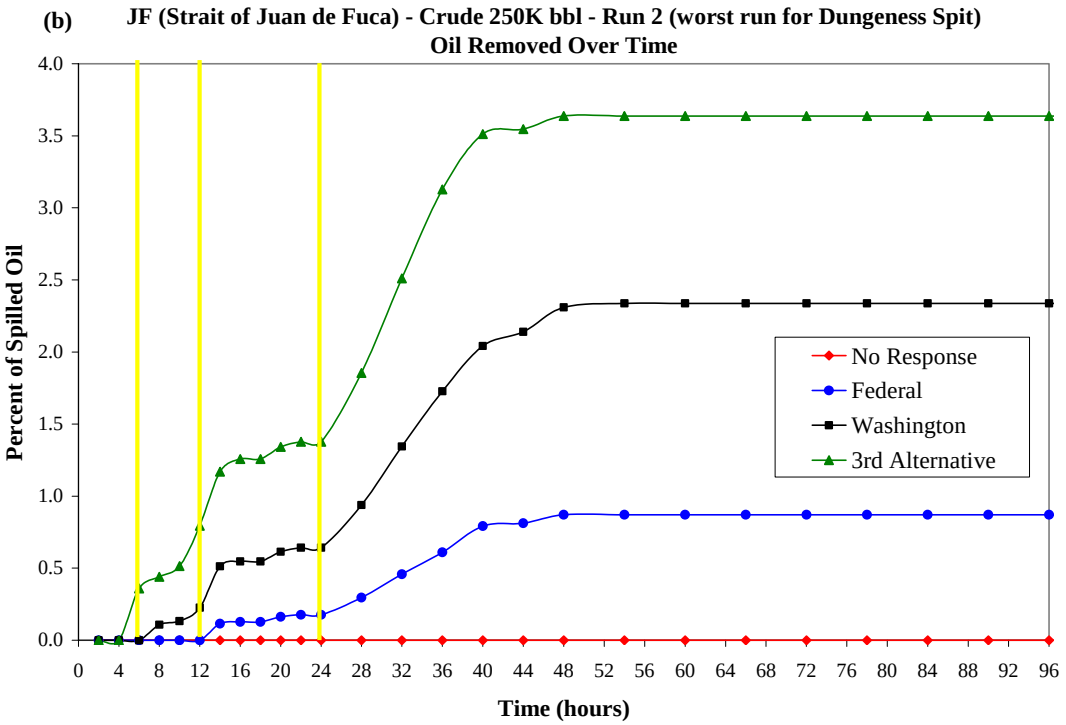


Figure XIV.B-6 Strait of Juan de Fuca - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Dungeness Spit. Part b of this figure is a subset of Part a.

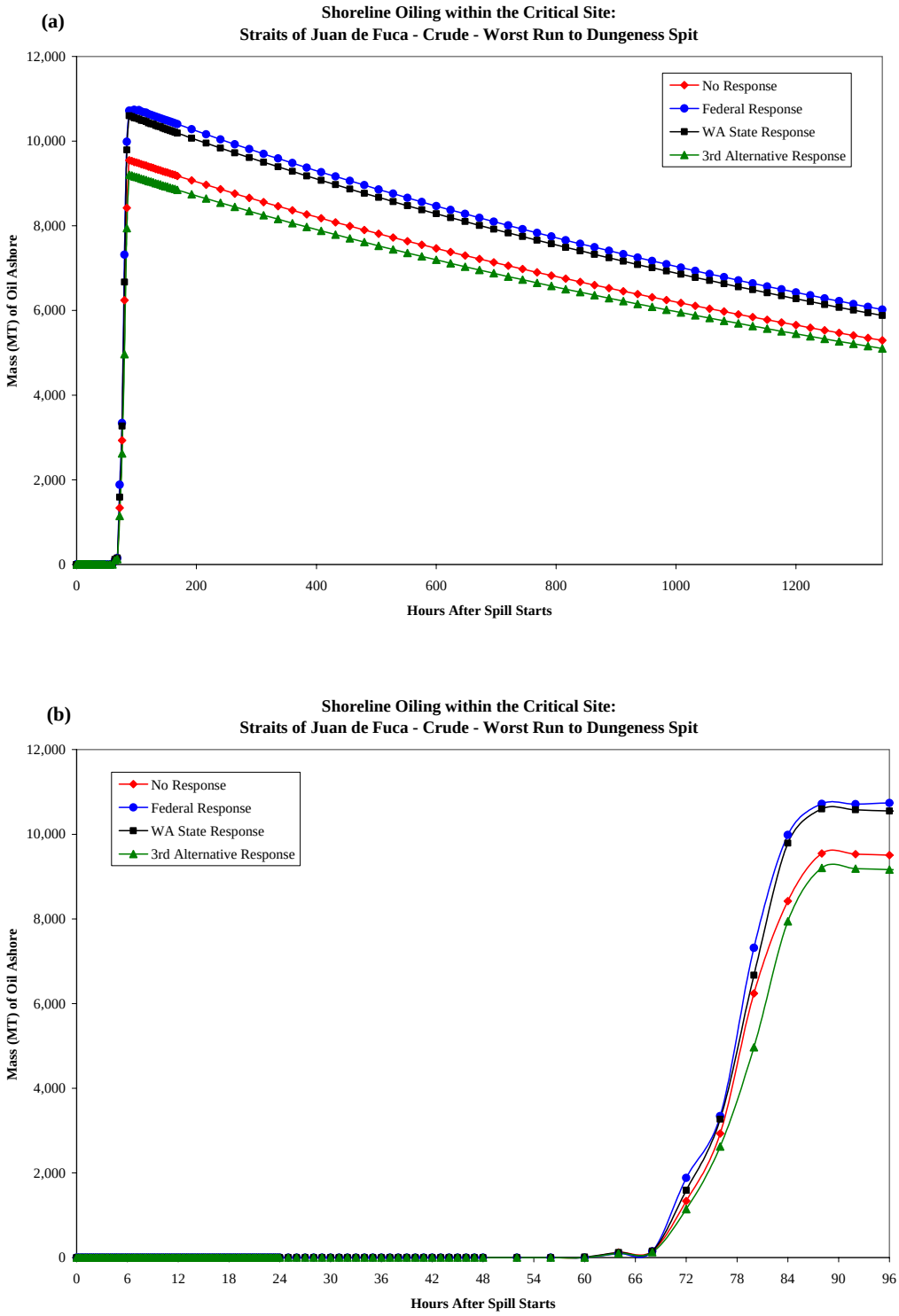
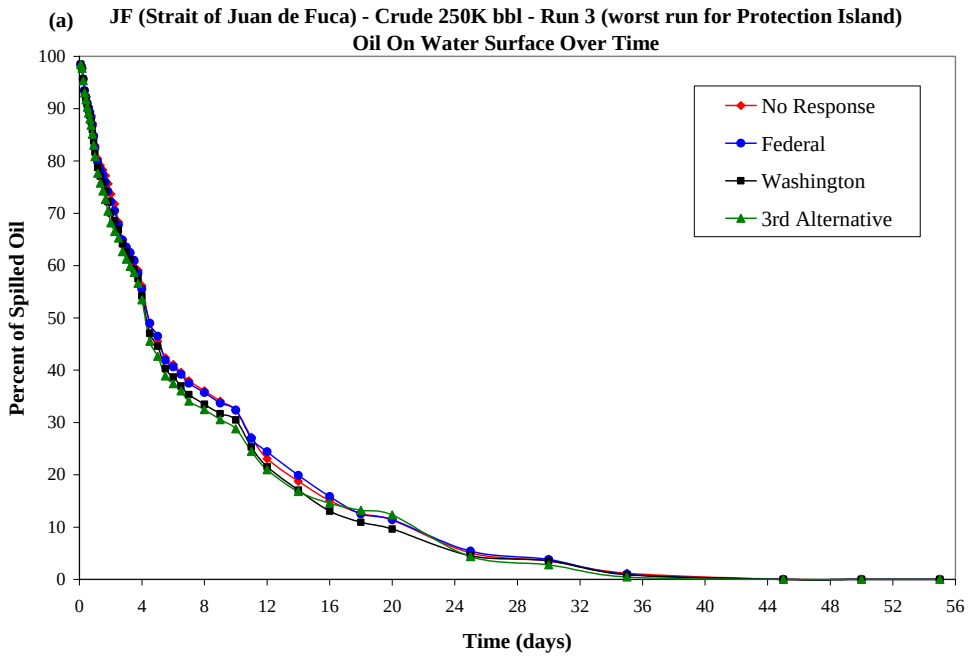


Figure XIV.B-7 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Dungeness Spit. Part b is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.



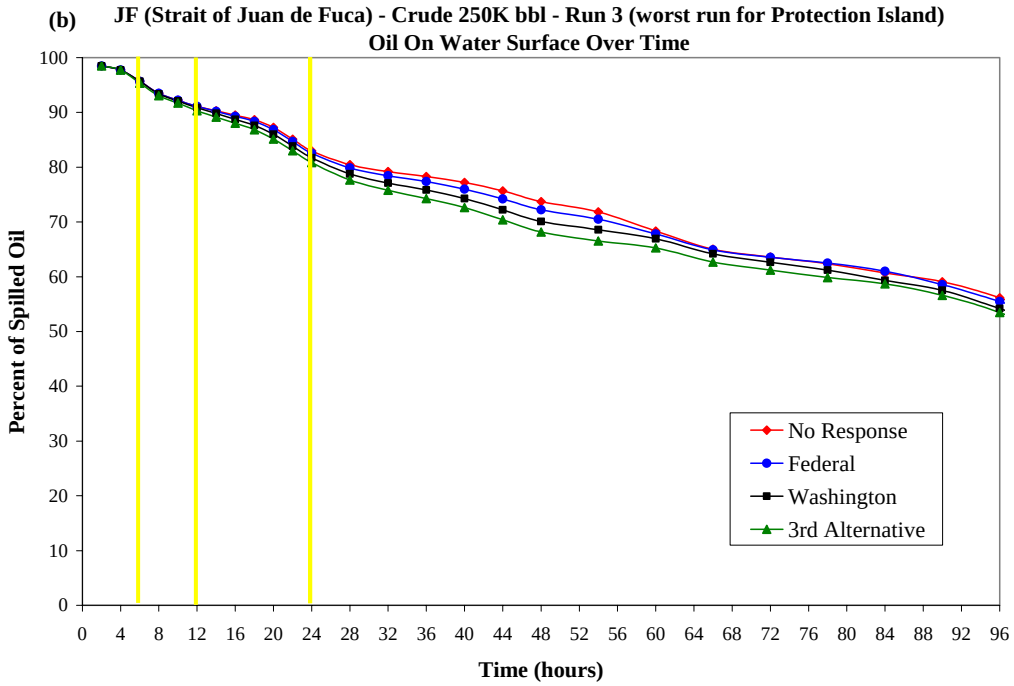


Figure XIV.B-8 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.

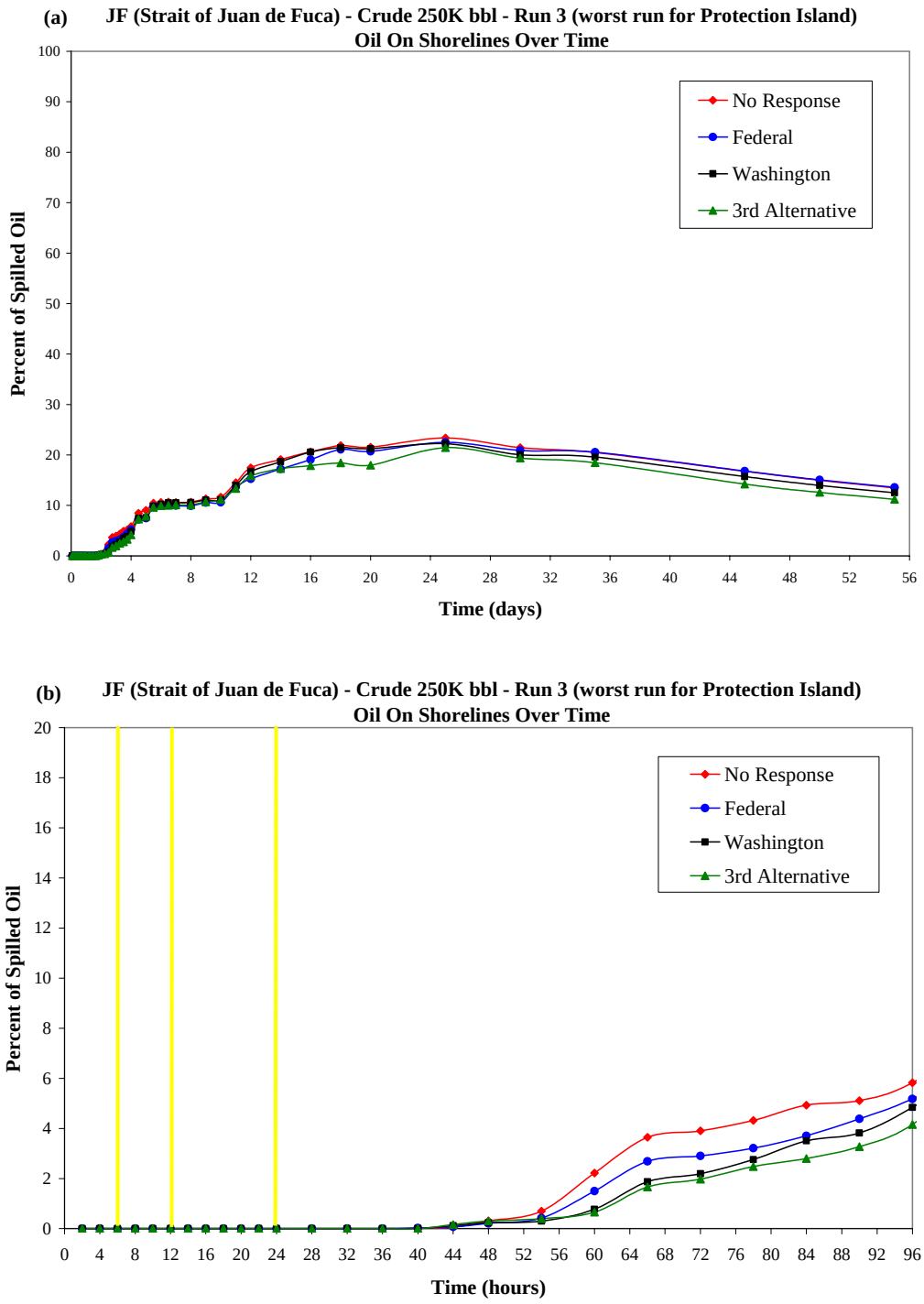
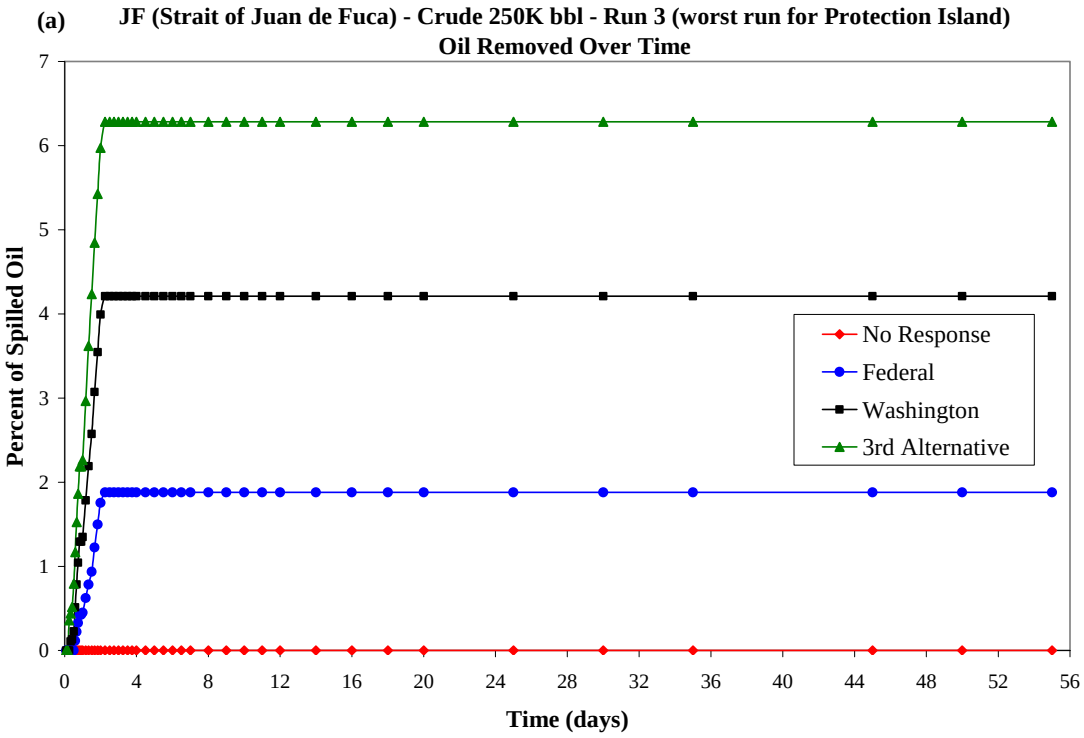


Figure XIV.B-9 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Protection Island. Part b of this figure is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.



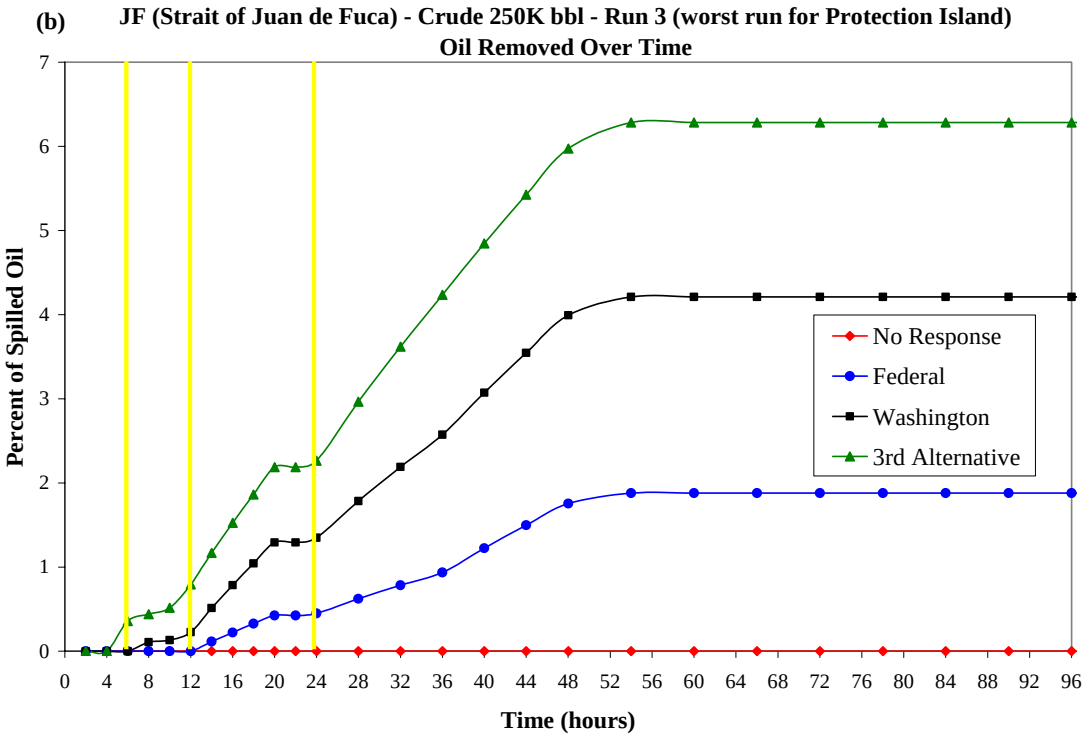


Figure XIV.B-10 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Protection Island. Part b of this figure is a subset of Part a.

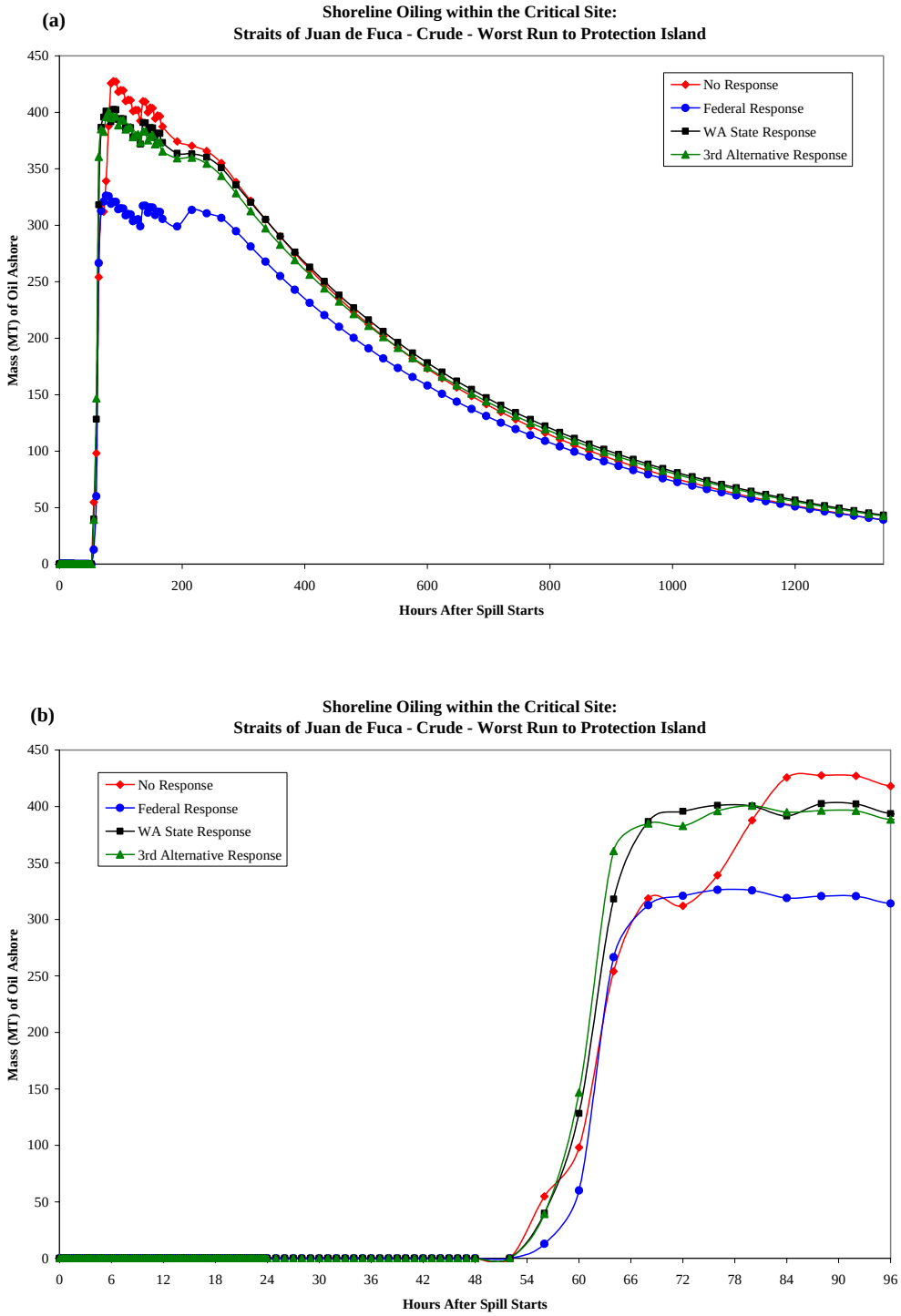


Figure XIV.B-11 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Protection Island. Part b is a subset of Part a. Differences between runs are less than the randomized variability in the model and are not significant.

Table XIV.B-1 Strait of Juan de Fuca - 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	98.61	1.35	0.00	0.00	0.00	0.05	0.00	0.00	98.61
4	0.17	97.24	2.60	0.08	0.00	0.00	0.09	0.00	0.00	97.24
6	0.25	94.82	4.98	0.03	0.00	0.00	0.17	0.00	0.00	94.82
8	0.33	92.53	7.21	0.01	0.00	0.00	0.24	0.00	0.00	92.53
10	0.42	89.64	10.00	0.05	0.00	0.00	0.32	0.00	0.00	89.64
12	0.50	86.92	12.63	0.06	0.00	0.00	0.39	0.00	0.00	86.92
14	0.58	84.16	15.30	0.07	0.00	0.00	0.47	0.00	0.00	84.16
16	0.67	81.71	17.65	0.10	0.00	0.00	0.53	0.00	0.00	81.71
18	0.75	80.06	19.25	0.09	0.00	0.00	0.60	0.00	0.00	80.06
20	0.83	78.56	20.68	0.10	0.00	0.00	0.67	0.00	0.00	78.56
22	0.92	77.26	21.88	0.13	0.00	0.00	0.73	0.00	0.00	77.26
24	1.00	76.48	22.64	0.08	0.00	0.00	0.80	0.00	0.00	76.48
28	1.17	75.50	23.53	0.05	0.00	0.00	0.92	0.00	0.00	75.50
32	1.33	74.73	24.18	0.05	0.00	0.00	1.05	0.00	0.00	74.73
36	1.50	73.87	24.92	0.04	0.00	0.00	1.17	0.00	0.00	73.87
40	1.67	73.30	25.37	0.03	0.00	0.00	1.30	0.00	0.00	73.30
44	1.83	72.77	25.75	0.03	0.00	0.03	1.42	0.00	0.00	72.77
48	2.00	71.89	26.20	0.03	0.00	0.34	1.54	0.00	0.00	71.89
54	2.25	70.48	26.97	0.03	0.00	0.81	1.72	0.00	0.00	70.48
60	2.50	69.49	27.51	0.04	0.00	1.06	1.89	0.00	0.00	69.49
66	2.75	68.69	28.02	0.04	0.01	1.18	2.07	0.00	0.00	68.69
72	3.00	67.56	28.68	0.05	0.01	1.45	2.24	0.00	0.00	67.56
78	3.25	66.49	29.56	0.05	0.03	1.45	2.42	0.00	0.00	66.49
84	3.50	65.54	30.37	0.05	0.04	1.43	2.59	0.00	0.00	65.54
90	3.75	64.80	30.94	0.04	0.05	1.42	2.75	0.00	0.00	64.80

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	64.28	31.30	0.05	0.05	1.40	2.92	0.00	0.00	64.28
108	4.50	62.81	32.45	0.05	0.07	1.37	3.24	0.00	0.00	62.81
120	5.00	61.88	33.07	0.05	0.09	1.34	3.56	0.00	0.00	61.88
132	5.50	60.09	34.22	0.05	0.11	1.64	3.88	0.00	0.00	60.09
144	6.00	57.91	35.76	0.08	0.14	1.93	4.18	0.00	0.00	57.91
156	6.50	56.14	37.03	0.06	0.16	2.13	4.48	0.00	0.00	56.14
168	7.00	53.64	38.36	0.08	0.19	2.97	4.77	0.00	0.00	53.64
192	8.00	47.88	41.60	0.25	0.31	4.65	5.32	0.00	0.00	47.88
216	9.00	36.38	46.11	0.22	0.49	10.98	5.82	0.00	0.00	36.38
240	10.00	30.38	47.93	0.31	0.79	14.29	6.30	0.00	0.00	30.38
264	11.00	27.25	48.99	0.36	1.17	15.49	6.75	0.00	0.00	27.25
288	12.00	22.82	50.13	0.35	1.64	17.87	7.19	0.00	0.00	22.82
336	14.00	15.13	51.66	0.58	2.68	21.94	8.01	0.00	0.00	15.13
384	16.00	9.39	52.63	0.53	4.14	24.53	8.78	0.00	0.00	9.39
432	18.00	5.35	53.24	0.51	5.61	25.80	9.48	0.00	0.00	5.35
480	20.00	2.84	53.60	0.48	7.13	25.83	10.14	0.00	0.00	2.84
600	25.00	0.09	53.93	0.37	10.51	23.24	11.56	0.00	0.30	0.39
720	30.00	0.00	53.94	0.29	13.15	19.59	12.73	0.00	0.30	0.30
840	35.00	0.00	53.94	0.22	15.15	16.68	13.71	0.00	0.30	0.30
1080	45.00	0.00	53.94	0.14	17.80	12.57	15.26	0.00	0.30	0.30
1200	50.00	0.00	53.94	0.13	18.67	11.10	15.87	0.00	0.30	0.30
1320	55.00	0.00	53.94	0.10	19.35	9.90	16.41	0.00	0.30	0.30
Maximum	56.00	99.13	53.94	0.58	19.48	25.83	16.51	0.00	0.30	99.13

Table XIV.B-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 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	98.61	1.35	0.00	0.00	0.00	0.05	0.00	0.00	98.61
4	0.17	97.22	2.60	0.10	0.00	0.00	0.09	0.00	0.00	97.22
6	0.25	94.81	4.97	0.05	0.00	0.00	0.17	0.00	0.00	94.81
8	0.33	92.53	7.18	0.04	0.00	0.00	0.24	0.00	0.00	92.53
10	0.42	89.64	9.94	0.10	0.00	0.00	0.32	0.00	0.00	89.64
12	0.50	86.98	12.55	0.08	0.00	0.00	0.39	0.00	0.00	86.98
14	0.58	84.04	15.19	0.19	0.00	0.00	0.47	0.11	0.00	84.04
16	0.67	81.35	17.51	0.38	0.00	0.00	0.53	0.22	0.00	81.35
18	0.75	79.74	19.09	0.24	0.00	0.00	0.60	0.33	0.00	79.74
20	0.83	78.12	20.49	0.30	0.00	0.00	0.67	0.43	0.00	78.12
22	0.92	76.72	21.67	0.36	0.00	0.00	0.73	0.52	0.00	76.72
24	1.00	75.94	22.40	0.25	0.00	0.00	0.80	0.61	0.00	75.94
28	1.17	74.85	23.27	0.16	0.00	0.00	0.92	0.79	0.00	74.85
32	1.33	73.95	23.90	0.15	0.00	0.00	1.05	0.95	0.00	73.95
36	1.50	72.98	24.62	0.13	0.00	0.00	1.17	1.10	0.00	72.98
40	1.67	72.15	25.05	0.12	0.00	0.00	1.29	1.39	0.00	72.15
44	1.83	71.44	25.39	0.10	0.00	0.00	1.41	1.66	0.00	71.44
48	2.00	70.41	25.79	0.10	0.00	0.25	1.53	1.92	0.00	70.41
54	2.25	69.22	26.40	0.09	0.00	0.53	1.70	2.04	0.00	69.22
60	2.50	68.01	27.02	0.10	0.00	0.95	1.88	2.04	0.00	68.01
66	2.75	67.22	27.52	0.09	0.01	1.08	2.05	2.04	0.00	67.22
72	3.00	66.28	28.08	0.10	0.01	1.27	2.22	2.04	0.00	66.28
78	3.25	65.29	28.88	0.10	0.02	1.27	2.39	2.04	0.00	65.29
84	3.50	64.43	29.60	0.10	0.03	1.24	2.55	2.04	0.00	64.43
90	3.75	63.77	30.11	0.08	0.04	1.24	2.72	2.04	0.00	63.77

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	63.30	30.43	0.08	0.04	1.22	2.88	2.04	0.00	63.30
108	4.50	61.96	31.46	0.08	0.06	1.19	3.20	2.04	0.00	61.96
120	5.00	61.10	32.02	0.08	0.08	1.17	3.52	2.04	0.00	61.10
132	5.50	59.30	33.11	0.08	0.10	1.54	3.82	2.04	0.00	59.30
144	6.00	57.36	34.48	0.12	0.12	1.75	4.13	2.04	0.00	57.36
156	6.50	55.56	35.70	0.09	0.14	2.05	4.42	2.04	0.00	55.56
168	7.00	52.58	37.14	0.11	0.17	3.26	4.70	2.04	0.00	52.58
192	8.00	47.55	40.03	0.59	0.28	4.26	5.25	2.04	0.00	47.55
216	9.00	38.22	44.26	0.39	0.44	8.89	5.75	2.04	0.00	38.22
240	10.00	32.04	46.29	0.39	0.71	12.31	6.22	2.04	0.00	32.04
264	11.00	27.83	47.65	0.46	1.10	14.24	6.67	2.04	0.00	27.83
288	12.00	21.75	49.20	0.42	1.61	17.89	7.10	2.04	0.00	21.75
336	14.00	14.61	50.72	0.59	2.65	21.48	7.90	2.04	0.00	14.61
384	16.00	10.18	51.55	0.53	4.07	22.98	8.65	2.04	0.00	10.18
432	18.00	6.80	52.10	0.55	5.44	23.72	9.34	2.04	0.00	6.80
480	20.00	3.70	52.56	0.56	6.86	24.29	9.98	2.04	0.00	3.70
600	25.00	0.79	53.02	0.42	10.15	22.20	11.37	2.04	0.01	0.80
720	30.00	0.05	53.08	0.31	12.76	19.22	12.53	2.04	0.01	0.06
840	35.00	0.00	53.08	0.23	14.78	16.36	13.49	2.04	0.01	0.01
1080	45.00	0.00	53.08	0.16	17.48	12.23	15.00	2.04	0.01	0.01
1200	50.00	0.00	53.08	0.14	18.37	10.75	15.60	2.04	0.01	0.01
1320	55.00	0.00	53.08	0.11	19.07	9.55	16.13	2.04	0.01	0.01
Maximum	56.00	99.13	53.08	0.96	19.21	24.29	16.22	2.04	0.01	99.13

Table XIV.B-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 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	98.61	1.35	0.00	0.00	0.00	0.05	0.00	0.00	98.61
4	0.17	97.22	2.60	0.10	0.00	0.00	0.09	0.00	0.00	97.22
6	0.25	94.81	4.97	0.05	0.00	0.00	0.17	0.00	0.00	94.81
8	0.33	92.52	7.18	0.04	0.00	0.00	0.24	0.01	0.00	92.52
10	0.42	89.60	9.94	0.10	0.00	0.00	0.32	0.04	0.00	89.60
12	0.50	86.85	12.55	0.08	0.00	0.00	0.39	0.13	0.00	86.85
14	0.58	83.74	15.19	0.19	0.00	0.00	0.47	0.42	0.00	83.74
16	0.67	80.89	17.51	0.38	0.00	0.00	0.53	0.69	0.00	80.89
18	0.75	79.17	19.07	0.21	0.00	0.00	0.60	0.95	0.00	79.17
20	0.83	77.37	20.47	0.30	0.00	0.00	0.67	1.20	0.00	77.37
22	0.92	75.78	21.64	0.42	0.00	0.00	0.73	1.44	0.00	75.78
24	1.00	74.93	22.37	0.24	0.00	0.00	0.79	1.67	0.00	74.93
28	1.17	73.57	23.23	0.18	0.00	0.00	0.92	2.10	0.00	73.57
32	1.33	72.45	23.85	0.15	0.00	0.00	1.04	2.51	0.00	72.45
36	1.50	71.28	24.56	0.11	0.00	0.00	1.16	2.89	0.00	71.28
40	1.67	70.25	24.98	0.10	0.00	0.00	1.28	3.39	0.00	70.25
44	1.83	69.27	25.34	0.09	0.00	0.04	1.39	3.86	0.00	69.27
48	2.00	67.85	25.83	0.09	0.00	0.41	1.51	4.31	0.00	67.85
54	2.25	66.73	26.37	0.08	0.00	0.62	1.68	4.53	0.00	66.73
60	2.50	65.77	26.88	0.09	0.00	0.89	1.85	4.53	0.00	65.77
66	2.75	65.04	27.34	0.08	0.01	0.99	2.01	4.53	0.00	65.04
72	3.00	63.83	28.00	0.09	0.01	1.36	2.18	4.53	0.00	63.83
78	3.25	62.90	28.77	0.09	0.03	1.36	2.34	4.53	0.00	62.90
84	3.50	62.07	29.45	0.09	0.03	1.33	2.50	4.53	0.00	62.07
90	3.75	61.43	29.94	0.07	0.04	1.33	2.66	4.53	0.00	61.43

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	60.97	30.25	0.08	0.05	1.31	2.81	4.53	0.00	60.97
108	4.50	59.69	31.24	0.07	0.07	1.28	3.12	4.53	0.00	59.69
120	5.00	58.86	31.78	0.07	0.08	1.26	3.43	4.53	0.00	58.86
132	5.50	56.63	33.00	0.08	0.10	1.94	3.73	4.53	0.00	56.63
144	6.00	54.73	34.32	0.11	0.13	2.16	4.02	4.53	0.00	54.73
156	6.50	53.34	35.38	0.08	0.16	2.22	4.30	4.53	0.00	53.34
168	7.00	50.44	36.79	0.10	0.18	3.38	4.57	4.53	0.00	50.44
192	8.00	45.28	39.65	0.69	0.29	4.47	5.10	4.53	0.00	45.28
216	9.00	35.44	43.94	0.45	0.45	9.60	5.58	4.53	0.00	35.44
240	10.00	29.57	45.84	0.54	0.74	12.75	6.03	4.53	0.00	29.57
264	11.00	26.03	47.07	0.54	1.12	14.26	6.46	4.53	0.00	26.03
288	12.00	20.57	48.49	0.37	1.61	17.56	6.88	4.53	0.00	20.57
336	14.00	12.64	50.12	0.59	2.64	21.84	7.65	4.53	0.00	12.64
384	16.00	7.32	51.05	0.54	4.07	24.13	8.36	4.53	0.00	7.32
432	18.00	3.76	51.61	0.54	5.53	25.01	9.02	4.53	0.00	3.76
480	20.00	1.59	51.95	0.50	7.02	24.78	9.63	4.53	0.00	1.59
600	25.00	0.00	52.17	0.35	10.35	21.58	10.94	4.53	0.08	0.08
720	30.00	0.00	52.17	0.29	12.86	18.05	12.02	4.53	0.08	0.08
840	35.00	0.00	52.17	0.22	14.78	15.31	12.92	4.53	0.08	0.08
1080	45.00	0.00	52.17	0.15	17.30	11.45	14.33	4.53	0.08	0.08
1200	50.00	0.00	52.17	0.39	17.85	10.09	14.89	4.53	0.08	0.08
1320	55.00	0.00	52.17	0.50	18.37	8.97	15.39	4.53	0.08	0.08
Maximum	56.00	99.13	52.17	0.69	18.64	25.09	15.57	4.53	0.08	99.13

Table XIV.B-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 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	98.61	1.35	0.00	0.00	0.00	0.05	0.00	0.00	98.61
4	0.17	97.22	2.60	0.10	0.00	0.00	0.09	0.00	0.00	97.22
6	0.25	94.45	4.97	0.05	0.00	0.00	0.17	0.36	0.00	94.45
8	0.33	92.16	7.18	0.04	0.00	0.00	0.24	0.37	0.00	92.16
10	0.42	89.21	9.93	0.10	0.00	0.00	0.32	0.44	0.00	89.21
12	0.50	86.25	12.53	0.11	0.00	0.00	0.39	0.72	0.00	86.25
14	0.58	83.06	15.16	0.22	0.00	0.00	0.46	1.10	0.00	83.06
16	0.67	80.18	17.47	0.36	0.00	0.00	0.53	1.45	0.00	80.18
18	0.75	78.35	19.03	0.23	0.00	0.00	0.60	1.79	0.00	78.35
20	0.83	76.47	20.42	0.33	0.00	0.00	0.66	2.12	0.00	76.47
22	0.92	74.91	21.59	0.35	0.00	0.00	0.73	2.43	0.00	74.91
24	1.00	73.92	22.32	0.24	0.00	0.00	0.79	2.73	0.00	73.92
28	1.17	72.30	23.19	0.17	0.00	0.00	0.91	3.43	0.00	72.30
32	1.33	70.93	23.80	0.15	0.00	0.00	1.03	4.09	0.00	70.93
36	1.50	69.52	24.49	0.14	0.00	0.00	1.15	4.70	0.00	69.52
40	1.67	68.39	24.91	0.12	0.00	0.00	1.26	5.31	0.00	68.39
44	1.83	67.32	25.26	0.12	0.00	0.03	1.38	5.89	0.00	67.32
48	2.00	66.05	25.64	0.11	0.00	0.27	1.49	6.44	0.00	66.05
54	2.25	64.65	26.25	0.11	0.00	0.58	1.65	6.75	0.00	64.65
60	2.50	63.43	26.87	0.11	0.00	1.02	1.81	6.75	0.00	63.43
66	2.75	62.56	27.39	0.10	0.01	1.22	1.97	6.75	0.00	62.56
72	3.00	61.57	27.96	0.11	0.01	1.46	2.13	6.75	0.00	61.57
78	3.25	60.65	28.71	0.11	0.03	1.46	2.29	6.75	0.00	60.65
84	3.50	59.85	29.38	0.11	0.03	1.43	2.45	6.75	0.00	59.85

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
90	3.75	59.24	29.86	0.07	0.05	1.43	2.60	6.75	0.00	59.24
96	4.00	58.80	30.16	0.08	0.05	1.41	2.75	6.75	0.00	58.80
108	4.50	57.54	31.13	0.08	0.07	1.38	3.05	6.75	0.00	57.54
120	5.00	56.74	31.65	0.09	0.09	1.35	3.34	6.75	0.00	56.74
132	5.50	55.03	32.68	0.09	0.11	1.71	3.63	6.75	0.00	55.03
144	6.00	53.11	34.00	0.11	0.14	1.98	3.91	6.75	0.00	53.11
156	6.50	51.69	35.05	0.09	0.16	2.07	4.19	6.75	0.00	51.69
168	7.00	48.90	36.41	0.11	0.19	3.19	4.45	6.75	0.00	48.90
192	8.00	43.78	39.20	0.68	0.30	4.34	4.96	6.75	0.00	43.78
216	9.00	34.15	43.36	0.48	0.46	9.37	5.43	6.75	0.00	34.15
240	10.00	29.61	44.94	0.37	0.73	11.74	5.87	6.75	0.00	29.61
264	11.00	25.93	46.19	0.37	1.07	13.39	6.28	6.75	0.00	25.93
288	12.00	20.54	47.53	0.35	1.51	16.63	6.69	6.75	0.00	20.54
336	14.00	14.15	48.89	0.53	2.46	19.78	7.44	6.75	0.00	14.15
384	16.00	9.54	49.74	0.50	3.74	21.59	8.14	6.75	0.00	9.54
432	18.00	5.70	50.35	0.53	5.04	22.84	8.79	6.75	0.00	5.70
480	20.00	3.27	50.71	0.63	6.37	22.88	9.39	6.75	0.00	3.27
600	25.00	0.03	51.22	0.36	9.54	21.41	10.69	6.75	0.00	0.03
720	30.00	0.00	51.22	0.29	12.03	17.94	11.76	6.75	0.00	0.00
840	35.00	0.00	51.22	0.22	13.94	15.21	12.66	6.75	0.00	0.00
1080	45.00	0.00	51.22	0.15	16.47	11.35	14.07	6.75	0.00	0.00
1200	50.00	0.00	51.22	0.13	17.30	9.97	14.62	6.75	0.00	0.00
1320	55.00	0.00	51.22	0.11	17.96	8.85	15.11	6.75	0.00	0.00
Maximum	56.00	99.13	51.22	0.83	18.09	22.96	15.20	6.75	0.00	99.13

Table XIV.B-5 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.40	0.56	0.00	0.00	0.00	0.05	0.00	0.00	99.40
4	0.17	99.10	0.81	0.00	0.00	0.00	0.09	0.00	0.00	99.10
6	0.25	98.01	1.82	0.00	0.00	0.00	0.17	0.00	0.00	98.01
8	0.33	96.26	3.48	0.00	0.00	0.00	0.25	0.00	0.00	96.26
10	0.42	94.73	4.94	0.00	0.00	0.00	0.33	0.00	0.00	94.73
12	0.50	93.00	6.59	0.00	0.00	0.00	0.41	0.00	0.00	93.00
14	0.58	91.76	7.75	0.00	0.00	0.00	0.49	0.00	0.00	91.76
16	0.67	90.38	9.06	0.00	0.00	0.00	0.56	0.00	0.00	90.38
18	0.75	89.45	9.92	0.00	0.00	0.00	0.64	0.00	0.00	89.45
20	0.83	88.07	11.22	0.00	0.00	0.00	0.71	0.00	0.00	88.07
22	0.92	86.33	12.88	0.00	0.00	0.00	0.78	0.00	0.00	86.33
24	1.00	85.06	14.08	0.00	0.00	0.00	0.85	0.00	0.00	85.06
28	1.17	82.64	16.37	0.00	0.00	0.00	0.99	0.00	0.00	82.64
32	1.33	80.97	17.90	0.00	0.00	0.00	1.13	0.00	0.00	80.97
36	1.50	78.75	19.99	0.00	0.00	0.00	1.26	0.00	0.00	78.75
40	1.67	77.13	21.48	0.00	0.00	0.00	1.39	0.00	0.00	77.13
44	1.83	76.23	22.25	0.00	0.00	0.00	1.52	0.00	0.00	76.23
48	2.00	74.88	23.46	0.01	0.00	0.00	1.65	0.00	0.00	74.88
54	2.25	73.23	24.93	0.00	0.00	0.00	1.83	0.00	0.00	73.23
60	2.50	71.94	25.95	0.00	0.00	0.09	2.01	0.00	0.00	71.94
66	2.75	70.48	26.76	0.00	0.00	0.57	2.19	0.00	0.00	70.48
72	3.00	65.24	29.12	0.01	0.00	3.26	2.37	0.00	0.00	65.24
78	3.25	41.88	38.67	0.01	0.00	16.91	2.53	0.00	0.00	41.88
84	3.50	25.26	45.35	0.04	0.00	26.68	2.67	0.00	0.00	25.26
90	3.75	19.24	47.81	0.02	0.01	30.11	2.81	0.00	0.00	19.24
96	4.00	18.82	48.10	0.07	0.01	30.06	2.94	0.00	0.00	18.82

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	15.40	49.59	0.11	0.05	31.66	3.19	0.00	0.00	15.40
120	5.00	14.25	50.17	0.14	0.10	31.90	3.44	0.00	0.00	14.25
132	5.50	13.62	50.69	0.14	0.20	31.66	3.69	0.00	0.00	13.62
144	6.00	13.13	51.13	0.12	0.28	31.41	3.93	0.00	0.00	13.13
156	6.50	12.53	51.65	0.12	0.37	31.17	4.16	0.00	0.00	12.53
168	7.00	11.96	52.04	0.13	0.44	31.04	4.40	0.00	0.00	11.96
192	8.00	10.22	52.77	0.14	0.58	31.44	4.85	0.00	0.00	10.22
216	9.00	8.39	53.31	0.16	0.74	32.10	5.29	0.00	0.00	8.39
240	10.00	7.13	53.66	0.19	0.92	32.38	5.72	0.00	0.00	7.13
264	11.00	6.67	53.81	0.19	1.13	32.06	6.15	0.00	0.00	6.67
288	12.00	6.30	53.98	0.16	1.39	31.63	6.56	0.00	0.00	6.30
336	14.00	5.12	54.20	0.21	1.72	31.39	7.36	0.00	0.00	5.12
384	16.00	4.12	54.35	0.17	2.18	31.05	8.14	0.00	0.00	4.12
432	18.00	3.51	54.42	0.16	2.61	30.41	8.88	0.00	0.00	3.51
480	20.00	3.21	54.46	0.16	3.00	29.56	9.60	0.00	0.00	3.21
600	25.00	1.60	54.66	0.15	3.90	28.40	11.29	0.00	0.00	1.60
720	30.00	0.45	54.81	0.16	4.82	26.93	12.83	0.00	0.00	0.45
840	35.00	0.04	54.86	0.13	5.70	25.04	14.23	0.00	0.00	0.04
1080	45.00	0.00	54.87	0.07	6.90	21.49	16.68	0.00	0.00	0.00
1200	50.00	0.00	54.87	0.06	7.28	20.03	17.76	0.00	0.00	0.00
1320	55.00	0.00	54.87	0.06	7.56	18.75	18.76	0.00	0.00	0.00
Maximum	56.00	99.57	54.87	0.21	7.63	32.38	18.95	0.00	0.00	99.57

Table XIV.B-6 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Dungeness Spit.

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	99.40	0.56	0.00	0.00	0.00	0.05	0.00	0.00	99.40
4	0.17	99.10	0.81	0.00	0.00	0.00	0.09	0.00	0.00	99.10
6	0.25	98.01	1.82	0.00	0.00	0.00	0.17	0.00	0.00	98.01
8	0.33	96.26	3.48	0.00	0.00	0.00	0.25	0.00	0.00	96.26
10	0.42	94.73	4.94	0.00	0.00	0.00	0.33	0.00	0.00	94.73
12	0.50	93.00	6.59	0.00	0.00	0.00	0.41	0.00	0.00	93.00
14	0.58	91.65	7.75	0.00	0.00	0.00	0.49	0.11	0.00	91.65
16	0.67	90.25	9.06	0.00	0.00	0.00	0.56	0.13	0.00	90.25
18	0.75	89.32	9.92	0.00	0.00	0.00	0.64	0.13	0.00	89.32
20	0.83	87.91	11.21	0.00	0.00	0.00	0.71	0.16	0.00	87.91
22	0.92	86.16	12.88	0.00	0.00	0.00	0.78	0.18	0.00	86.16
24	1.00	84.89	14.08	0.00	0.00	0.00	0.85	0.18	0.00	84.89
28	1.17	82.35	16.36	0.00	0.00	0.00	0.99	0.30	0.00	82.35
32	1.33	80.52	17.89	0.00	0.00	0.00	1.13	0.46	0.00	80.52
36	1.50	78.16	19.97	0.00	0.00	0.00	1.26	0.61	0.00	78.16
40	1.67	76.36	21.45	0.00	0.00	0.00	1.39	0.79	0.00	76.36
44	1.83	75.45	22.22	0.00	0.00	0.00	1.52	0.81	0.00	75.45
48	2.00	74.05	23.43	0.01	0.00	0.00	1.64	0.87	0.00	74.05
54	2.25	72.41	24.89	0.00	0.00	0.00	1.82	0.87	0.00	72.41
60	2.50	71.19	25.88	0.00	0.00	0.06	2.00	0.87	0.00	71.19
66	2.75	69.85	26.64	0.00	0.00	0.46	2.18	0.87	0.00	69.85
72	3.00	61.64	30.20	0.02	0.00	4.93	2.35	0.87	0.00	61.64
78	3.25	44.67	37.17	0.01	0.00	14.77	2.51	0.87	0.00	44.67
84	3.50	24.88	45.10	0.04	0.00	26.45	2.66	0.87	0.00	24.88
90	3.75	18.78	47.57	0.02	0.01	29.96	2.79	0.87	0.00	18.78
96	4.00	18.48	47.81	0.07	0.01	29.84	2.92	0.87	0.00	18.48

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	15.12	49.27	0.11	0.05	31.41	3.17	0.87	0.00	15.12
120	5.00	13.96	49.85	0.14	0.11	31.66	3.42	0.87	0.00	13.96
132	5.50	13.34	50.36	0.14	0.20	31.42	3.66	0.87	0.00	13.34
144	6.00	12.86	50.80	0.13	0.29	31.16	3.90	0.87	0.00	12.86
156	6.50	12.27	51.31	0.13	0.38	30.92	4.13	0.87	0.00	12.27
168	7.00	11.76	51.68	0.13	0.45	30.75	4.36	0.87	0.00	11.76
192	8.00	10.15	52.39	0.14	0.59	31.06	4.81	0.87	0.00	10.15
216	9.00	7.72	53.05	0.17	0.75	32.19	5.25	0.87	0.00	7.72
240	10.00	6.91	53.30	0.19	0.93	32.12	5.67	0.87	0.00	6.91
264	11.00	6.61	53.43	0.19	1.14	31.68	6.09	0.87	0.00	6.61
288	12.00	6.25	53.60	0.16	1.39	31.24	6.50	0.87	0.00	6.25
336	14.00	5.23	53.81	0.20	1.71	30.90	7.29	0.87	0.00	5.23
384	16.00	3.83	54.00	0.17	2.16	30.91	8.06	0.87	0.00	3.83
432	18.00	3.17	54.09	0.16	2.60	30.32	8.80	0.87	0.00	3.17
480	20.00	2.85	54.13	0.16	2.99	29.49	9.51	0.87	0.00	2.85
600	25.00	1.66	54.28	0.14	3.90	27.97	11.17	0.87	0.00	1.66
720	30.00	0.53	54.43	0.16	4.78	26.55	12.69	0.87	0.00	0.53
840	35.00	0.09	54.48	0.13	5.61	24.74	14.08	0.87	0.00	0.09
1080	45.00	0.00	54.49	0.07	6.78	21.29	16.50	0.87	0.00	0.00
1200	50.00	0.00	54.49	0.06	7.16	19.85	17.57	0.87	0.00	0.00
1320	55.00	0.00	54.49	0.06	7.44	18.57	18.56	0.87	0.00	0.00
Maximum	56.00	99.57	54.49	0.20	7.51	32.19	18.75	0.87	0.00	99.57

Table XIV.B-7 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 worst run for Dungeness Spit.

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	99.40	0.56	0.00	0.00	0.00	0.05	0.00	0.00	99.40
4	0.17	99.10	0.81	0.00	0.00	0.00	0.09	0.00	0.00	99.10
6	0.25	98.01	1.82	0.00	0.00	0.00	0.17	0.00	0.00	98.01
8	0.33	96.16	3.48	0.00	0.00	0.00	0.25	0.11	0.00	96.16
10	0.42	94.60	4.94	0.00	0.00	0.00	0.33	0.13	0.00	94.60
12	0.50	92.77	6.59	0.00	0.00	0.00	0.41	0.23	0.00	92.77
14	0.58	91.25	7.75	0.00	0.00	0.00	0.48	0.51	0.00	91.25
16	0.67	89.84	9.05	0.00	0.00	0.00	0.56	0.55	0.00	89.84
18	0.75	88.91	9.91	0.00	0.00	0.00	0.63	0.55	0.00	88.91
20	0.83	87.48	11.19	0.00	0.00	0.00	0.71	0.61	0.00	87.48
22	0.92	85.72	12.85	0.00	0.00	0.00	0.78	0.64	0.00	85.72
24	1.00	84.46	14.05	0.00	0.00	0.00	0.85	0.64	0.00	84.46
28	1.17	81.75	16.32	0.00	0.00	0.00	0.99	0.94	0.00	81.75
32	1.33	79.69	17.84	0.00	0.00	0.00	1.12	1.34	0.00	79.69
36	1.50	77.11	19.91	0.00	0.00	0.00	1.25	1.73	0.00	77.11
40	1.67	75.20	21.38	0.00	0.00	0.00	1.38	2.04	0.00	75.20
44	1.83	74.22	22.13	0.00	0.00	0.00	1.51	2.14	0.00	74.22
48	2.00	72.73	23.33	0.01	0.00	0.00	1.63	2.31	0.00	72.73
54	2.25	71.08	24.77	0.01	0.00	0.00	1.81	2.34	0.00	71.08
60	2.50	69.80	25.78	0.01	0.00	0.10	1.98	2.34	0.00	69.80
66	2.75	68.64	26.46	0.01	0.00	0.40	2.16	2.34	0.00	68.64
72	3.00	59.38	30.44	0.01	0.00	5.51	2.33	2.34	0.00	59.38
78	3.25	36.64	39.70	0.01	0.00	18.84	2.48	2.34	0.00	36.64
84	3.50	21.31	45.86	0.03	0.00	27.85	2.62	2.34	0.00	21.31
90	3.75	14.46	48.62	0.02	0.01	31.81	2.75	2.34	0.00	14.46

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	14.20	48.82	0.07	0.01	31.71	2.87	2.34	0.00	14.20
108	4.50	12.35	49.68	0.10	0.04	32.38	3.11	2.34	0.00	12.35
120	5.00	11.34	50.18	0.12	0.09	32.59	3.35	2.34	0.00	11.34
132	5.50	10.83	50.62	0.12	0.17	32.34	3.59	2.34	0.00	10.83
144	6.00	10.42	50.98	0.11	0.24	32.10	3.82	2.34	0.00	10.42
156	6.50	9.94	51.41	0.11	0.31	31.86	4.04	2.34	0.00	9.94
168	7.00	9.54	51.71	0.11	0.37	31.67	4.27	2.34	0.00	9.54
192	8.00	8.05	52.31	0.12	0.49	31.99	4.70	2.34	0.00	8.05
216	9.00	6.14	52.82	0.14	0.62	32.81	5.13	2.34	0.00	6.14
240	10.00	5.15	53.07	0.17	0.78	32.96	5.55	2.34	0.00	5.15
264	11.00	4.76	53.18	0.17	0.95	32.65	5.96	2.34	0.00	4.76
288	12.00	4.47	53.30	0.14	1.17	32.23	6.36	2.34	0.00	4.47
336	14.00	3.46	53.48	0.18	1.45	31.95	7.14	2.34	0.00	3.46
384	16.00	2.54	53.61	0.15	1.86	31.61	7.89	2.34	0.00	2.54
432	18.00	1.98	53.68	0.14	2.25	31.00	8.62	2.34	0.00	1.98
480	20.00	1.73	53.71	0.14	2.59	30.18	9.32	2.34	0.00	1.73
600	25.00	0.85	53.82	0.12	3.38	28.53	10.97	2.34	0.00	0.85
720	30.00	0.13	53.91	0.13	4.10	26.91	12.48	2.34	0.00	0.13
840	35.00	0.00	53.93	0.10	4.75	25.01	13.87	2.34	0.00	0.00
1080	45.00	0.00	53.93	0.05	5.63	21.72	16.33	2.34	0.00	0.00
1200	50.00	0.00	53.93	0.05	5.91	20.35	17.42	2.34	0.00	0.00
1320	55.00	0.00	53.93	0.05	6.12	19.12	18.44	2.34	0.00	0.00
Maximum	56.00	99.57	53.93	0.18	6.17	32.96	18.63	2.34	0.00	99.57

Table XIV.B-8 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 worst run for Dungeness Spit.

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	99.40	0.56	0.00	0.00	0.00	0.05	0.00	0.00	99.40
4	0.17	99.10	0.81	0.00	0.00	0.00	0.09	0.00	0.00	99.10
6	0.25	97.65	1.82	0.00	0.00	0.00	0.17	0.36	0.00	97.65
8	0.33	95.83	3.48	0.00	0.00	0.00	0.25	0.44	0.00	95.83
10	0.42	94.22	4.93	0.00	0.00	0.00	0.33	0.51	0.00	94.22
12	0.50	92.22	6.58	0.00	0.00	0.00	0.41	0.79	0.00	92.22
14	0.58	90.62	7.73	0.00	0.00	0.00	0.48	1.17	0.00	90.62
16	0.67	89.17	9.01	0.00	0.00	0.00	0.56	1.26	0.00	89.17
18	0.75	88.24	9.87	0.00	0.00	0.00	0.63	1.26	0.00	88.24
20	0.83	86.80	11.15	0.00	0.00	0.00	0.70	1.34	0.00	86.80
22	0.92	85.05	12.80	0.00	0.00	0.00	0.78	1.38	0.00	85.05
24	1.00	83.79	13.98	0.00	0.00	0.00	0.85	1.38	0.00	83.79
28	1.17	80.92	16.24	0.00	0.00	0.00	0.98	1.85	0.00	80.92
32	1.33	78.62	17.75	0.00	0.00	0.00	1.12	2.51	0.00	78.62
36	1.50	75.83	19.80	0.00	0.00	0.00	1.25	3.13	0.00	75.83
40	1.67	73.86	21.25	0.00	0.00	0.00	1.37	3.51	0.00	73.86
44	1.83	72.96	22.00	0.00	0.00	0.00	1.49	3.55	0.00	72.96
48	2.00	71.56	23.18	0.01	0.00	0.00	1.61	3.64	0.00	71.56
54	2.25	69.96	24.60	0.00	0.00	0.00	1.79	3.64	0.00	69.96
60	2.50	68.79	25.56	0.00	0.00	0.05	1.96	3.64	0.00	68.79
66	2.75	67.53	26.28	0.00	0.00	0.42	2.13	3.64	0.00	67.53
72	3.00	60.05	29.53	0.01	0.00	4.46	2.30	3.64	0.00	60.05
78	3.25	39.12	38.08	0.01	0.00	16.69	2.46	3.64	0.00	39.12
84	3.50	22.78	44.64	0.03	0.00	26.32	2.59	3.64	0.00	22.78
90	3.75	16.59	47.15	0.02	0.01	29.88	2.72	3.64	0.00	16.59

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	16.29	47.38	0.05	0.01	29.80	2.84	3.64	0.00	16.29
108	4.50	12.59	48.93	0.10	0.03	31.62	3.08	3.64	0.00	12.59
120	5.00	11.76	49.37	0.13	0.09	31.70	3.32	3.64	0.00	11.76
132	5.50	11.22	49.82	0.13	0.17	31.47	3.55	3.64	0.00	11.22
144	6.00	10.80	50.19	0.11	0.25	31.23	3.78	3.64	0.00	10.80
156	6.50	10.20	50.66	0.12	0.33	31.06	4.00	3.64	0.00	10.20
168	7.00	9.75	50.97	0.12	0.40	30.90	4.22	3.64	0.00	9.75
192	8.00	8.57	51.52	0.12	0.53	30.97	4.65	3.64	0.00	8.57
216	9.00	6.71	52.03	0.15	0.67	31.73	5.07	3.64	0.00	6.71
240	10.00	5.66	52.31	0.17	0.82	31.91	5.48	3.64	0.00	5.66
264	11.00	5.35	52.42	0.17	1.00	31.53	5.89	3.64	0.00	5.35
288	12.00	5.07	52.56	0.14	1.23	31.09	6.28	3.64	0.00	5.07
336	14.00	4.22	52.72	0.18	1.51	30.68	7.05	3.64	0.00	4.22
384	16.00	3.11	52.87	0.15	1.90	30.53	7.79	3.64	0.00	3.11
432	18.00	2.48	52.95	0.14	2.29	29.99	8.51	3.64	0.00	2.48
480	20.00	2.17	52.99	0.15	2.63	29.23	9.20	3.64	0.00	2.17
600	25.00	1.04	53.14	0.13	3.43	27.81	10.82	3.64	0.00	1.04
720	30.00	0.21	53.25	0.14	4.20	26.27	12.30	3.64	0.00	0.21
840	35.00	0.02	53.27	0.10	4.90	24.40	13.66	3.64	0.00	0.02
1080	45.00	0.00	53.27	0.06	5.87	21.10	16.05	3.64	0.00	0.00
1200	50.00	0.00	53.27	0.05	6.19	19.74	17.12	3.64	0.00	0.00
1320	55.00	0.00	53.27	0.06	6.42	18.51	18.10	3.64	0.00	0.00
Maximum	56.00	99.57	53.27	0.18	6.48	31.91	18.29	3.64	0.00	99.57

Table XIV.B-9 Strait of Juan de Fuca - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	98.45	1.43	0.07	0.00	0.00	0.05	0.00	0.00	98.45
4	0.17	97.74	2.15	0.02	0.00	0.00	0.09	0.00	0.00	97.74
6	0.25	95.68	4.13	0.02	0.00	0.00	0.17	0.00	0.00	95.68
8	0.33	93.48	6.25	0.02	0.00	0.00	0.25	0.00	0.00	93.48
10	0.42	92.20	7.46	0.02	0.00	0.00	0.32	0.00	0.00	92.20
12	0.50	91.08	8.51	0.01	0.00	0.00	0.40	0.00	0.00	91.08
14	0.58	90.31	9.21	0.01	0.00	0.00	0.48	0.00	0.00	90.31
16	0.67	89.51	9.93	0.01	0.00	0.00	0.55	0.00	0.00	89.51
18	0.75	88.65	10.71	0.01	0.00	0.00	0.62	0.00	0.00	88.65
20	0.83	87.27	12.02	0.01	0.00	0.00	0.70	0.00	0.00	87.27
22	0.92	85.10	14.11	0.03	0.00	0.00	0.77	0.00	0.00	85.10
24	1.00	82.97	16.15	0.04	0.00	0.00	0.84	0.00	0.00	82.97
28	1.17	80.46	18.55	0.01	0.00	0.00	0.98	0.00	0.00	80.46
32	1.33	79.18	19.70	0.01	0.00	0.00	1.11	0.00	0.00	79.18
36	1.50	78.28	20.47	0.01	0.00	0.00	1.24	0.00	0.00	78.28
40	1.67	77.20	21.43	0.01	0.00	0.00	1.37	0.00	0.00	77.20
44	1.83	75.67	22.77	0.01	0.00	0.06	1.50	0.00	0.00	75.67
48	2.00	73.71	24.32	0.03	0.00	0.31	1.62	0.00	0.00	73.71
54	2.25	71.83	25.66	0.01	0.00	0.70	1.80	0.00	0.00	71.83
60	2.50	68.35	27.42	0.03	0.00	2.22	1.98	0.00	0.00	68.35
66	2.75	65.02	29.15	0.02	0.01	3.64	2.16	0.00	0.00	65.02
72	3.00	63.59	30.11	0.06	0.02	3.90	2.33	0.00	0.00	63.59
78	3.25	62.35	30.76	0.04	0.03	4.32	2.50	0.00	0.00	62.35
84	3.50	60.68	31.60	0.08	0.04	4.93	2.67	0.00	0.00	60.68
90	3.75	59.07	32.77	0.14	0.09	5.11	2.83	0.00	0.00	59.07
96	4.00	56.15	34.66	0.27	0.11	5.82	2.99	0.00	0.00	56.15

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
108	4.50	48.86	38.88	0.35	0.17	8.44	3.29	0.00	0.00	48.86
120	5.00	45.48	41.12	0.53	0.25	9.05	3.58	0.00	0.00	45.48
132	5.50	42.39	42.83	0.16	0.32	10.45	3.85	0.00	0.00	42.39
144	6.00	41.10	43.63	0.17	0.40	10.58	4.12	0.00	0.00	41.10
156	6.50	39.61	44.60	0.24	0.50	10.68	4.38	0.00	0.00	39.61
168	7.00	37.98	45.82	0.39	0.60	10.59	4.63	0.00	0.00	37.98
192	8.00	36.08	47.20	0.19	0.77	10.64	5.12	0.00	0.00	36.08
216	9.00	34.09	47.89	0.20	0.94	11.29	5.59	0.00	0.00	34.09
240	10.00	32.38	48.48	0.29	1.14	11.65	6.06	0.00	0.00	32.38
264	11.00	27.19	49.80	0.63	1.38	14.50	6.50	0.00	0.00	27.19
288	12.00	23.09	50.67	0.25	1.60	17.46	6.93	0.00	0.00	23.09
336	14.00	18.76	51.33	0.75	2.28	19.12	7.76	0.00	0.00	18.76
384	16.00	15.08	51.86	0.93	2.94	20.64	8.55	0.00	0.00	15.08
432	18.00	12.61	52.30	0.37	3.58	21.84	9.30	0.00	0.00	12.61
480	20.00	11.35	52.47	0.32	4.31	21.53	10.02	0.00	0.00	11.35
600	25.00	5.07	53.34	0.35	6.21	23.36	11.67	0.00	0.00	5.07
720	30.00	3.51	53.57	0.30	8.09	21.43	13.10	0.00	0.00	3.51
840	35.00	1.17	53.89	0.32	9.79	20.47	14.36	0.00	0.00	1.17
1080	45.00	0.05	54.06	0.21	12.52	16.76	16.40	0.00	0.00	0.05
1200	50.00	0.00	54.06	0.17	13.53	14.99	17.24	0.00	0.00	0.00
1320	55.00	0.00	54.06	0.13	14.36	13.47	17.98	0.00	0.00	0.00
Maximum	56.00	98.87	54.06	0.93	14.48	23.78	18.12	0.00	0.00	98.87

Table XIV.B-10 Strait of Juan de Fuca - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Protection 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	98.45	1.43	0.07	0.00	0.00	0.05	0.00	0.00	98.45
4	0.17	97.74	2.15	0.02	0.00	0.00	0.09	0.00	0.00	97.74
6	0.25	95.68	4.13	0.02	0.00	0.00	0.17	0.00	0.00	95.68
8	0.33	93.48	6.25	0.02	0.00	0.00	0.25	0.00	0.00	93.48
10	0.42	92.20	7.46	0.01	0.00	0.00	0.32	0.00	0.00	92.20
12	0.50	91.08	8.51	0.01	0.00	0.00	0.40	0.00	0.00	91.08
14	0.58	90.19	9.21	0.01	0.00	0.00	0.48	0.11	0.00	90.19
16	0.67	89.28	9.93	0.01	0.00	0.00	0.55	0.22	0.00	89.28
18	0.75	88.33	10.71	0.01	0.00	0.00	0.62	0.33	0.00	88.33
20	0.83	86.84	12.02	0.01	0.00	0.00	0.70	0.43	0.00	86.84
22	0.92	84.68	14.10	0.03	0.00	0.00	0.77	0.43	0.00	84.68
24	1.00	82.55	16.13	0.03	0.00	0.00	0.84	0.45	0.00	82.55
28	1.17	79.86	18.52	0.02	0.00	0.00	0.97	0.62	0.00	79.86
32	1.33	78.43	19.68	0.01	0.00	0.00	1.10	0.78	0.00	78.43
36	1.50	77.38	20.44	0.01	0.00	0.00	1.23	0.94	0.00	77.38
40	1.67	75.97	21.41	0.01	0.00	0.03	1.36	1.23	0.00	75.97
44	1.83	74.20	22.73	0.01	0.00	0.07	1.49	1.50	0.00	74.20
48	2.00	72.22	24.18	0.02	0.00	0.21	1.61	1.76	0.00	72.22
54	2.25	70.51	25.38	0.02	0.00	0.43	1.79	1.88	0.00	70.51
60	2.50	67.81	26.83	0.02	0.00	1.50	1.96	1.88	0.00	67.81
66	2.75	64.90	28.38	0.01	0.01	2.69	2.14	1.88	0.00	64.90
72	3.00	63.55	29.31	0.05	0.01	2.90	2.30	1.88	0.00	63.55
78	3.25	62.49	29.89	0.04	0.02	3.21	2.47	1.88	0.00	62.49
84	3.50	61.01	30.67	0.07	0.03	3.71	2.63	1.88	0.00	61.01
90	3.75	58.55	32.13	0.20	0.07	4.38	2.80	1.88	0.00	58.55
96	4.00	55.49	34.06	0.35	0.09	5.18	2.95	1.88	0.00	55.49

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	48.99	37.94	0.58	0.15	7.21	3.25	1.88	0.00	48.99
120	5.00	46.50	40.01	0.40	0.23	7.45	3.53	1.88	0.00	46.50
132	5.50	41.90	42.11	0.21	0.30	9.81	3.80	1.88	0.00	41.90
144	6.00	40.64	42.93	0.15	0.38	9.96	4.06	1.88	0.00	40.64
156	6.50	39.20	43.88	0.23	0.47	10.02	4.32	1.88	0.00	39.20
168	7.00	37.51	45.13	0.38	0.58	9.96	4.57	1.88	0.00	37.51
192	8.00	35.72	46.51	0.19	0.75	9.91	5.04	1.88	0.00	35.72
216	9.00	33.71	47.23	0.22	0.92	10.54	5.50	1.88	0.00	33.71
240	10.00	32.35	47.79	0.28	1.13	10.62	5.95	1.88	0.00	32.35
264	11.00	26.95	49.15	0.61	1.38	13.65	6.39	1.88	0.00	26.95
288	12.00	24.42	49.76	0.30	1.60	15.24	6.80	1.88	0.00	24.42
336	14.00	19.90	50.42	0.72	2.26	17.20	7.61	1.88	0.00	19.90
384	16.00	15.86	50.98	0.92	2.89	19.08	8.38	1.88	0.00	15.86
432	18.00	12.51	51.53	0.37	3.50	21.10	9.12	1.88	0.00	12.51
480	20.00	11.42	51.67	0.30	4.19	20.71	9.82	1.88	0.00	11.42
600	25.00	5.43	52.50	0.32	5.92	22.51	11.43	1.88	0.00	5.43
720	30.00	3.79	52.75	0.26	7.57	20.90	12.84	1.88	0.00	3.79
840	35.00	0.97	53.12	0.28	9.11	20.55	14.09	1.88	0.00	0.97
1080	45.00	0.00	53.26	0.20	11.72	16.80	16.13	1.88	0.00	0.00
1200	50.00	0.00	53.26	0.16	12.68	15.04	16.97	1.88	0.00	0.00
1320	55.00	0.00	53.26	0.12	13.46	13.56	17.72	1.88	0.00	0.00
Maximum	56.00	98.87	53.26	0.92	13.58	22.80	17.86	1.88	0.00	98.87

Table XIV.B-11 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 worst run for Protection 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	98.45	1.43	0.07	0.00	0.00	0.05	0.00	0.00	98.45
4	0.17	97.74	2.15	0.02	0.00	0.00	0.09	0.00	0.00	97.74
6	0.25	95.68	4.13	0.02	0.00	0.00	0.17	0.00	0.00	95.68
8	0.33	93.36	6.26	0.03	0.00	0.00	0.25	0.11	0.00	93.36
10	0.42	92.06	7.47	0.02	0.00	0.00	0.32	0.13	0.00	92.06
12	0.50	90.85	8.51	0.01	0.00	0.00	0.40	0.23	0.00	90.85
14	0.58	89.79	9.21	0.01	0.00	0.00	0.47	0.51	0.00	89.79
16	0.67	88.72	9.93	0.01	0.00	0.00	0.55	0.78	0.00	88.72
18	0.75	87.61	10.71	0.01	0.00	0.00	0.62	1.04	0.00	87.61
20	0.83	86.00	12.01	0.01	0.00	0.00	0.69	1.29	0.00	86.00
22	0.92	83.84	14.07	0.04	0.00	0.00	0.77	1.29	0.00	83.84
24	1.00	81.69	16.09	0.04	0.00	0.00	0.83	1.35	0.00	81.69
28	1.17	78.76	18.46	0.03	0.00	0.00	0.97	1.78	0.00	78.76
32	1.33	77.10	19.60	0.01	0.00	0.00	1.10	2.19	0.00	77.10
36	1.50	75.83	20.36	0.01	0.00	0.00	1.23	2.57	0.00	75.83
40	1.67	74.27	21.29	0.01	0.00	0.00	1.35	3.07	0.00	74.27
44	1.83	72.20	22.66	0.01	0.00	0.12	1.47	3.55	0.00	72.20
48	2.00	70.09	24.07	0.02	0.00	0.23	1.59	3.99	0.00	70.09
54	2.25	68.58	25.13	0.02	0.00	0.30	1.76	4.21	0.00	68.58
60	2.50	66.92	26.14	0.02	0.00	0.77	1.94	4.21	0.00	66.92
66	2.75	64.16	27.63	0.02	0.01	1.87	2.10	4.21	0.00	64.16
72	3.00	62.65	28.61	0.05	0.01	2.19	2.27	4.21	0.00	62.65
78	3.25	61.20	29.35	0.04	0.02	2.76	2.43	4.21	0.00	61.20
84	3.50	59.33	30.27	0.07	0.03	3.50	2.59	4.21	0.00	59.33
90	3.75	57.52	31.49	0.15	0.07	3.82	2.75	4.21	0.00	57.52

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	54.20	33.53	0.24	0.08	4.84	2.90	4.21	0.00	54.20
108	4.50	47.05	37.61	0.36	0.14	7.44	3.18	4.21	0.00	47.05
120	5.00	44.58	39.53	0.43	0.22	7.57	3.46	4.21	0.00	44.58
132	5.50	40.28	41.54	0.17	0.28	9.81	3.72	4.21	0.00	40.28
144	6.00	38.69	42.41	0.17	0.36	10.20	3.97	4.21	0.00	38.69
156	6.50	36.98	43.39	0.24	0.45	10.52	4.22	4.21	0.00	36.98
168	7.00	35.35	44.56	0.35	0.55	10.51	4.46	4.21	0.00	35.35
192	8.00	33.50	45.89	0.18	0.73	10.58	4.92	4.21	0.00	33.50
216	9.00	31.70	46.53	0.22	0.90	11.07	5.37	4.21	0.00	31.70
240	10.00	30.47	47.05	0.27	1.11	11.09	5.80	4.21	0.00	30.47
264	11.00	25.33	48.31	0.59	1.35	13.99	6.22	4.21	0.00	25.33
288	12.00	21.54	49.09	0.27	1.56	16.70	6.63	4.21	0.00	21.54
336	14.00	17.07	49.78	0.66	2.20	18.67	7.41	4.21	0.00	17.07
384	16.00	13.04	50.38	0.80	2.85	20.57	8.15	4.21	0.00	13.04
432	18.00	10.92	50.75	0.35	3.46	21.44	8.86	4.21	0.00	10.92
480	20.00	9.63	50.94	0.30	4.16	21.22	9.54	4.21	0.00	9.63
600	25.00	4.53	51.68	0.32	5.94	22.24	11.09	4.21	0.00	4.53
720	30.00	3.57	51.82	0.27	7.63	20.05	12.44	4.21	0.00	3.57
840	35.00	0.90	52.17	0.29	9.22	19.57	13.63	4.21	0.00	0.90
1080	45.00	0.00	52.31	0.21	12.01	15.71	15.55	4.21	0.00	0.00
1200	50.00	0.00	52.31	0.17	13.02	13.95	16.34	4.21	0.00	0.00
1320	55.00	0.00	52.31	0.12	13.83	12.50	17.02	4.21	0.00	0.00
Maximum	56.00	98.87	52.31	0.80	13.95	22.55	17.15	4.21	0.00	98.87

Table XIV.B-12 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 worst run for Protection 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	98.45	1.43	0.07	0.00	0.00	0.05	0.00	0.00	98.45
4	0.17	97.74	2.15	0.02	0.00	0.00	0.09	0.00	0.00	97.74
6	0.25	95.33	4.13	0.02	0.00	0.00	0.17	0.36	0.00	95.33
8	0.33	93.04	6.25	0.02	0.00	0.00	0.25	0.44	0.00	93.04
10	0.42	91.69	7.46	0.02	0.00	0.00	0.32	0.51	0.00	91.69
12	0.50	90.30	8.50	0.02	0.00	0.00	0.40	0.79	0.00	90.30
14	0.58	89.15	9.19	0.01	0.00	0.00	0.47	1.17	0.00	89.15
16	0.67	88.01	9.91	0.01	0.00	0.00	0.55	1.52	0.00	88.01
18	0.75	86.82	10.68	0.01	0.00	0.00	0.62	1.86	0.00	86.82
20	0.83	85.14	11.97	0.01	0.00	0.00	0.69	2.19	0.00	85.14
22	0.92	82.99	14.02	0.03	0.00	0.00	0.76	2.19	0.00	82.99
24	1.00	80.84	16.03	0.04	0.00	0.00	0.83	2.26	0.00	80.84
28	1.17	77.67	18.39	0.02	0.00	0.00	0.96	2.96	0.00	77.67
32	1.33	75.76	19.52	0.01	0.00	0.00	1.09	3.62	0.00	75.76
36	1.50	74.27	20.27	0.01	0.00	0.00	1.21	4.24	0.00	74.27
40	1.67	72.62	21.19	0.01	0.00	0.00	1.34	4.85	0.00	72.62
44	1.83	70.38	22.57	0.01	0.00	0.16	1.46	5.42	0.00	70.38
48	2.00	68.15	23.98	0.02	0.00	0.31	1.57	5.97	0.00	68.15
54	2.25	66.52	25.03	0.01	0.00	0.40	1.74	6.28	0.00	66.52
60	2.50	65.25	25.88	0.02	0.00	0.66	1.91	6.28	0.00	65.25
66	2.75	62.67	27.30	0.01	0.01	1.66	2.07	6.28	0.00	62.67
72	3.00	61.20	28.26	0.05	0.01	1.97	2.23	6.28	0.00	61.20
78	3.25	59.84	28.95	0.03	0.02	2.48	2.39	6.28	0.00	59.84
84	3.50	58.68	29.60	0.07	0.03	2.80	2.54	6.28	0.00	58.68
90	3.75	56.61	30.91	0.16	0.07	3.28	2.70	6.28	0.00	56.61

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	53.46	32.85	0.33	0.09	4.15	2.84	6.28	0.00	53.46
108	4.50	45.53	37.19	0.42	0.15	7.30	3.12	6.28	0.00	45.53
120	5.00	42.68	39.27	0.33	0.23	7.82	3.39	6.28	0.00	42.68
132	5.50	38.91	41.09	0.18	0.30	9.60	3.64	6.28	0.00	38.91
144	6.00	37.44	41.93	0.15	0.38	9.93	3.88	6.28	0.00	37.44
156	6.50	36.03	42.83	0.24	0.49	10.00	4.12	6.28	0.00	36.03
168	7.00	34.08	44.04	0.53	0.60	10.11	4.36	6.28	0.00	34.08
192	8.00	32.46	45.34	0.21	0.79	10.11	4.80	6.28	0.00	32.46
216	9.00	30.56	46.02	0.24	0.97	10.69	5.23	6.28	0.00	30.56
240	10.00	28.81	46.63	0.27	1.20	11.16	5.65	6.28	0.00	28.81
264	11.00	24.48	47.75	0.64	1.45	13.35	6.06	6.28	0.00	24.48
288	12.00	20.94	48.49	0.32	1.67	15.85	6.45	6.28	0.00	20.94
336	14.00	16.81	49.02	1.08	2.32	17.29	7.20	6.28	0.00	16.81
384	16.00	14.57	49.35	1.08	2.94	17.87	7.92	6.28	0.00	14.57
432	18.00	13.22	49.63	0.34	3.50	18.42	8.61	6.28	0.00	13.22
480	20.00	12.31	49.73	0.30	4.13	17.98	9.27	6.28	0.00	12.31
600	25.00	4.37	50.82	0.39	5.94	21.43	10.78	6.28	0.00	4.37
720	30.00	2.79	51.05	0.33	8.10	19.38	12.07	6.28	0.00	2.79
840	35.00	0.46	51.35	0.29	10.00	18.44	13.18	6.28	0.00	0.46
1080	45.00	0.00	51.41	0.21	12.91	14.24	14.94	6.28	0.00	0.00
1200	50.00	0.00	51.41	0.17	13.92	12.57	15.65	6.28	0.00	0.00
1320	55.00	0.00	51.41	0.12	14.72	11.20	16.26	6.28	0.00	0.00
Maximum	56.00	98.87	51.41	1.08	14.84	21.69	16.38	6.28	0.00	98.87

Table XIV.B-13 Strait of Juan de Fuca - 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,236	1,117	593
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	817	556	543
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	7,661	1,789	2,407
Shoreline length (km) oiled by > 100 g/m^2	3,109	1,382	1,901
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	5,936,100	575,260	975,730
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,725,200	1,213,600	1,431,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	309	104	141

Table XIV.B-14 Strait of Juan de Fuca - 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,299	1,065	576
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	954	578	522
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	6,731	1,949	2,620
Shoreline length (km) oiled by > 100 g/m^2	3,378	1,366	2,062
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	5,296,600	839,800	1,308,200
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,434,600	1,109,600	1,312,200
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	255	103	143

Table XIV.B-15 Strait of Juan de Fuca - 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,255	864	584
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	916	493	527
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	5,930	1,364	2,526
Shoreline length (km) oiled by > 100 g/m^2	2,944	1,158	1,928
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	4,194,700	289,320	1,126,300
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,735,000	1,074,700	1,399,700
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	240	90	142

Table XIV.B-16 Strait of Juan de Fuca - 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 Dungeness Spit	Worst run for Protection Island
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,200	878	561
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	839	527	496
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	5,991	1,440	2,521
Shoreline length (km) oiled by > 100 g/m^2	2,846	1,265	1,926
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	4,458,700	326,870	1,312,200
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	1,532,600	1,113,000	1,208,500
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	234	92	135

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 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 XIV.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
99th Percentile Run (based on shore cost)	49,403	25,292	103	6,510	1	0	7	-	81,316	81,310	7
Worst run for Dungeness Spit	20,855	22,503	43	2,709	1	0	3	-	46,115	46,112	3
Worst run for Protection Island	19,452	22,366	62	3,928	28	0	3	-	45,840	45,837	3

Table XIV.C-2 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
99th Percentile Run (based on shore cost)	64,256	26,743	112	7,102	1	0	8	-	98,223	98,214	8
Worst run for Dungeness Spit	23,156	22,728	42	2,674	1	0	3	-	48,605	48,602	3
Worst run for Protection Island	17,188	22,145	68	4,284	26	0	3	-	43,713	43,711	3

Table XIV.C-3 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
99th Percentile Run (based on shore cost)	60,053	26,332	97	6,146	1	0	8	-	92,638	92,630	8
Worst run for Dungeness Spit	13,921	21,826	35	2,215	1	0	2	-	38,001	37,999	2
Worst run for Protection Island	17,678	22,193	63	3,988	28	0	3	-	43,953	43,950	3

Table XIV.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
99th Percentile Run (based on shore cost)	51,681	25,514	94	5,931	1	0	7	-	83,228	83,221	7
Worst run for Dungeness Spit	17,622	22,188	39	2,451	1	0	3	-	42,303	42,301	3
Worst run for Protection Island	14,372	21,870	62	3,906	28	0	2	-	40,241	40,238	2

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 (i.e., the data were not corrected to be seasonal means).

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
99th Percentile Run (based on shore cost)	1,991	3,5876	39	16	2,314	362,273	370,220
Worst run for Dungeness Spit	1,577	1,716	36	15	1,776	178,216	183,336
Worst run for Protection Island	2,371	5,307	43	17	2,809	213,674	224,221

Table XIV.D-2. 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
99th Percentile Run (based on shore cost)	2,410	5,484	43	17	2,860	396,760	407,574
Worst run for Dungeness Spit	1,567	1,670	35	15	1,763	165,597	170,648
Worst run for Protection Island	2,362	5,263	43	17	2,796	247,182	257,663

Table XIV.D-3. 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
99th Percentile Run (based on shore cost)	2,107	4,110	40	16	2,465	319,546	328,284
Worst run for Dungeness Spit	1,550	1,597	35	15	1,742	147,144	152,083
Worst run for Protection Island	2,224	4,643	41	17	2,618	214,160	223,703

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
99th Percentile Run (based on shore cost)	2,258	4,795	42	17	2,662	309,835	319,609
Worst run for Dungeness Spit	1,544	1,568	35	15	1,733	161,711	166,607
Worst run for Protection Island	2,538	6,061	44	18	3,026	223,385	235,072

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 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 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	1,991	1,577	2,371
Large pelagic fish	3,587	1,716	5,307
Demersal fish	39	36	43
Decapods	16	15	17
Molluscs	364,587	179,992	216,483
Birds:			
Waterfowl (# * kg each)	37,588	15,867	14,800
Seabirds (# * kg each)	27,652	24,604	24,454
Waders (# * kg each)	112	47	68
Shorebirds (# * kg each)	7,118	2,962	4,295
Raptors (# * kg each)	1.5	1.2	31
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	7.1	3.4	3.2
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	370,220	183,336	224,221
Subtotal birds	72,472	43,481	43,647
Subtotal other wildlife	7	3	3
Total all species	442,699	226,821	267,871

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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	277	199	214
Saltmarsh Area (acres)	684	491	528
Saltmarsh Cost (millions of 2004$)	128.2	92.0	98.9
Eelgrass Area (m2)	173	124	134
Eelgrass Area (acres)	428	307	330
Eelgrass Cost (millions of 2004$)	51.0	36.6	39.4

Table XIV.E-3. 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	2,411	1,567	2,362
Large pelagic fish	5,484	1,671	5,263
Demersal fish	43	36	43
Decapods	17	15	17
Molluscs	399,620	167,360	249,978
Birds:			
Waterfowl (# * kg each)	48,888	17,618	13,077
Seabirds (# * kg each)	29,239	24,849	24,212
Waders (# * kg each)	123	46	74
Shorebirds (# * kg each)	7,765	2,924	4,684
Raptors (# * kg each)	1.6	1.2	28
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	9.0	3.7	3.0
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	407,574	170,648	257,663
Subtotal birds	86,016	45,439	42,075
Subtotal other wildlife	9	4	3
Total all species	493,599	216,090	299,741

Table XIV.E-4. Strait of Juan de Fuca - 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 Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	311	201	215
Saltmarsh Area (acres)	769	496	530
Saltmarsh Cost (millions of 2004$)	144.0	92.9	99.3
Eelgrass Area (m2)	194	125	134
Eelgrass Area (acres)	480	310	331
Eelgrass Cost (millions of 2004$)	57.3	37.0	39.6

Table XIV.E-5. 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	2,107	1,550	2,225
Large pelagic fish	4,110	1,597	4,643
Demersal fish	40	35	41
Decapods	16	15	17
Molluscs	322,010	148,886	216,778
Birds:			
Waterfowl (# * kg each)	45,691	10,591	13,450
Seabirds (# * kg each)	28,790	23,863	24,264
Waders (# * kg each)	106	39	69
Shorebirds (# * kg each)	6,720	2,422	4,360
Raptors (# * kg each)	1.5	1.2	30.7
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	8.5	2.5	3.0
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	328,284	152,083	223,703
Subtotal birds	81,308	36,916	42,174
Subtotal other wildlife	9	3	3
Total all species	409,600	189,002	265,881

Table XIV.E-6. 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	290	183	209
Saltmarsh Area (acres)	715	452	517
Saltmarsh Cost (millions of 2004$)	134.0	84.7	96.8
Eelgrass Area (m2)	181	114	131
Eelgrass Area (acres)	447	283	323
Eelgrass Cost (millions of 2004$)	53.4	33.7	38.5

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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Fish and Invertebrates:			
Small pelagic fish	2,258	1,544	2,538
Large pelagic fish	4,795	1,568	6,061
Demersal fish	42	35	44
Decapods	17	15	18
Molluscs	312,497	163,445	226,411
Birds:			
Waterfowl (# * kg each)	39,321	13,407	10,934
Seabirds (# * kg each)	27,896	24,258	23,911
Waders (# * kg each)	102	43	68
Shorebirds (# * kg each)	6,484	2,680	4,271
Raptors (# * kg each)	1.5	1.5	31
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	7.4	3.0	2.6
Cetaceans	0.0	0.0	0.0
Totals:			
Subtotal fish and invertebrates	319,609	166,607	235,072
Subtotal birds	73,804	40,389	39,215
Subtotal other wildlife	7	3	3
Total all species	393,420	207,000	274,290

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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Saltmarsh Area (ha)	277	191	209
Saltmarsh Area (acres)	684	471	517
Saltmarsh Cost (millions of 2004$)	128.2	88.3	96.9
Eelgrass Area (m2)	173	119	131
Eelgrass Area (acres)	428	295	323
Eelgrass Cost (millions of 2004$)	51.1	35.2	38.6

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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	25.56	23.65	21.14
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	268.4	248.3	222.0

Table XIV.F-2. 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	25.55	23.69	21.12
% Removed by 24 hours	2.73	1.38	2.26
Compensation (millions $)	261.0	245.3	216.8

Table XIV.F-3. 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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	25.55	23.64	21.13
% Removed by 24 hours	1.67	0.64	1.35
Compensation (millions $)	263.8	246.7	218.9

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	99th Percentile Run (based on shore cost)	Worst run for Dungeness Spit	Worst run for Protection Island
Vulnerability Score ($/gal.)	25.55	23.64	21.15
% Removed by 24 hours	2.73	1.38	2.26
Compensation (millions $)	261.0	244.8	217.0

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

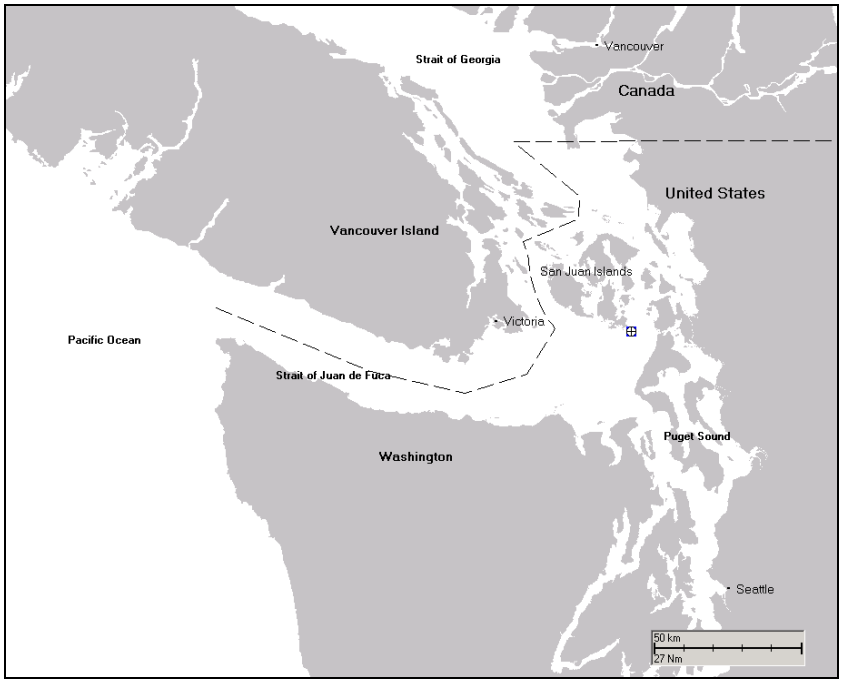


Figure XV.B.1-1 Map of the vicinity of the potential spill locations.

XV.B.2. Gridded Habitat Mapping

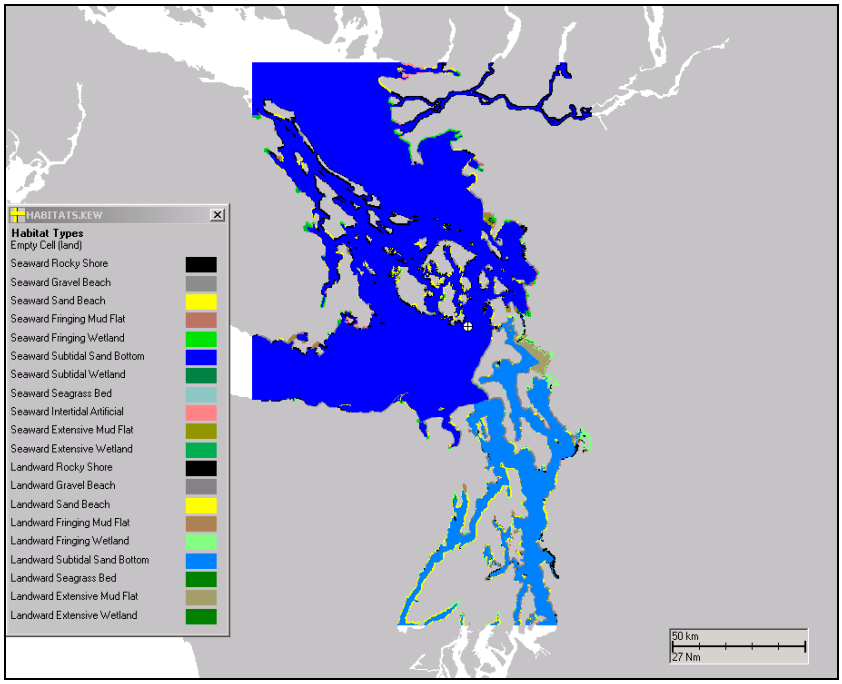


Figure XV.B.2-1 Habitat grid used for modeling the potential spills.

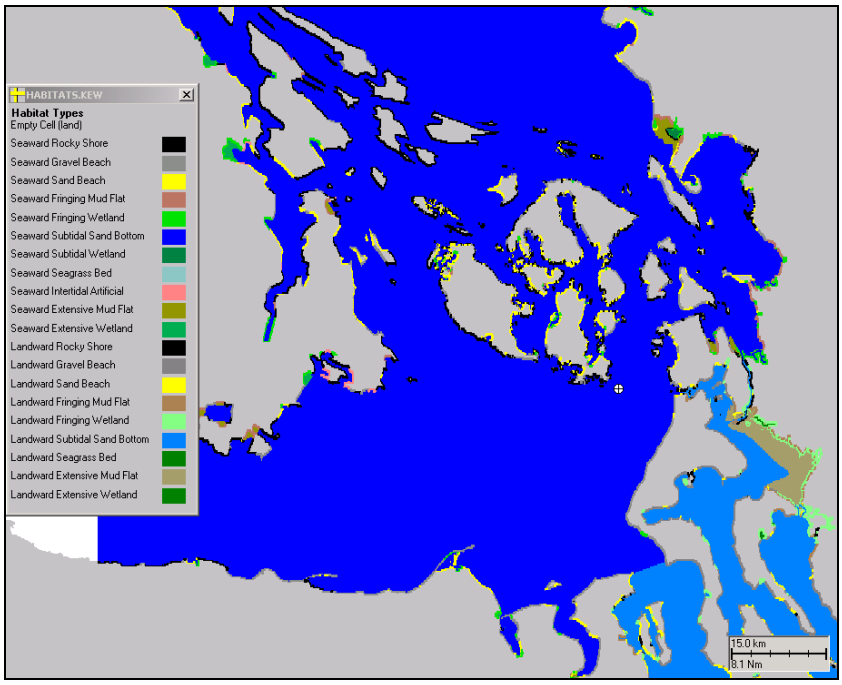


Figure XV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XV.B-3. Gridded Depth Data

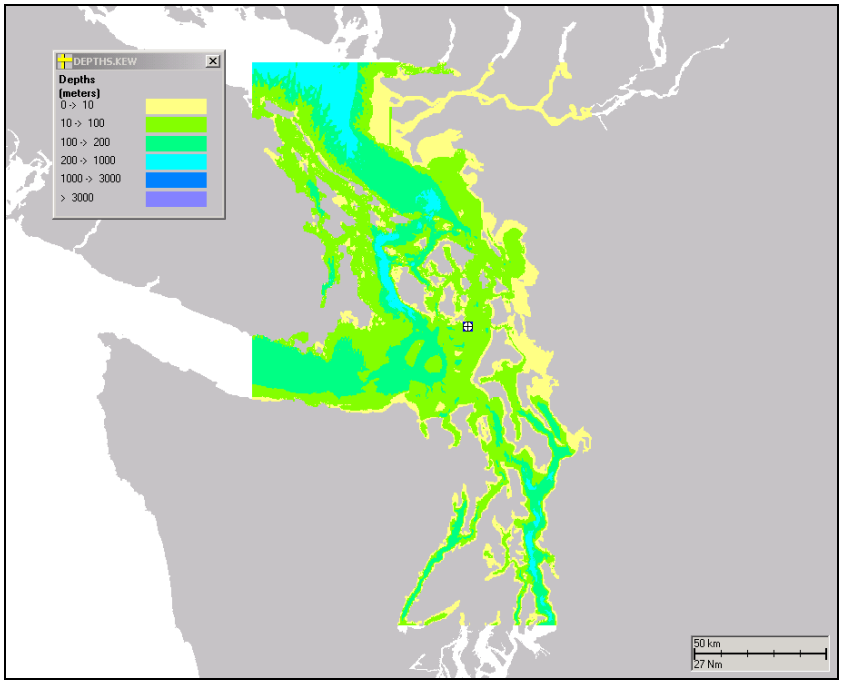


Figure XV.B.3-1 Depth grid used for modeling the potential spills.

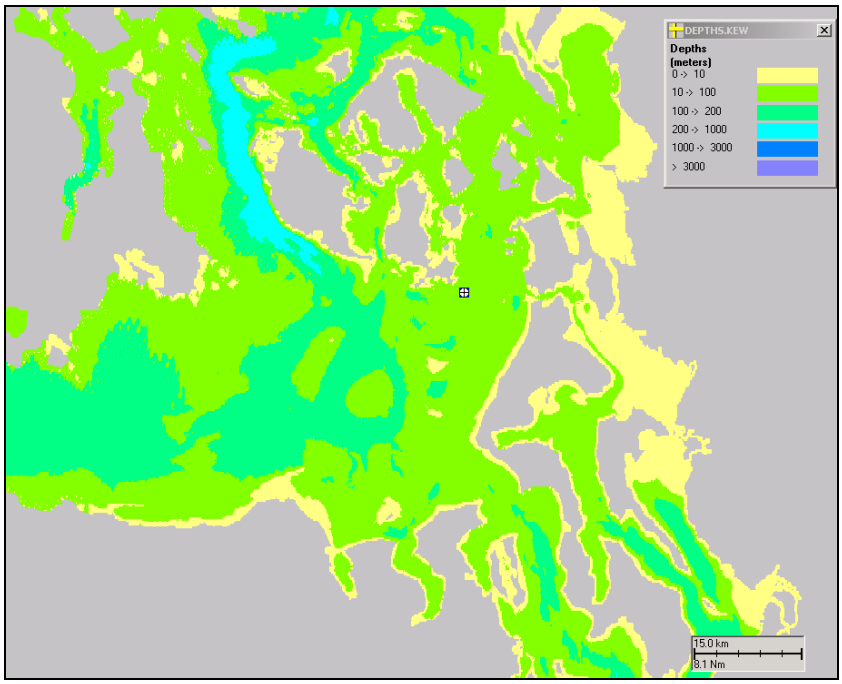


Figure XV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XV.B-4. Areas Where Response Actions Assumed

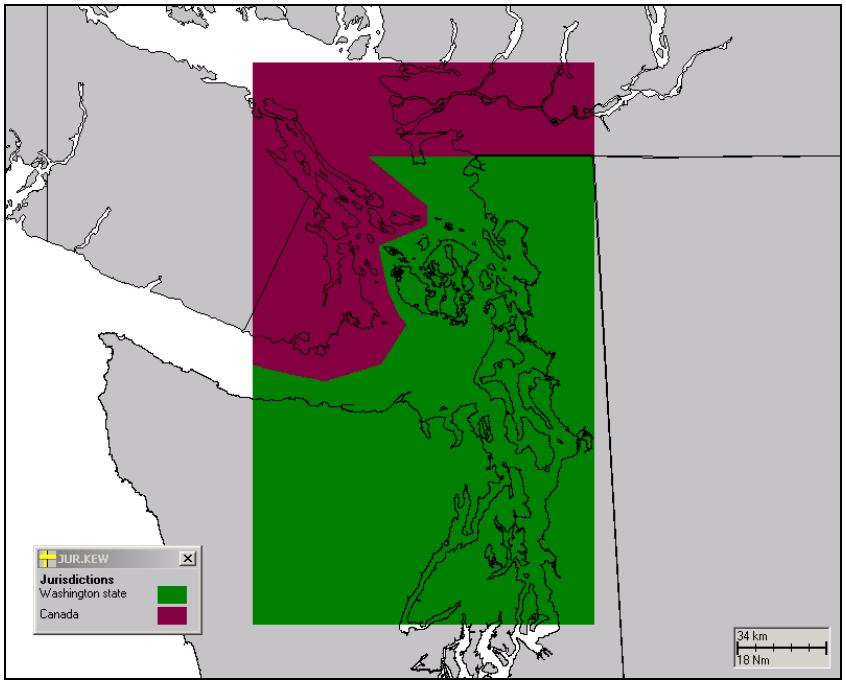


Figure XV.B.4-1 Jurisdictions in the area of the potential spills.

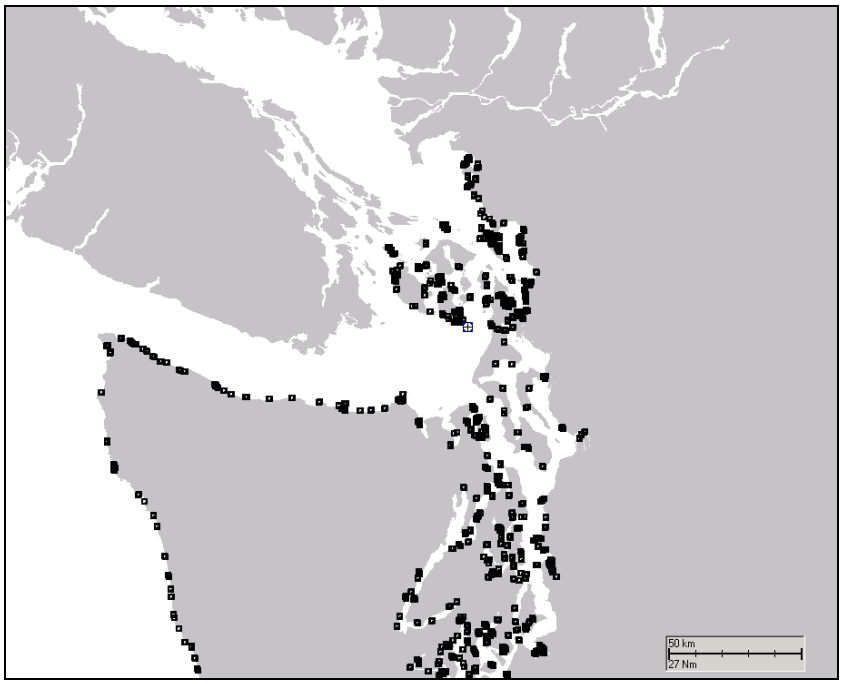


Figure XV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

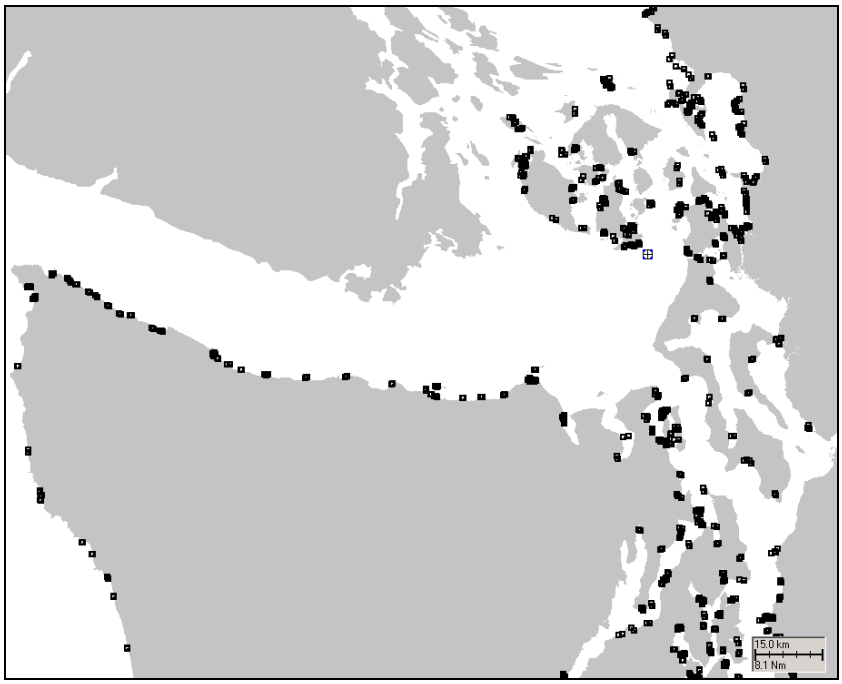


Figure XV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

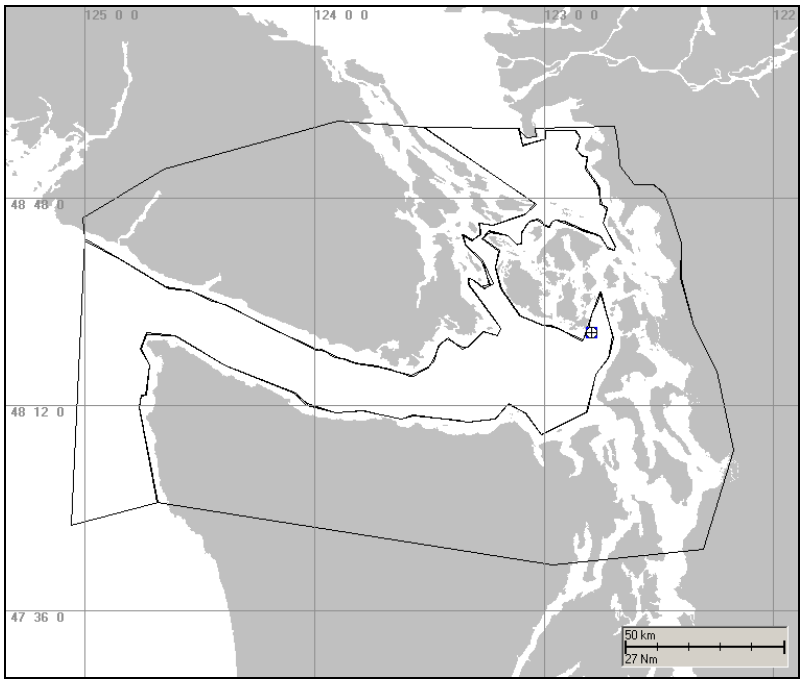


Figure XV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

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).

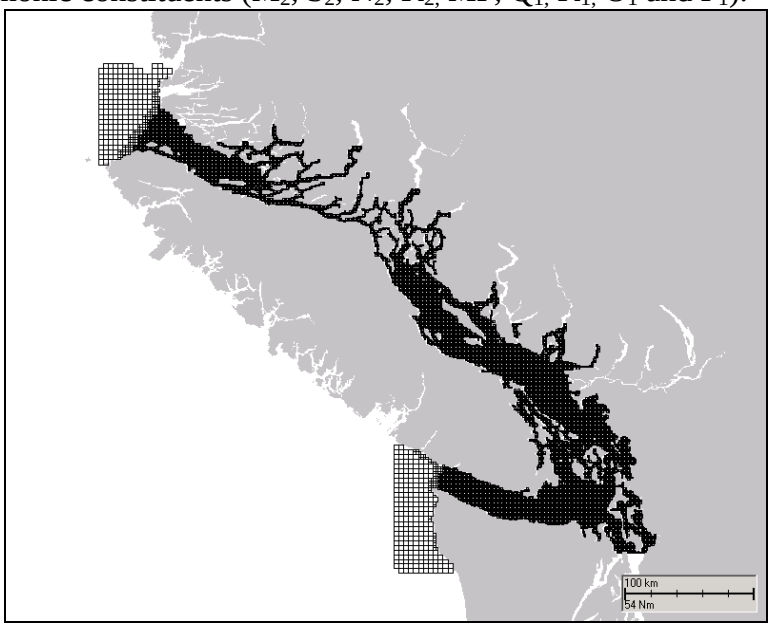


Figure XV.C.1-1 Grid used for the hydrodynamic model-generated current data.

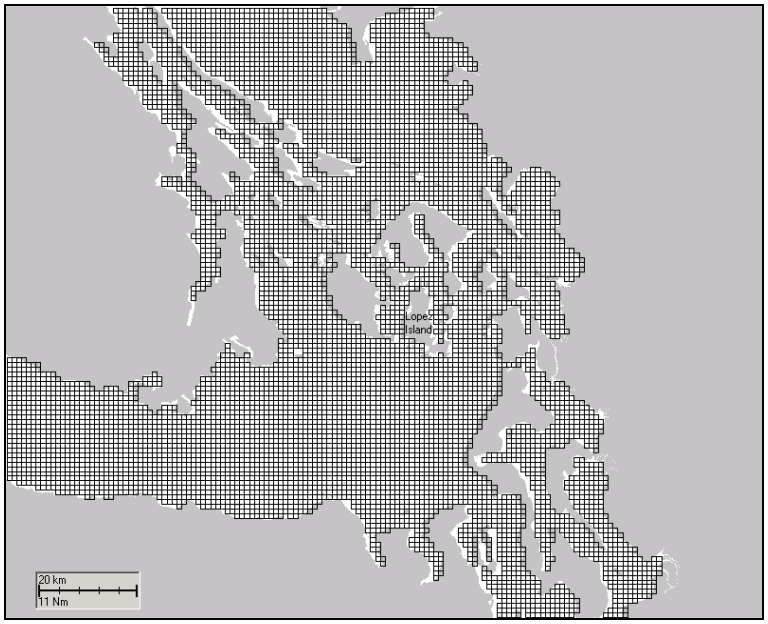


Figure XV.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Lopez Island).

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.

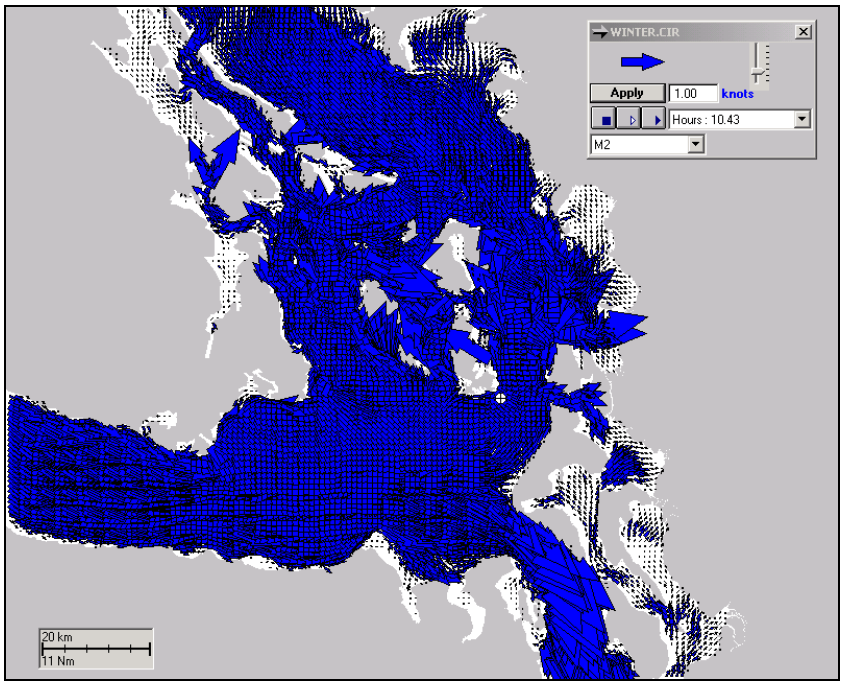


Figure XV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Lopez Island.

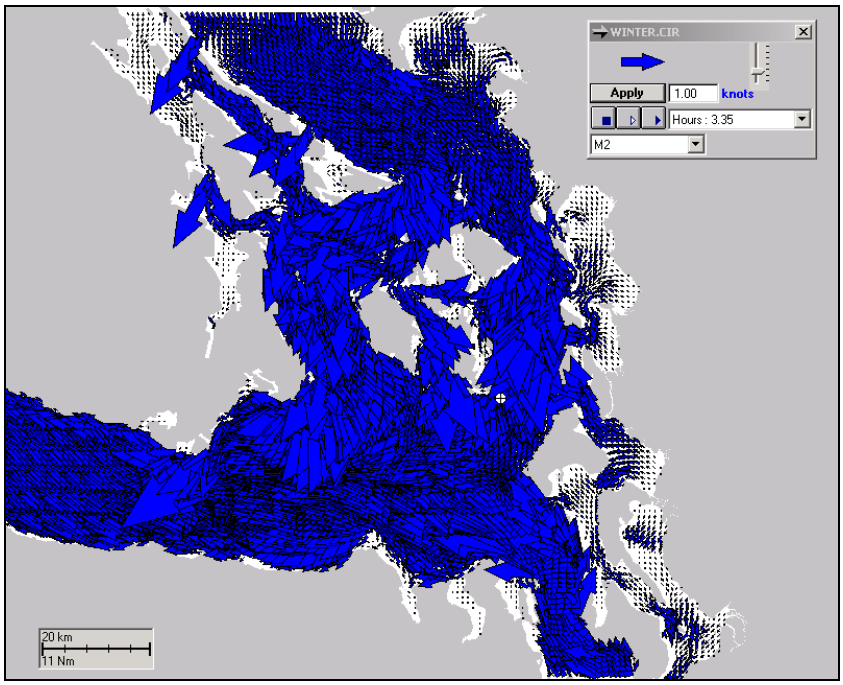


Figure XV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Lopez Island.

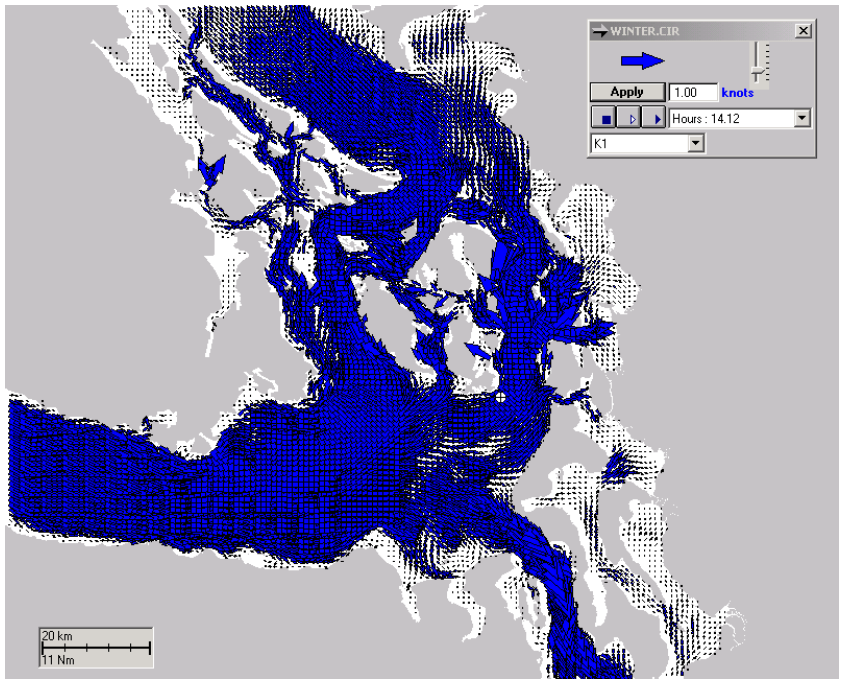


Figure XV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Lopez Island.

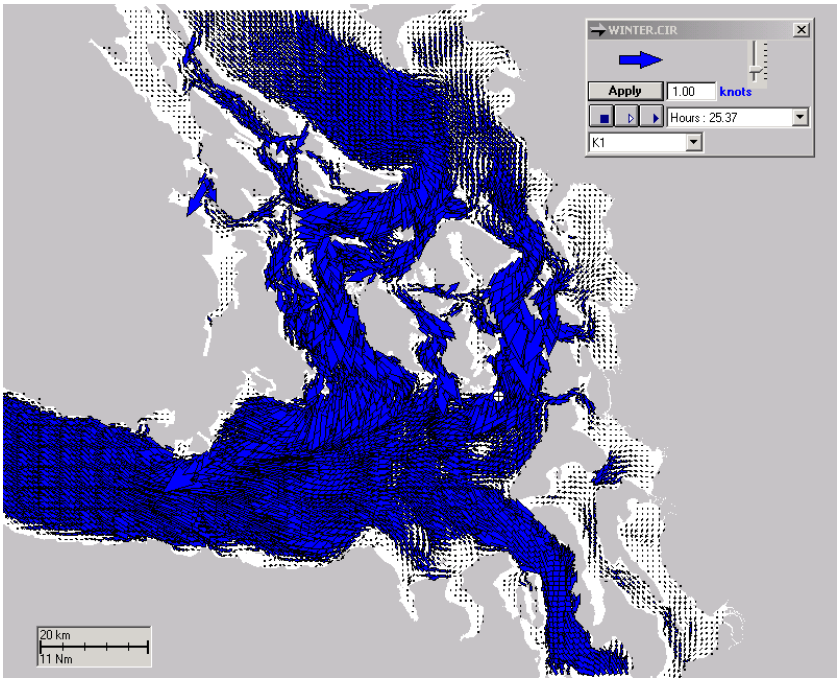


Figure XV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Lopez Island.

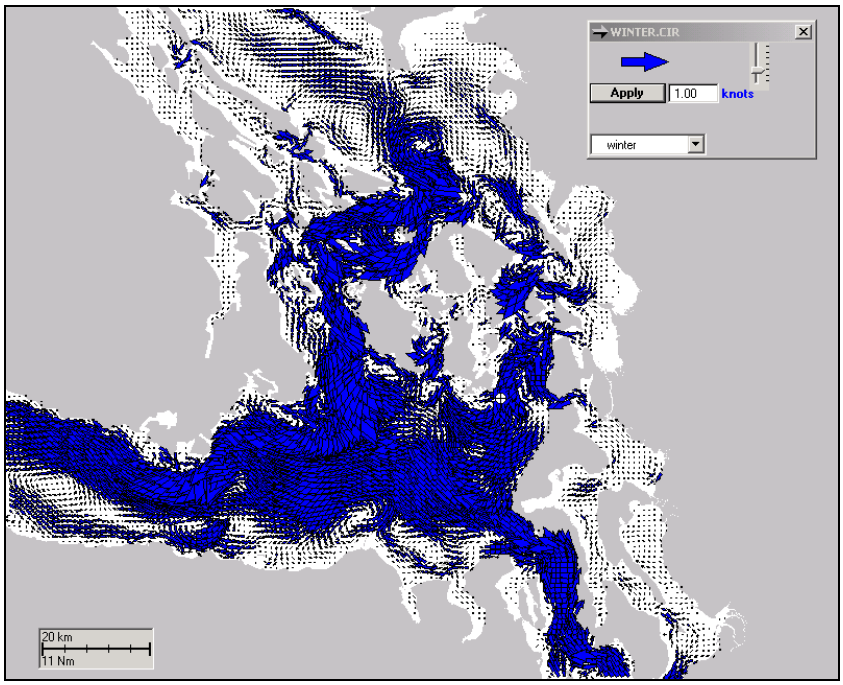


Figure XV.C.2-5 Current component data used in modeling: Seasonal mean flow for winter. Vector length indicates speed in the indicated direction.

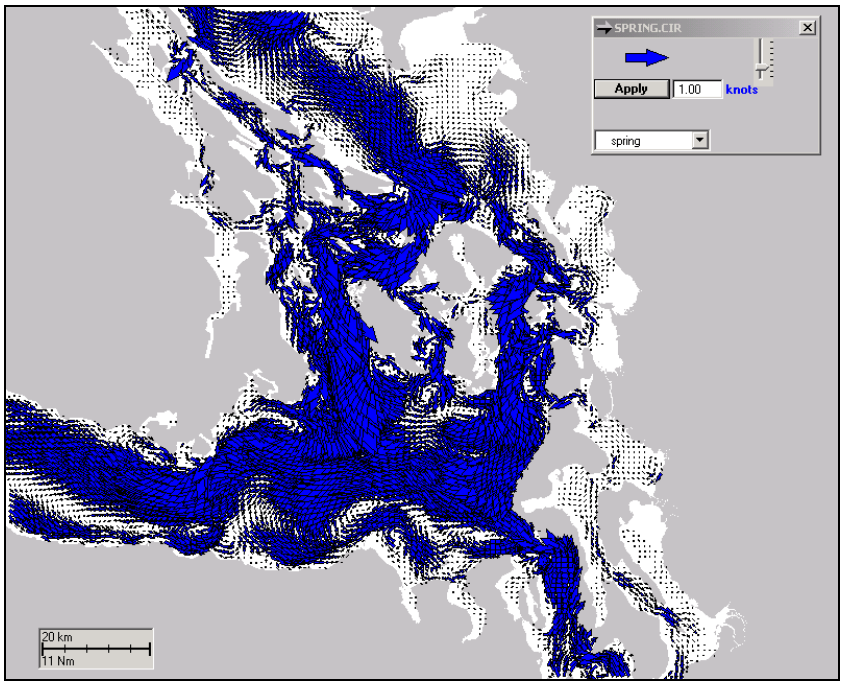


Figure XV.C.2-6 Current component data used in modeling: Seasonal mean flow for spring. Vector length indicates speed in the indicated direction.

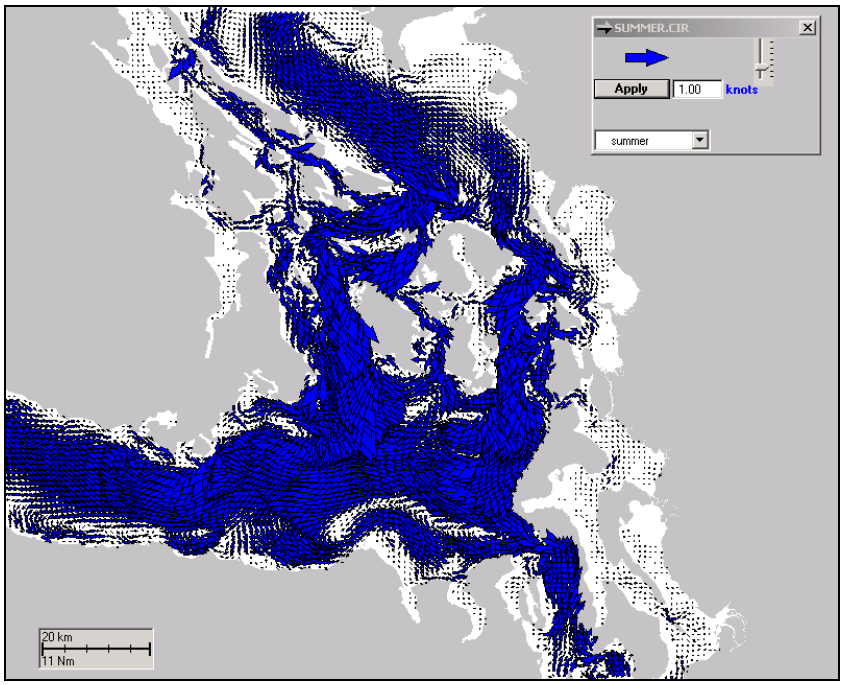


Figure XV.C.2-7 Current component data used in modeling: Seasonal mean flow for summer. Vector length indicates speed in the indicated direction.

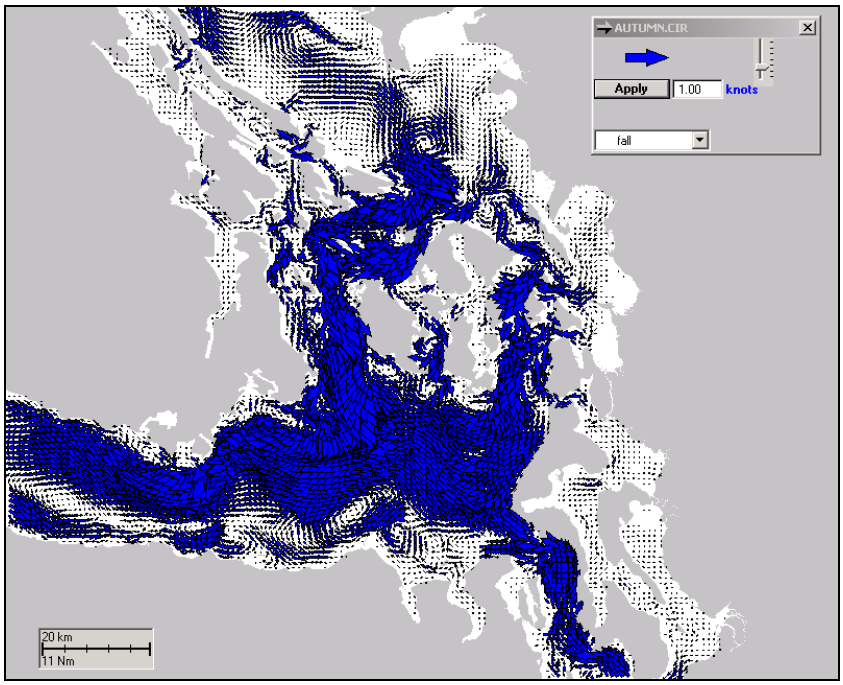


Figure XV.C.2-8 Current component data used in modeling: Seasonal mean flow for fall. Vector length indicates speed in the indicated direction.

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 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Salinity	Surface water salinity	ppt	French et al. (1996b) province 51	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 51	monthly means (see Table XV.E-4)
Air Temperature	Air water temperature at water surface	Degrees C	(assume = water temperature)	(= water temperature)
Fetch	Fetch = distance to land to N, S, E, W (if landfall not in model domain)	km	Chart	(calculated from model grid)
Wind drift speed	Speed oil moves down wind relative to wind	% of wind speed	Youssef (1993); Youssef and Spaulding (1993)	(model calculated)
Wind drift angle	Angle to right of wind (in northern hemisphere) that oil drifts	Deg. to right of down wind	Youssef (1993); Youssef and Spaulding (1993, 1994)	(model calculated)
Horizontal turbulent diffusion coefficient	Randomized turbulent mixing parameter in x & y	m^2/sec	French et al. (1996, 1999a) based on Okubo (1971)	1 m^2/sec (estuaries and low energy coastal areas)
Vertical turbulent diffusion coefficient	Randomized turbulent mixing parameter in z	m^2/sec	French et al. (1996, 1999) based on Okubo (1971)	0.0001 m^2/sec
Suspended sediment concentration	Average suspended sediment concentration during spill period	mg/l	French et al. (1996b)	10 mg/l
Suspended sediment settling rate	Net settling rate for suspended sediments	m/day	French et al. (1996b)	1 m/day

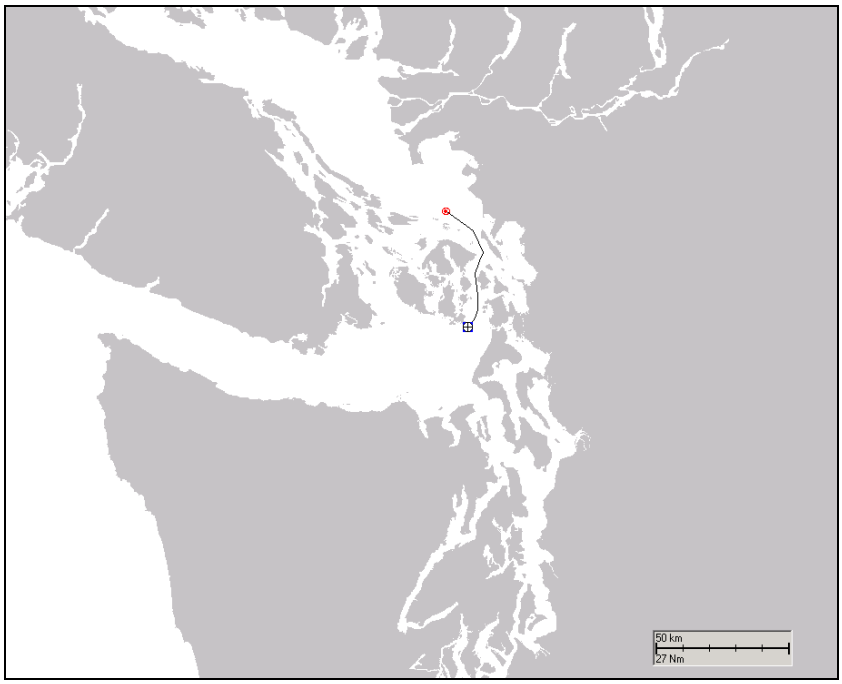


Figure XV.E-1 Varied range of spill site, Rosario Strait/Georgia Strait from the south end of Lopez Island to off Cherry Point.

Table XV.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	2002	10	25	3	48.79085	122.8576
2	1992	5	12	8	48.63506	122.7353
3	1993	10	23	20	48.54226	122.7459
4	1999	3	7	5	48.61182	122.7485
5	1993	11	18	11	48.81049	122.8989
6	1998	11	21	3	48.51369	122.7412
7	1998	5	29	20	48.77623	122.8268
8	1996	6	15	9	48.80529	122.888
9	1995	5	31	18	48.41553	122.7824
10	2000	12	5	17	48.58387	122.7532
11	1999	4	23	14	48.48296	122.738
12	2003	8	3	10	48.44713	122.7527
13	2003	12	15	9	48.43967	122.759
14	1997	1	9	7	48.54966	122.7472
15	1997	1	12	14	48.54472	122.7463
16	2001	11	13	6	48.66917	122.7128
17	2002	8	28	23	48.7191	122.746
18	2002	1	21	20	48.43344	122.765
19	1996	11	4	22	48.5928	122.7548
20	1999	12	18	14	48.63166	122.7372
21	1994	6	20	10	48.5304	122.7438
22	1992	10	31	6	48.63742	122.734
23	1994	3	12	7	48.76853	122.8106
24	2001	11	5	14	48.43426	122.7642
25	2000	10	20	22	48.52842	122.7434
26	1995	11	9	1	48.77577	122.8259
27	2001	7	11	4	48.41615	122.7818
28	1993	5	26	4	48.73642	122.7575
29	1992	6	17	18	48.80195	122.881
30	1993	2	7	18	48.75351	122.779
31	2002	2	20	10	48.51136	122.7409
32	1993	5	23	17	48.72731	122.7514
33	1997	1	6	21	48.64153	122.7317
34	1995	3	28	12	48.66311	122.7169
35	1992	8	8	18	48.61361	122.7475
36	1993	8	21	16	48.50145	122.7399
37	1994	3	17	20	48.62929	122.7386
38	1995	6	3	17	48.5179	122.7416
39	1993	11	30	23	48.66429	122.7161
40	1993	3	16	5	48.59597	122.7554
41	2000	8	30	13	48.5145	122.7412
42	1995	9	5	14	48.7494	122.7704
43	2002	3	10	13	48.74996	122.7715
44	1997	4	24	5	48.77132	122.8165
45	1999	7	31	5	48.53325	122.7443
46	1998	9	4	1	48.577	122.752
47	1994	7	21	19	48.4921	122.7389
48	1996	11	9	16	48.50862	122.7406
49	2002	6	10	20	48.70258	122.735
50	1999	3	15	21	48.7546	122.7813
51	2000	8	30	18	48.65939	122.7195

52	1998	1	15	10	48.67227	122.7149
53	1996	4	19	3	48.43198	122.7664
54	2000	3	7	12	48.50174	122.7399
55	1995	7	17	21	48.72907	122.7526
56	2001	3	30	8	48.59129	122.7545
57	1994	6	15	8	48.47271	122.7395
58	1996	3	9	17	48.75243	122.7767
59	1992	12	1	17	48.75869	122.7899
60	1998	2	24	8	48.61583	122.7462
61	2003	4	30	12	48.50673	122.7404
62	1996	3	2	19	48.43837	122.7602
63	1994	11	8	17	48.53302	122.7442
64	1998	4	12	18	48.68127	122.7208
65	2000	7	9	21	48.76229	122.7975
66	1998	12	8	18	48.57396	122.7515
67	2003	1	17	18	48.6074	122.751
68	1992	12	23	2	48.80341	122.8841
69	2001	11	17	7	48.80557	122.8886
70	1998	1	12	19	48.72387	122.7491
71	1993	7	18	23	48.46932	122.7412
72	1993	5	7	6	48.51317	122.7411
73	1998	10	21	22	48.43058	122.7678
74	1994	4	11	21	48.79472	122.8658
75	1993	11	1	1	48.68985	122.7265
76	1992	4	22	6	48.75858	122.7897
77	1999	6	8	0	48.52494	122.7428
78	1998	2	27	20	48.75238	122.7766
79	2002	6	22	16	48.60842	122.7504
80	2000	4	8	6	48.5786	122.7523
81	2000	11	16	7	48.46533	122.7433
82	1992	1	28	9	48.43696	122.7616
83	2000	6	22	0	48.74442	122.7628
84	2002	12	29	3	48.74872	122.7689
85	1994	4	24	4	48.62067	122.7435
86	1995	6	19	4	48.75866	122.7899
87	2002	3	3	4	48.76675	122.8069
88	1994	2	27	2	48.64845	122.727
89	2000	11	9	13	48.41859	122.7795
90	1997	2	13	16	48.63328	122.7363
91	2003	4	30	12	48.59886	122.7558
92	1994	2	26	1	48.77412	122.8224
93	1998	7	7	18	48.58145	122.7528
94	1995	12	28	3	48.45767	122.7472
95	1996	8	8	10	48.78553	122.8464
96	2003	3	24	15	48.76492	122.803
97	2002	10	30	15	48.64107	122.7319
98	2000	10	5	10	48.54698	122.7467
99	2002	9	10	19	48.71212	122.7413
100	1992	5	5	13	48.6987	122.7324

Table XV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	SI_HABS2.HAB
Grid W edge	123° 57.76'W
Grid S edge	47° 22.01' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^o N
Cell size (m) west-east	150.14
Cell size (m) south-north	221.67
# cells west-east	890
# cells south-north	978
Water cell area (m^2)	33,279.9
Shore cell length (m)	182.43
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	3.0
Shore cell width – Gravel beach (m)	7.0
Shore cell width – Sand beach (m)	15.0
Shore cell width – Mud flat (m)	210.0
Shore cell width – Wetlands (fringing,m)	210.0

Table XV.E-4. Water temperature by month of the year (from French et al., 1996b).

Month	**Surface Water Temperature (^{o}C)**	**Bottom Water Temperature (^{o}C)**	**Pycnocline Depth (m)**
January	10	8	20
February	10	8	20
March	10	8	20
April	11	8	20
May	12	8	20
June	14	8	20
July	14	7	10
August	14	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	10	7	20

Table XV.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
SISW1_1992_2003_ LST.WNE	Station SISW1 - Smith Island, WA	48.32 ºN 122.84 ºW	1991-2003	National Data Buoy Center

The SISW1_1992_2003_LST.WNE wind data were downloaded from one buoy Station SISW1 - Smith Island, WA. Figure XV.E-2 displays where the buoy is located along with surrounding buoys. SISW1_1992_2003_LST.WNE data start on 31 December 1991 and end on 31 December 2003.

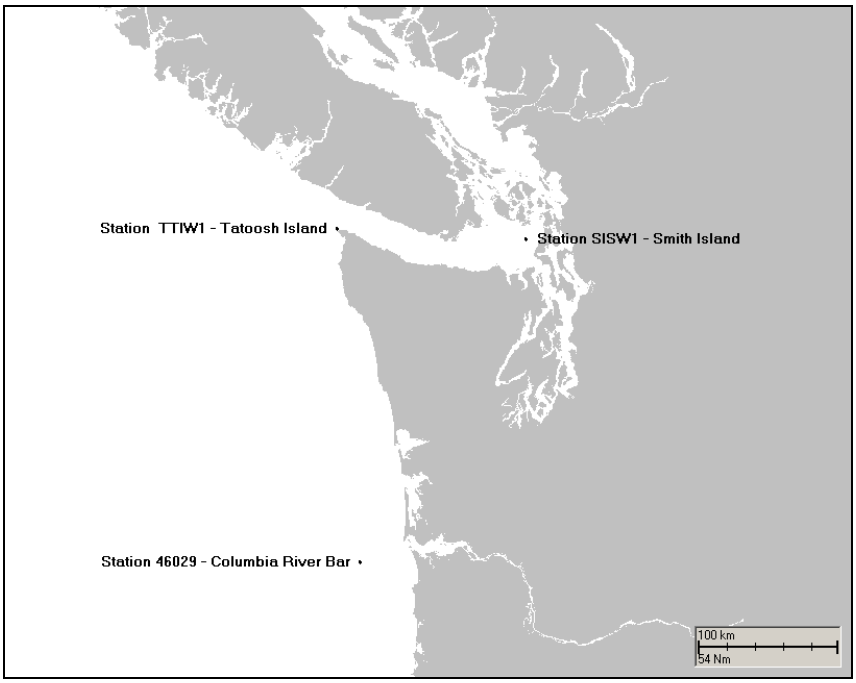


Figure XV.E-2 Wind Station Locations.

Phase II: Final Report

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

Volume XVI: Model Results for Runs Assuming No Response for San Juan Islands – Alaskan North Slope Crude

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)

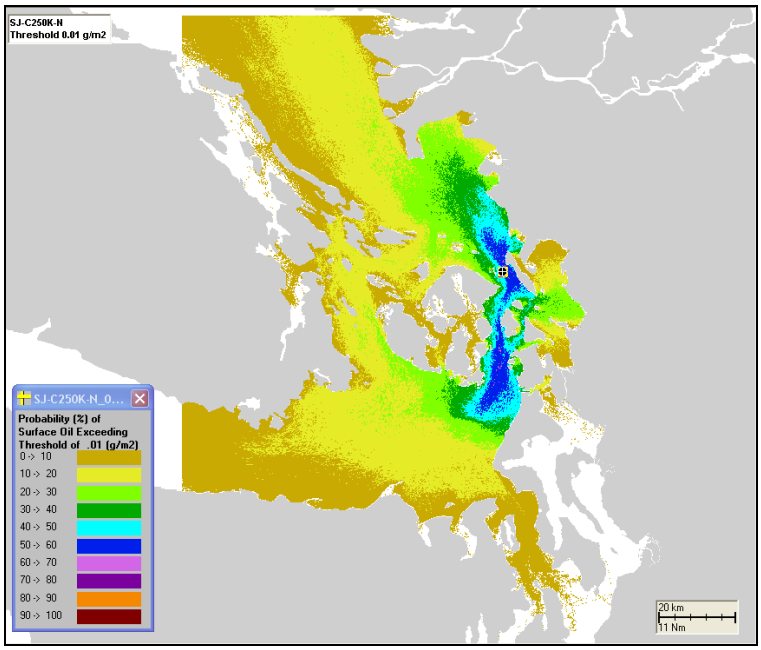


Figure XVI.B-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

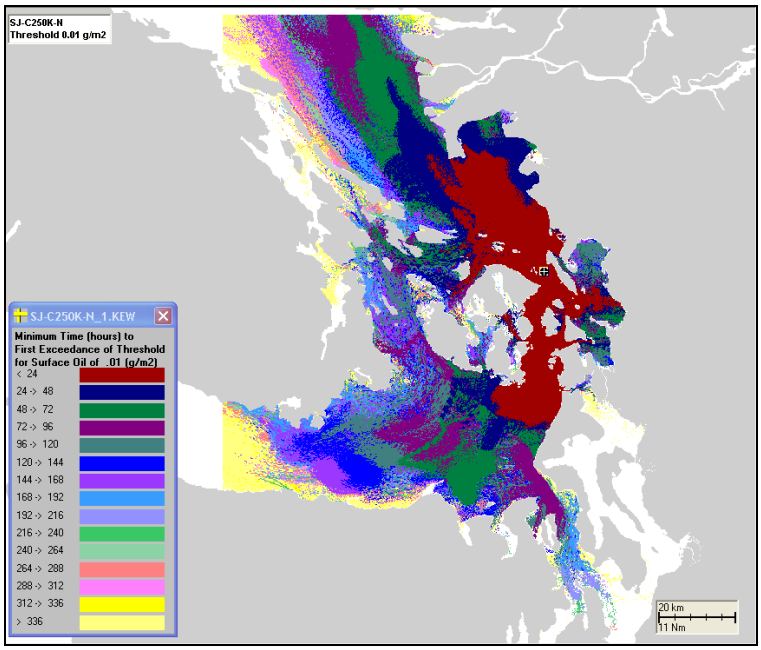


Figure XVI.B-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

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

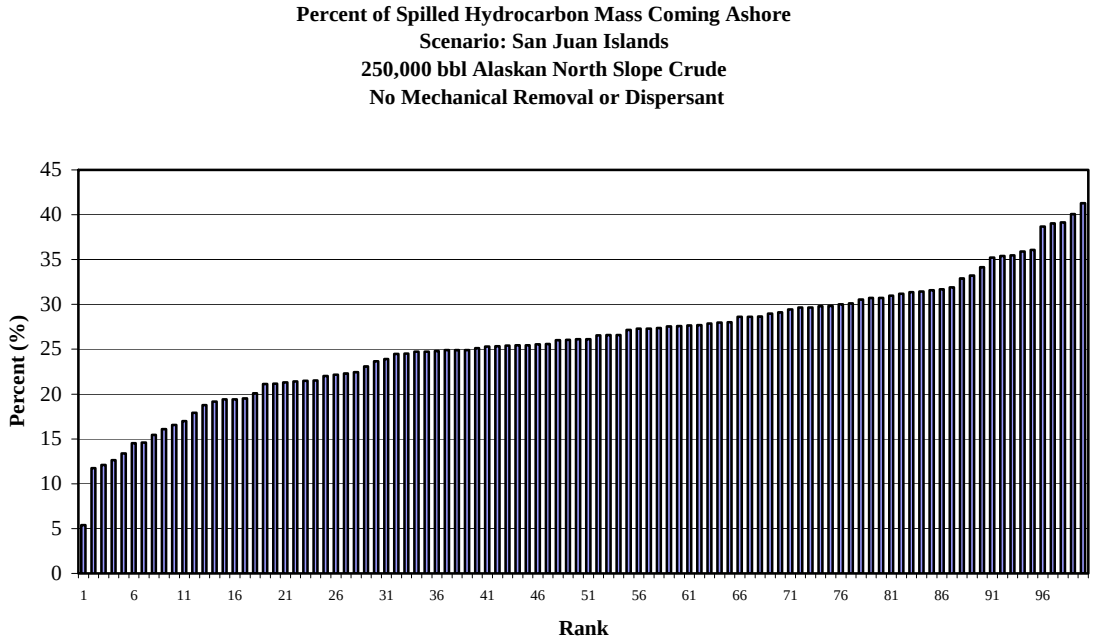


Figure XVI.C-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

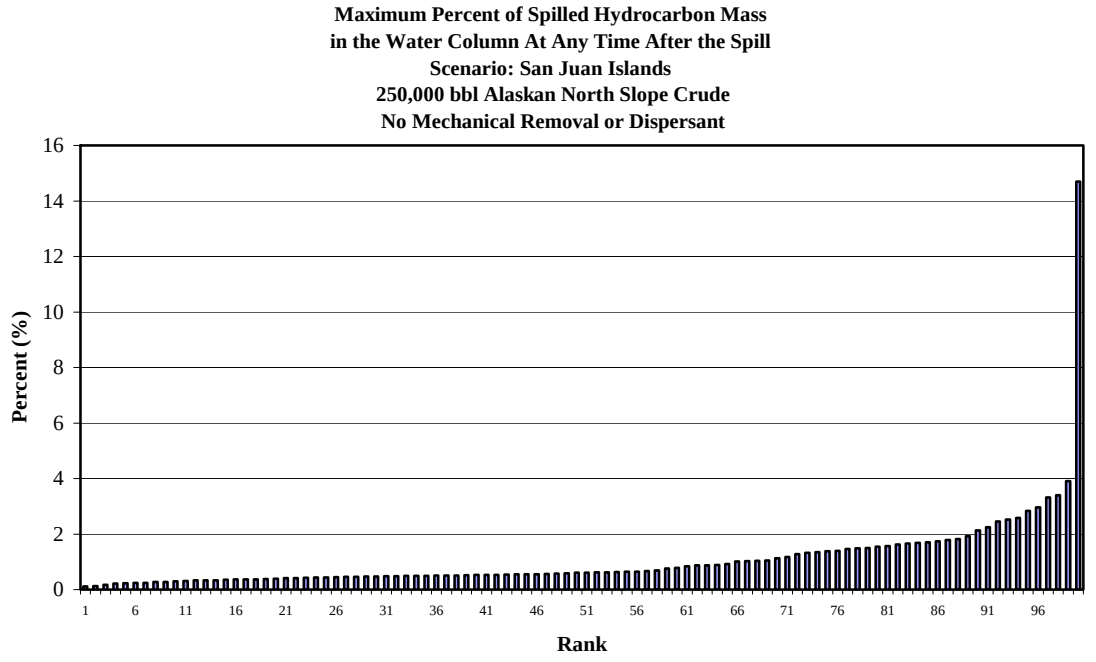


Figure XVI.C-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill (%).

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.

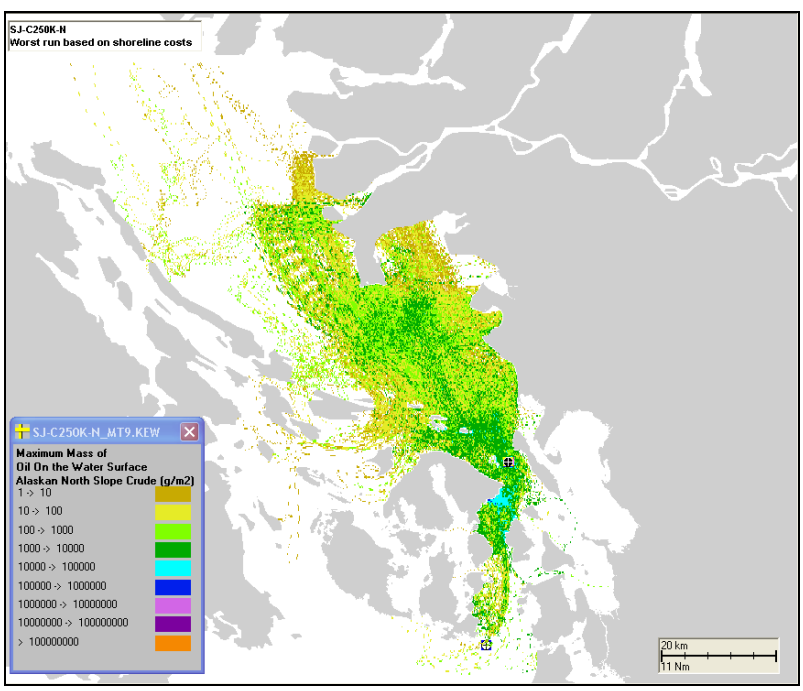


Figure XVI.E-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

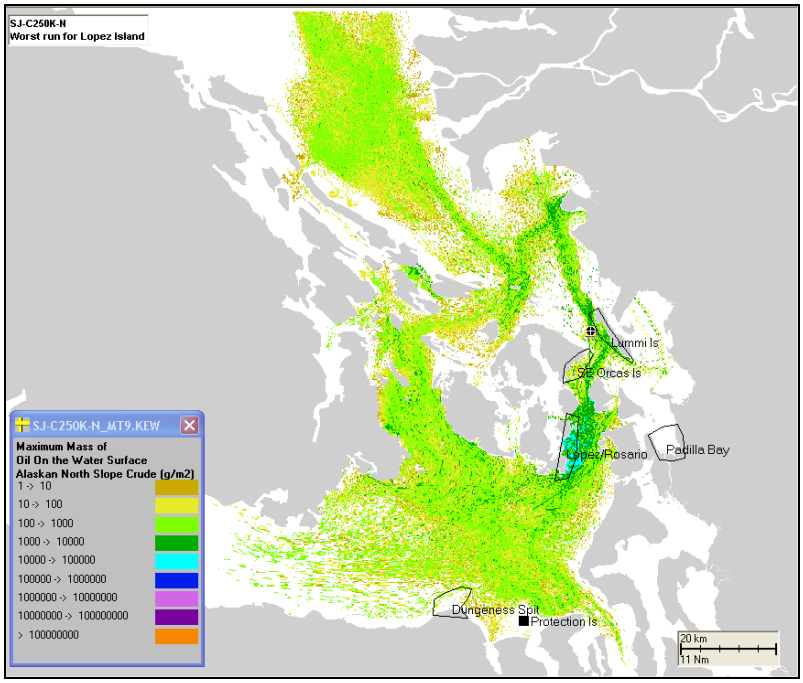


Figure XVI.E-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lopez Island.

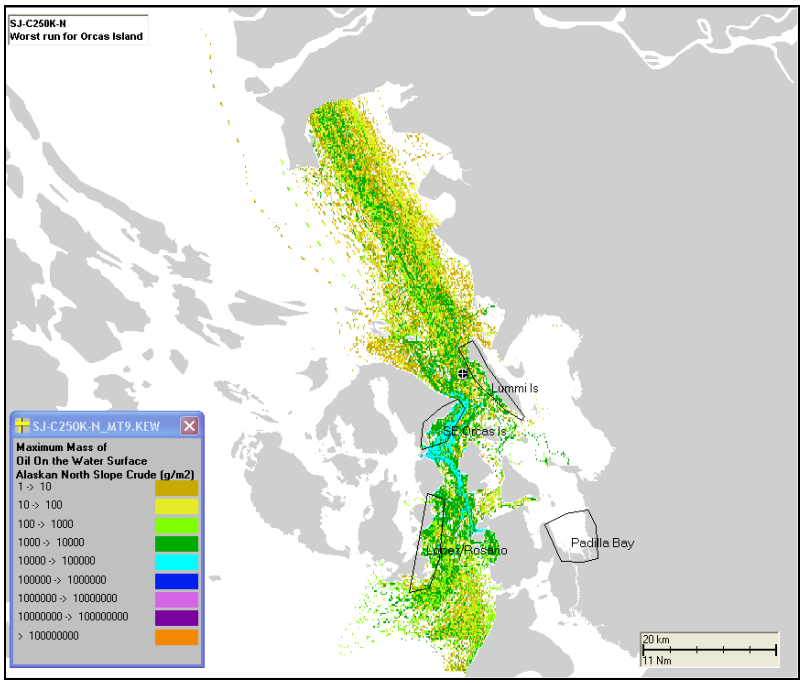


Figure XVI.E-3. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Orcas Island.

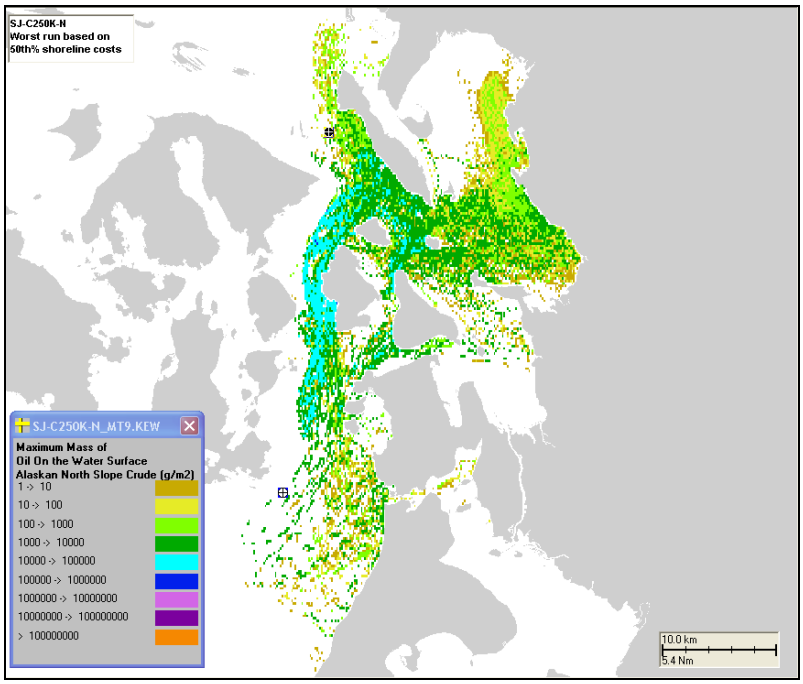


Figure XVI.E-4. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the 50th percentile run based on shoreline costs.

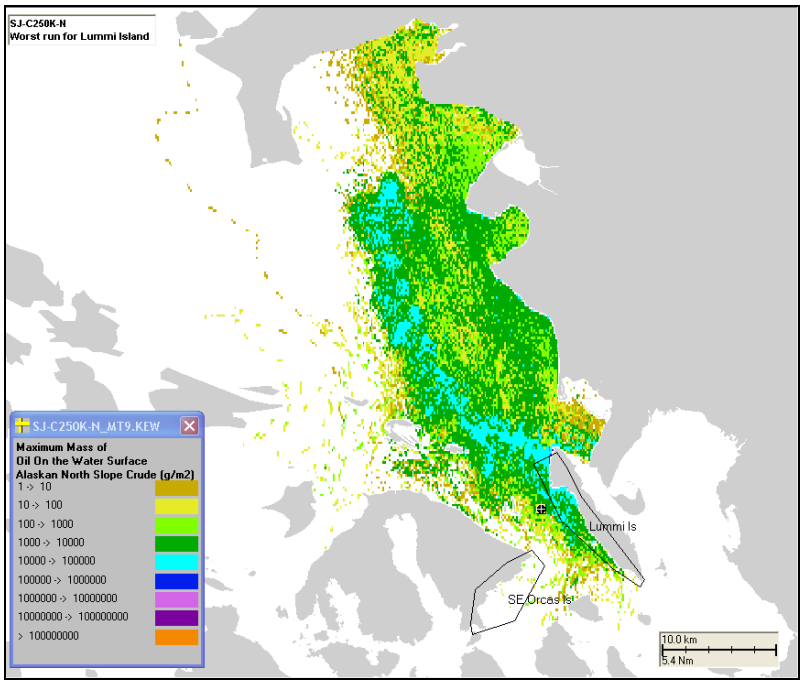


Figure XVI.E-5. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lummi Island.

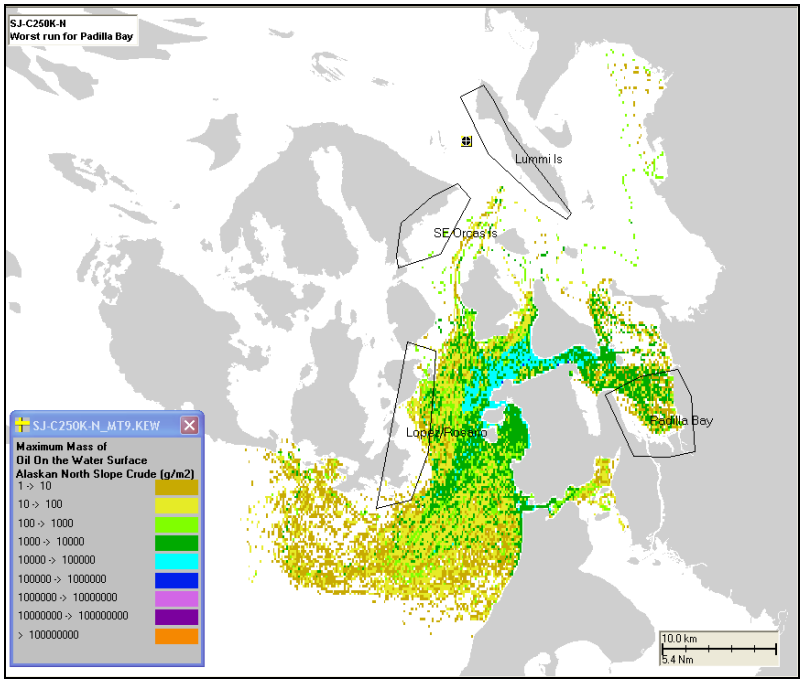


Figure XVI.E-6. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Padilla Bay.

XVI.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (TableXVI.F-1), were used to estimate wildlife impacts for the other 88 runs in the stochastic scenario.

The wildlife impacts for all 100 runs were estimated from the habitat area occupied by the species group that was oiled, i.e., areas of water swept by oil $> 10 g/m^2$ and shoreline oiled by $>100 g/m^2$, using the methods described in Section 2.3 of Volume I. The 100 estimates of wildlife impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the wildlife group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Table XVI.F-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose.

Wildlife Injuries (kg)	Slope[1]	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Waterfowl	2.04E-05	27,455.99	22,229.16	0.2676	0.5173
Seabirds	6.22E-06	10,149.46	6,452.79	0.2878	0.5364
Wading birds	1.49E-05	100.67	104.49	0.0135	0.1164
Shorebirds	-2.05E-04	844.40	386.25	0.1600	-0.4000
Raptors	1.55E-07	12.25	5.76	0.0058	0.0761
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans	1.67E-08	24.84	22.23	0.1972	0.4441
Pinnipeds (seals)	3.74E-07	739.84	662.04	0.1219	0.3491
Other mammals[2]	0.00E+00	0.00	0.00	0.0000	0.0000

[1] For regressions in which the slope was not significantly different from zero, the mean weight of injured wildlife (i.e., the regression's intercept) was used to estimate wildlife impacts for the additional 88 stochastic runs.
[2] Results of these regressions reflect the fact that no injuries were sustained for these wildlife species.

Table XVI.F-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Cetaceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
5th Percentile	44,504	13,068	89	5,629	2	0	6	-	63,983	63,977	6.01
50th Percentile	62,771	13,663	106	6,740	3	0	7	-	83,483	83,475	7.46
95th Percentile	116,619	15,420	124	7,856	3	0	12	-	139,410	139,398	11.74
Mean	72,525	13,982	107	6,767	3	0	8	-	93,392	93,384	8.24
Std Dev (SD)	26,956	879	10	666	0	0	2	-	28,124	28,122	2.14
Mean - 2SD	18,614	12,223	86	5,436	2	0	4	-	37,144	37,140	3.95
Mean + 2SD	126,437	15,740	128	8,099	4	0	12	-	149,640	149,627	12.52

XVI.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XVI.G-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column.

Fish and Invertebrate Injuries (kg)	Slope[1]	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Total small pelagic fish	2.07E+03	-588.04	2,035.02	0.3321	0.5763
Total large pelagic fish	3.79E+03	-928.53	3,963.09	0.3042	0.5516
Total demersal fish	6.09E+01	14.49	167.37	0.0596	0.2441
Total demersal invertebrates	1.94E+01	-1.40	46.61	0.0769	0.2773
Total mollusks	1.28E+02	1,629.14	2,114.08	0.0018	0.0419

[1] For regressions in which the slope was not significantly different from zero, the mean weight of injured fishes and invertebrates (i.e., the regression's intercept) was used to estimate injuries for the additional 88 stochastic runs.

Table XVI.G-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
5th Percentile	-	-	29.21	3.30	1,660.11	117,942	119,634
50th Percentile	677.34	1,382.43	51.64	10.47	1,707.31	287,366	291,195
95th Percentile	5,308.17	9,839.72	187.62	53.89	1,993.36	528,744	546,127
Mean	1,698.87	3,237.66	81.25	19.92	1,769.58	305,639	312,446
Std Dev (SD)	3,277.50	5,991.23	96.46	30.80	202.92	130,644	140,243
Mean - 2SD	-	-	-	-	1,363.75	44,351	45,715
Mean + 2SD	8,253.86	15,220.13	274.16	81.53	2,175.42	566,926	592,932

XVI.H. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All injuries used to calculate habitat restoration costs are expressed as wet weight; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

The NRDA costs for all 100 runs were estimated from the wildlife, fish and invertebrate impact estimates for each run. The 100 estimates were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Table XVI.H-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Fish and Invertebrates:						
Small pelagic fish	-	677.3	5,308.2	1,698.9	-	8,253.9
Large pelagic fish	-	1,382.4	9,839.7	3,237.7	-	15,220.1
Demersal fish	29.2	51.6	187.6	81.2	-	274.2
Decapods	3.3	10.5	53.9	19.9	-	81.5
Molluscs	119,602	289,074	530,738	307,408	45,715	569,102
Birds:						
Waterfowl (# * kg each)	29,224	41,220	76,580	47,625	12,223	83,027
Seabirds (# * kg each)	15,191	15,884	17,926	16,254	14,209	18,298
Waders (# * kg each)	103	124	144	124	100	148
Shorebirds (# * kg each)	6,543	7,835	9,132	7,867	6,319	9,415
Raptors (# * kg each)	2.9	3.0	3.7	3.1	2.0	4.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	7.0	8.6	13.6	9.5	4.6	14.5
Cetaceans	0.0	0.0	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	119,634	291,195	546,127	312,446	45,715	592,932
Subtotal birds	51,065	65,065	103,785	71,873	32,853	110,892
Subtotal other wildlife	7	9	14	10	5	15
Total all species	170,706	356,269	649,926	384,328	78,573	703,838

Table XVI.H-2. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	5th Percentile	50th Percentile	95th Percentile	Mean	Standard deviation (SD)	Mean – 2SD	Mean + 2SD
Saltmarsh Area (ha)	150.3	195.4	307.6	213.4	62.9	114.5	339.3
Saltmarsh Area (acres)	371.3	482.8	760.0	527.2	155.5	282.8	838.3
Saltmarsh Cost (millions of 2004$)	69.6	90.5	142.4	98.8	29.1	53.0	157.1
Eelgrass Area (m^2)	93.9	122.1	192.2	133.3	39.3	71.5	212.0
Eelgrass Area (acres)	232.0	301.7	474.9	329.5	97.2	176.7	523.8
Eelgrass Cost (millions of 2004$)	27.7	36.0	56.7	39.3	11.6	21.1	62.5

XVI.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XVI.I-1. San Juan Islands – Alaskan North Slope Crude, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	5th Percentile	50th Percentile	95th Percentile	Mean	Mean – 2SD	Mean + 2SD
Vulnerability Score ($/gal.)	21.74	23.67	25.58	23.71	20.41	27.00
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	228	249	269	249	214	284

Phase II: Final Report

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

Volume XVII: Results of Alternative Response Scenarios for San Juan Islands – Alaskan North Slope Crude

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 (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Lopez Island;
3. the worst case run for impacts at Orcas Island;
4. the 50th percentile run based on shoreline oiling and area-based costs for cleanup;
5. the worst case run for impacts at Lummi Island; and
6. the worst case run for impacts at Padilla Bay.

Locations of the sensitive sites are shown in Figure XVII.A-1.

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

In the tables, the results as oil fate over time; wildlife, fish and invertebrate impacts; and the NRDA costs (damages) for the individual representative runs are presented. The

same representative runs were used when comparing one response alternative to another, i.e., the dates and times are held constant across alternate response scenarios so inter-comparisons between scenarios may be made.

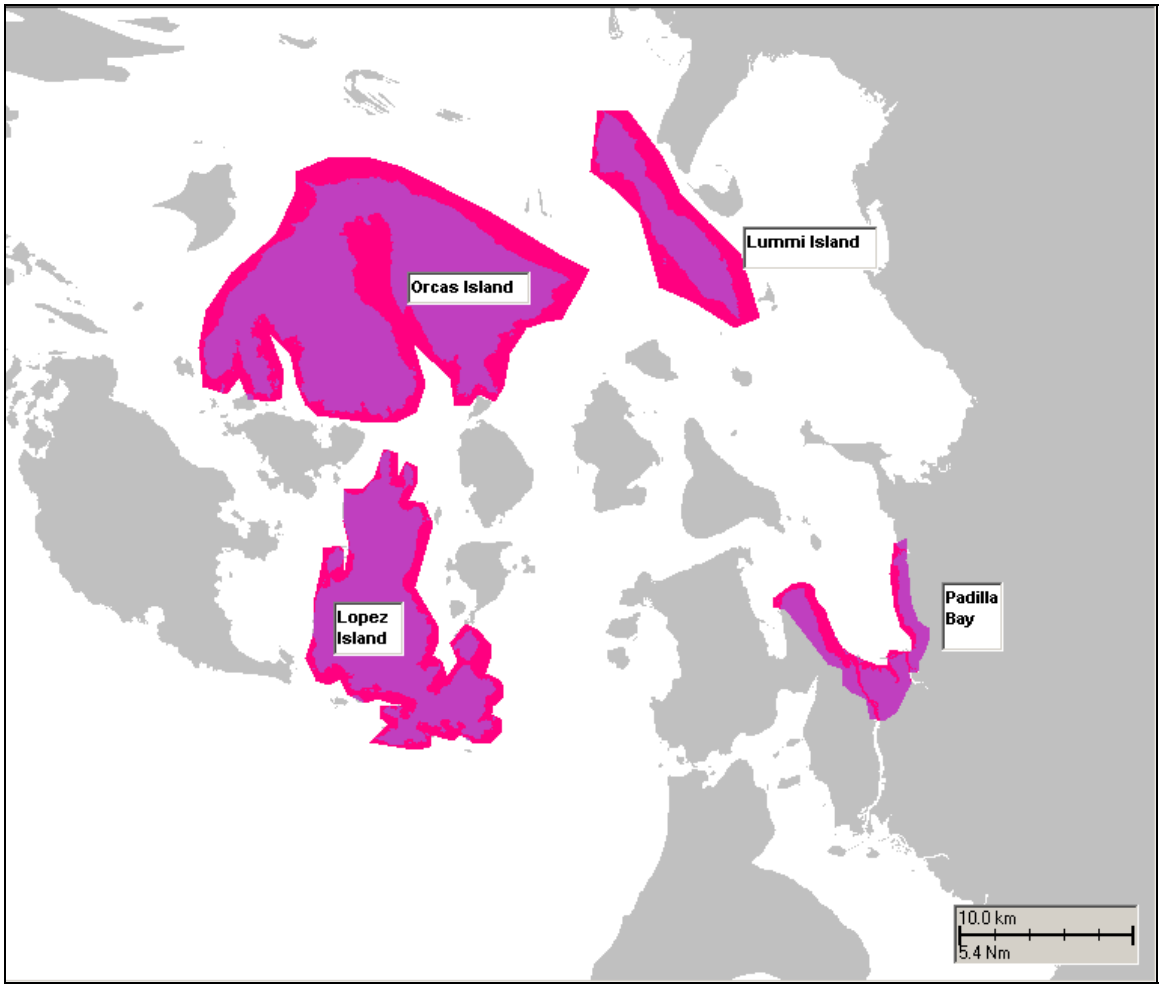
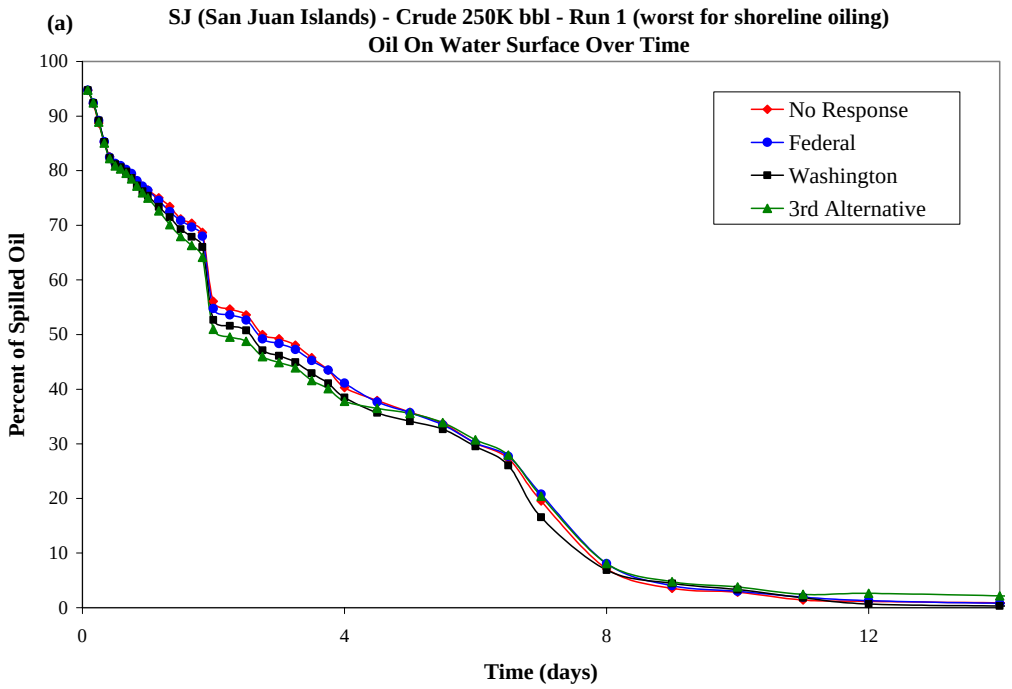


Figure XVII.A-1 Sensitive sites for location: San Juan Islands.

XVII.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XVII.B-1 to XVII.B-24 list the mass balance of oil as a function of time. The oil on the water surface is floating oil (thick, sheen or tar balls) within the model grid. The percent "out of grid" is floating oil that has been transported out of the model grid. The sum of these (right-most column) is the total amount of oil floating at a given time. Oil in the water column is either entrained oil droplets or dissolved. Percent in the sediment represents oil in subtidal sediments, while percent on shore is oil in intertidal sediments on the shorelines. The percent decayed is by natural degradation. The percent removed is by mechanical removal during the response to the spill. Figures XVII.B-1 to XVII.B-22 summarize the results, showing comparisons of the alternative responses for each of the individual runs. Note that for the worst run to each critical site, the figures showing the *percentage* of oil on the shoreline display information on oil hitting *all* coastal areas, while the figures showing the *amount* of oil on the shoreline include only oil coming ashore within the critical site.

Tables XVII.B-25 to XVII.B-28 summarize the water surface area exposed to oil at some time after the spill (i.e., cumulative total area) and the shoreline oiled to varying degrees at any time after the spill (i.e., areas above thresholds using the maximum amount of oil on shore at any time). These tables also include the per-unit-area component of shoreline cleanup costs. The total shoreline cleanup and other response costs are described in Etkin (2005b,c) and French-McCay (2005). Note that the variability in these results is due to randomized variations (simulating natural variability and turbulence) included in the model and variations in the exact time and locations oil reaches shorelines due to differences in response timing and equipment used. The variability is greater than the signal related to response alternatives in many cases.



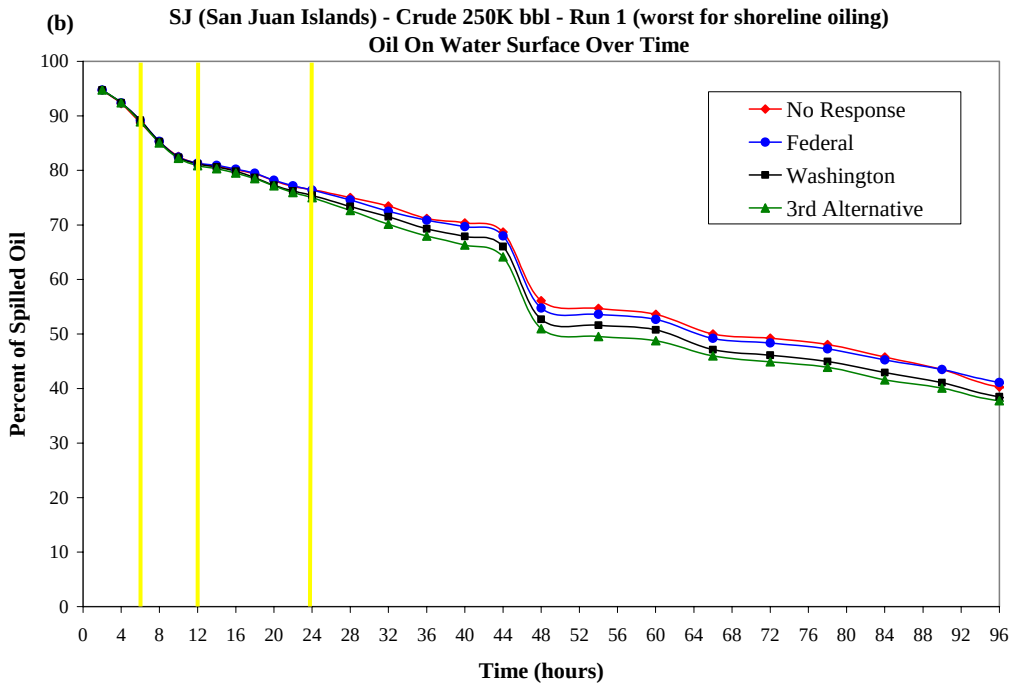
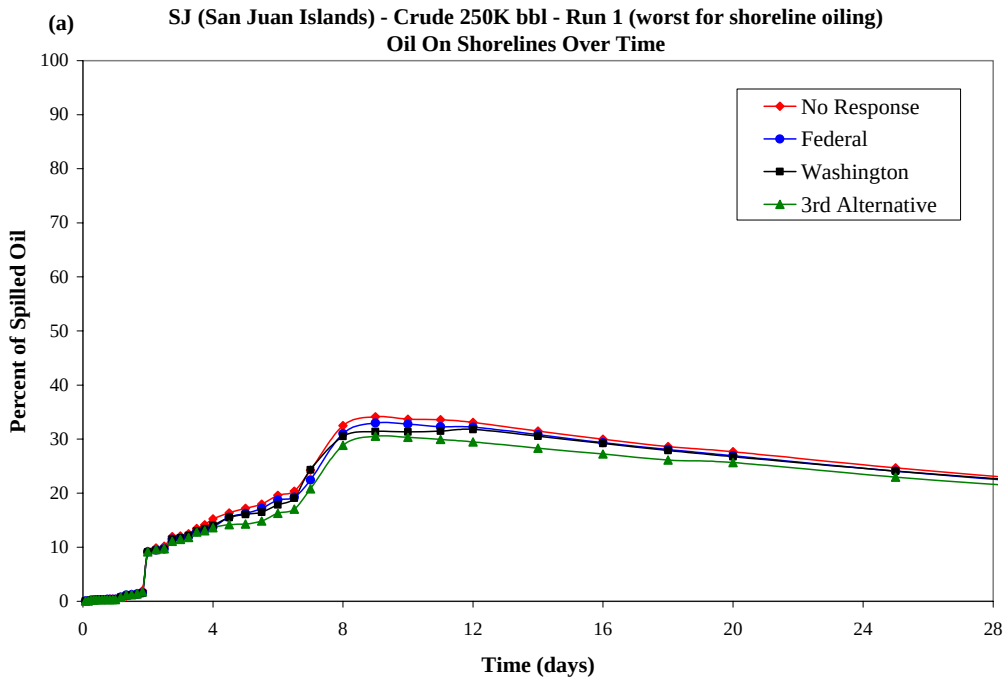


Figure XVII.B-1 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



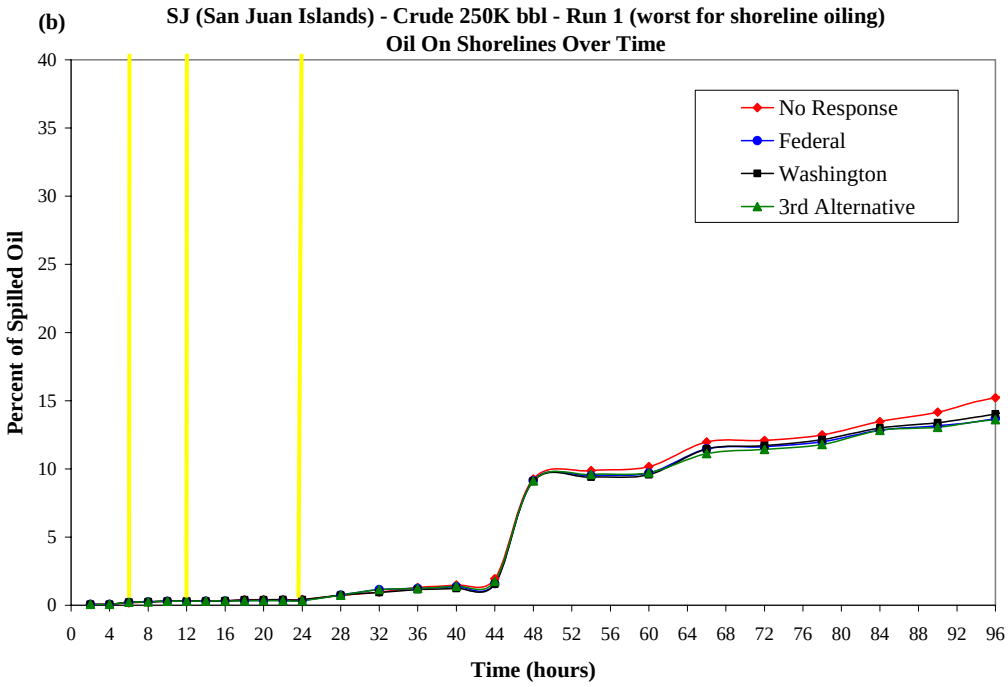


Figure XVII.B-2 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

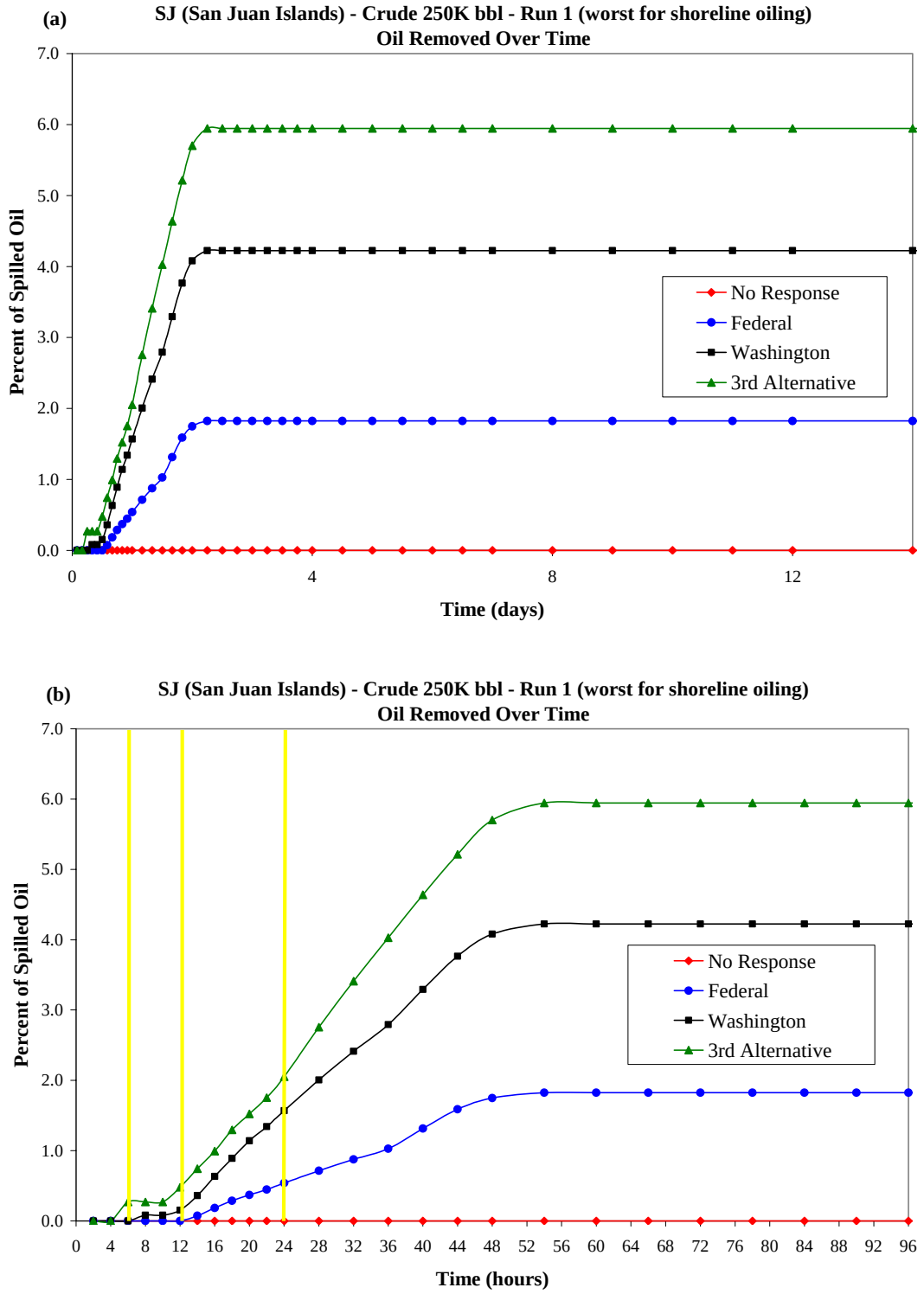
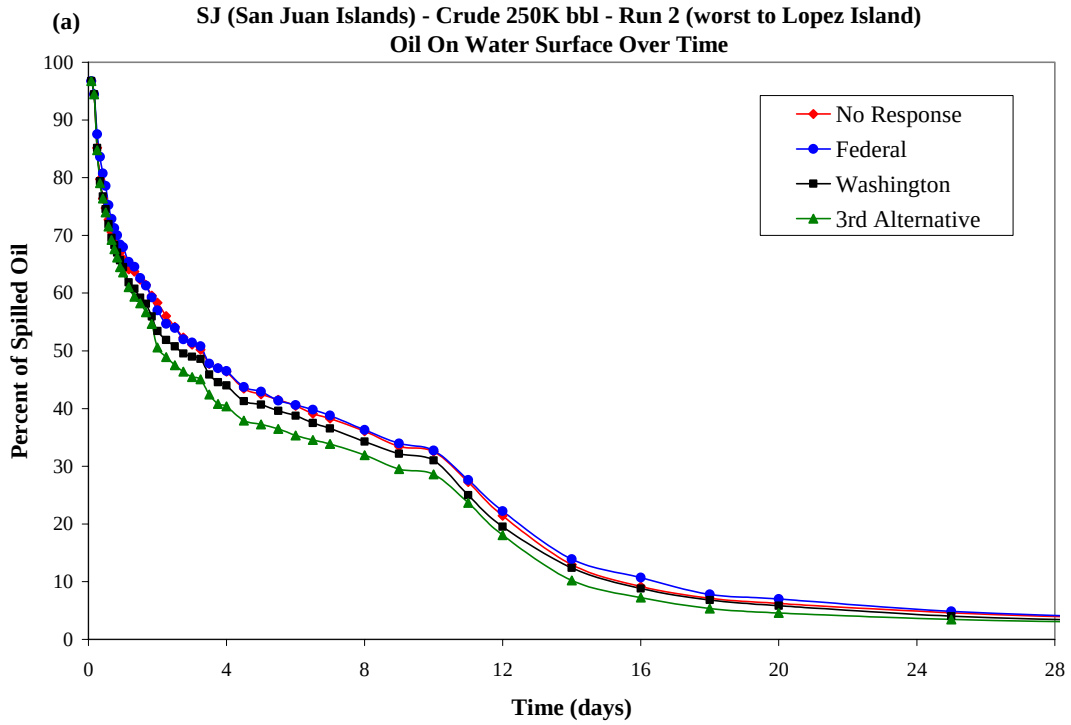


Figure XVII.B-3 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



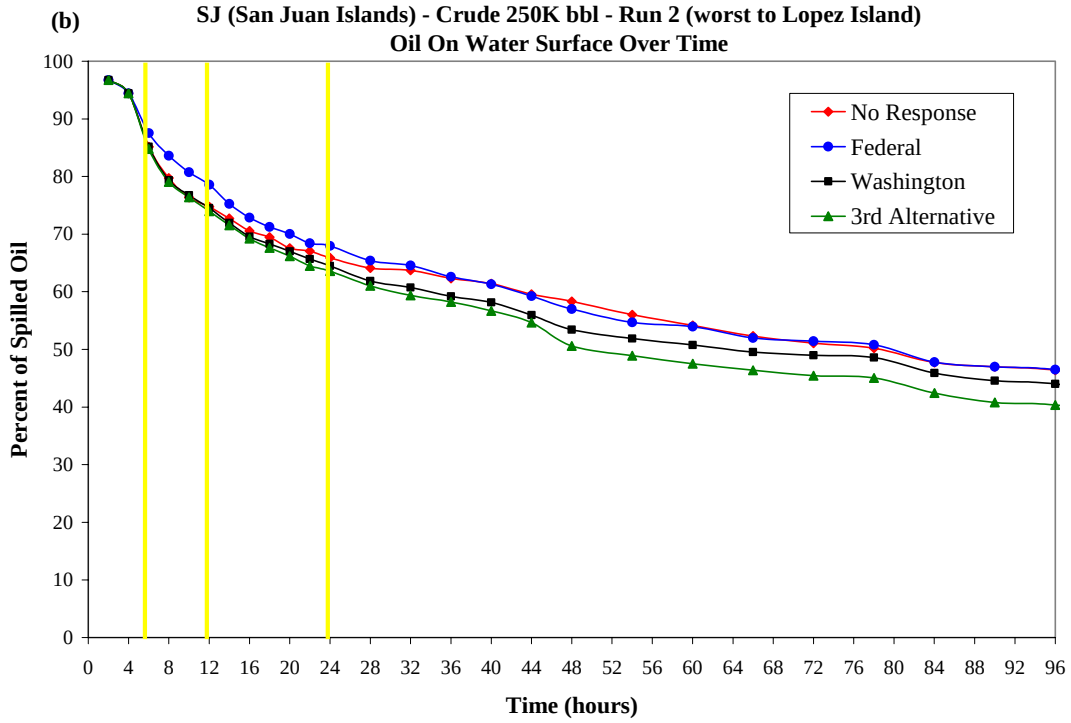
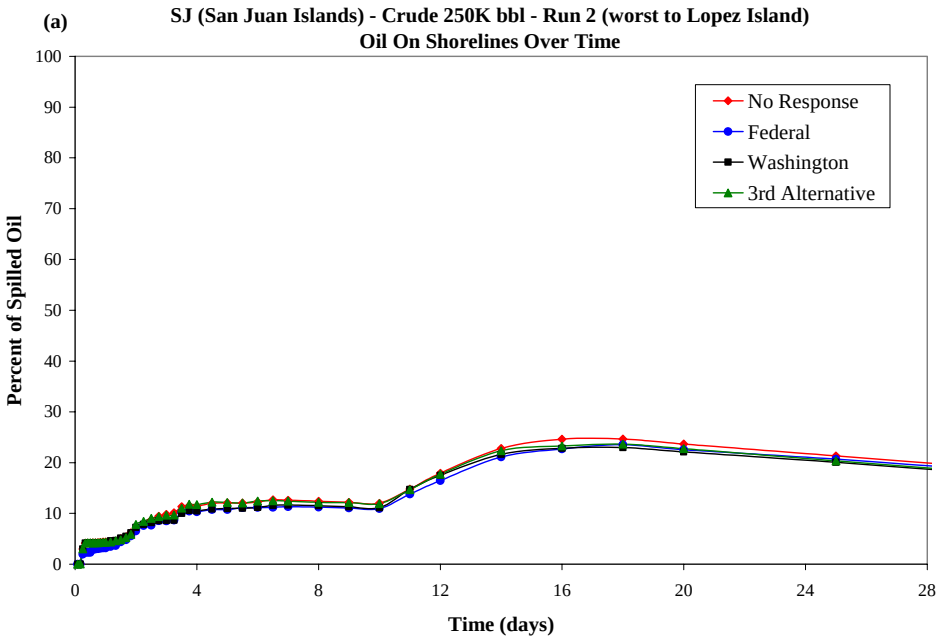


Figure XVII.B-4 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



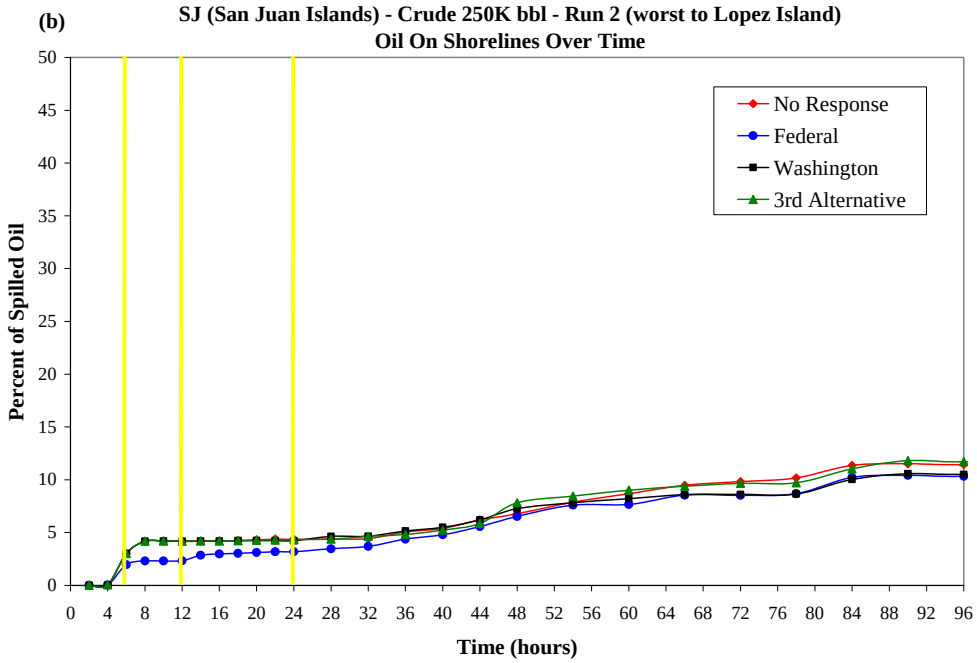
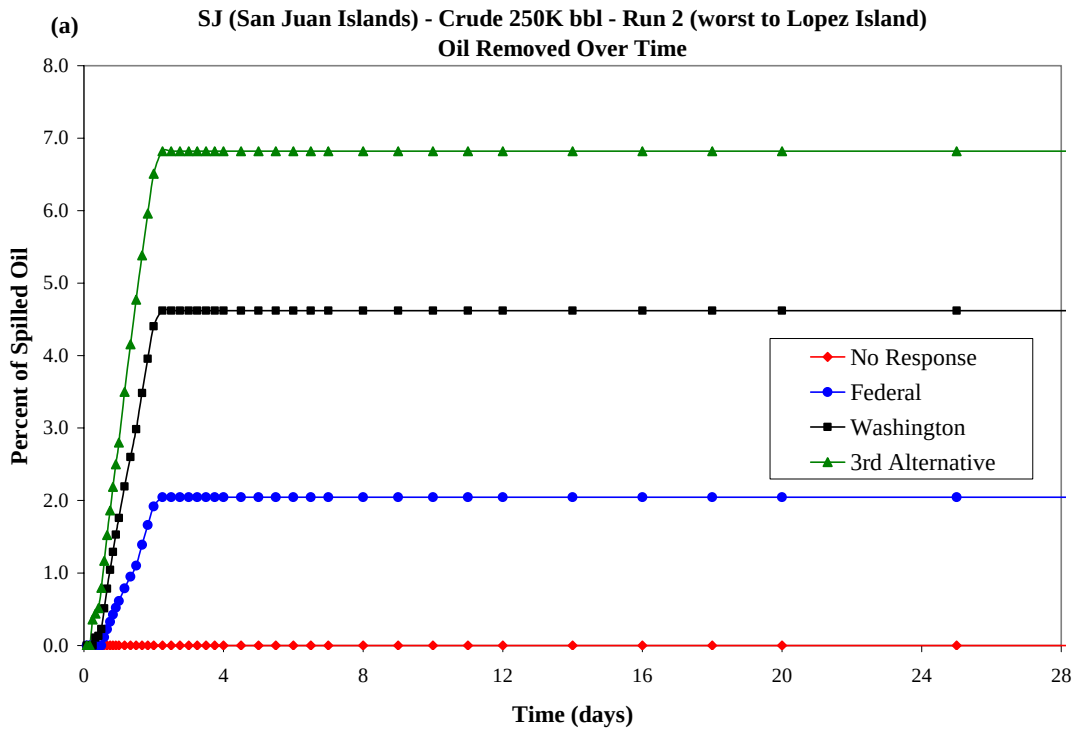


Figure XVII.B-5 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



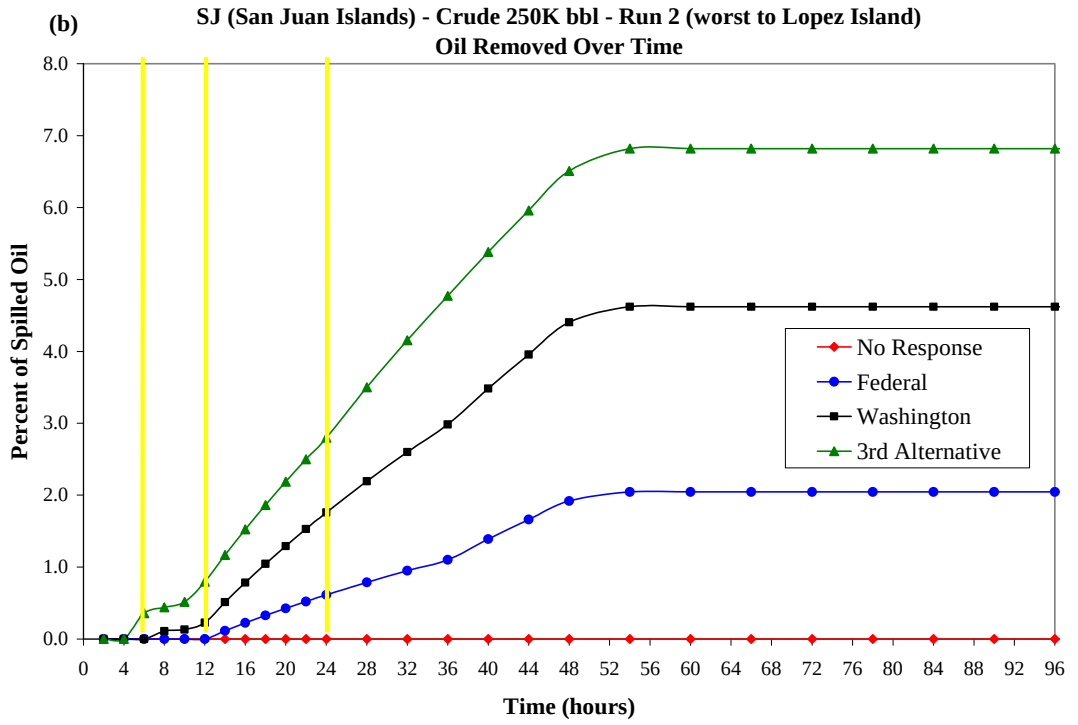


Figure XVII.B-6 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a.

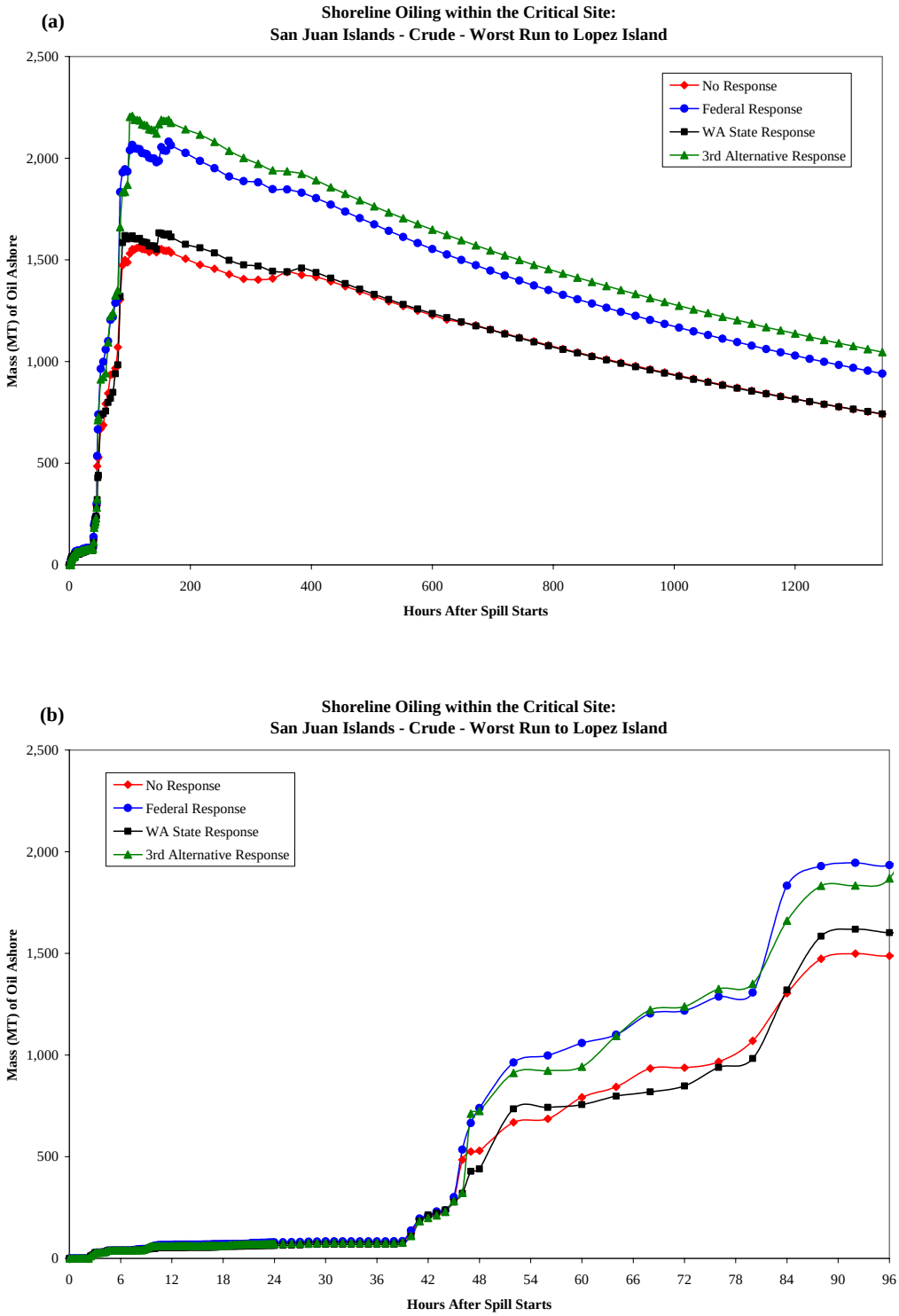
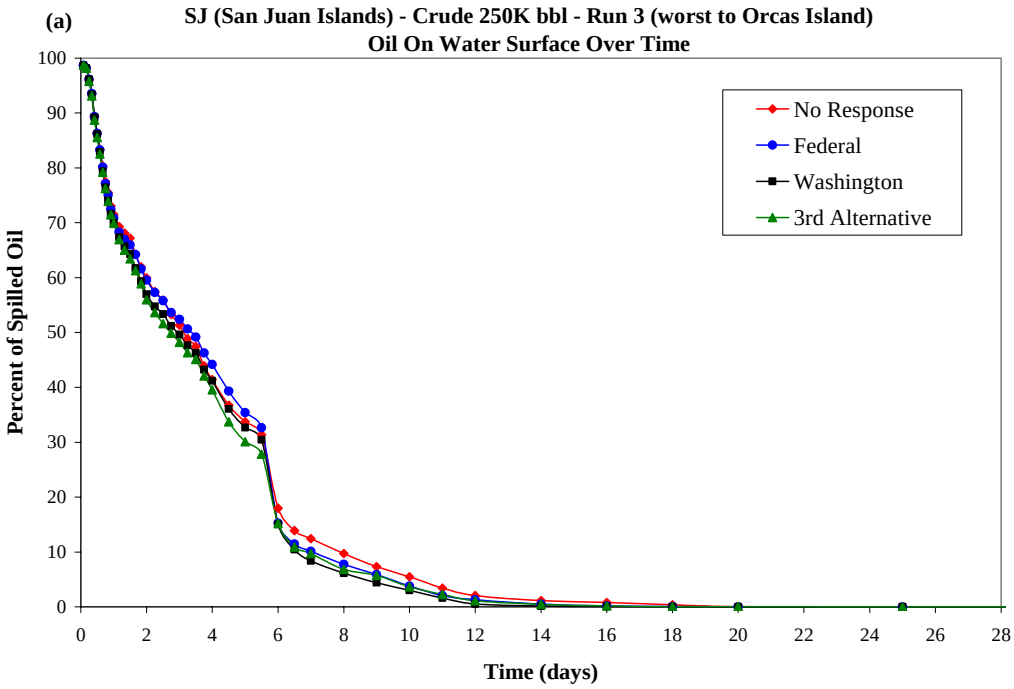


Figure XVII.B-7 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lopez Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



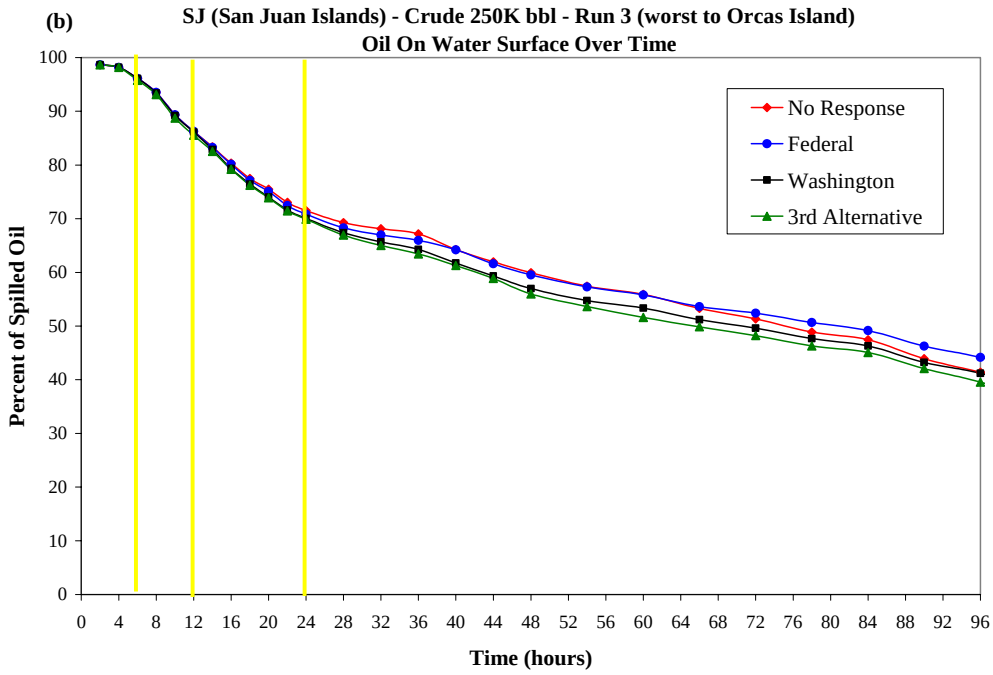
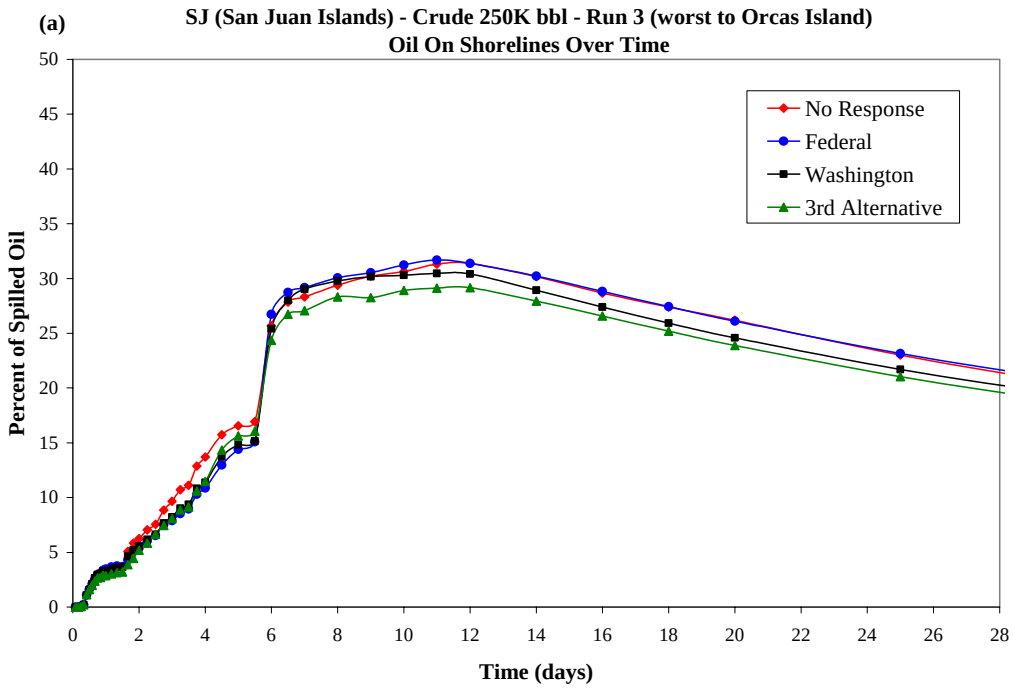


Figure XVII.B-8 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



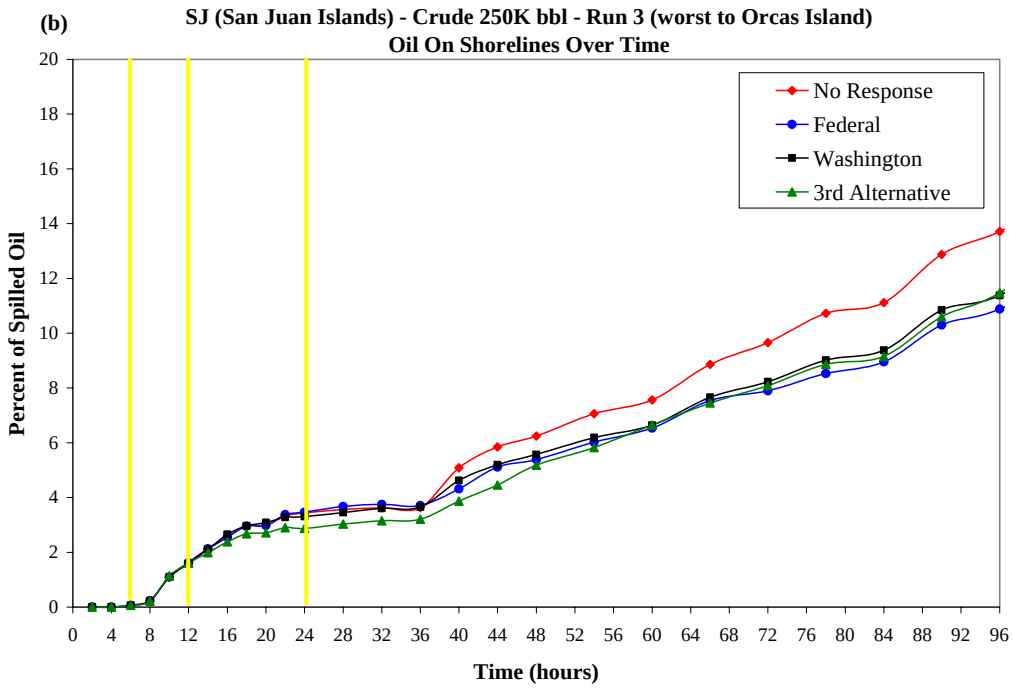


Figure XVII.B-9 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

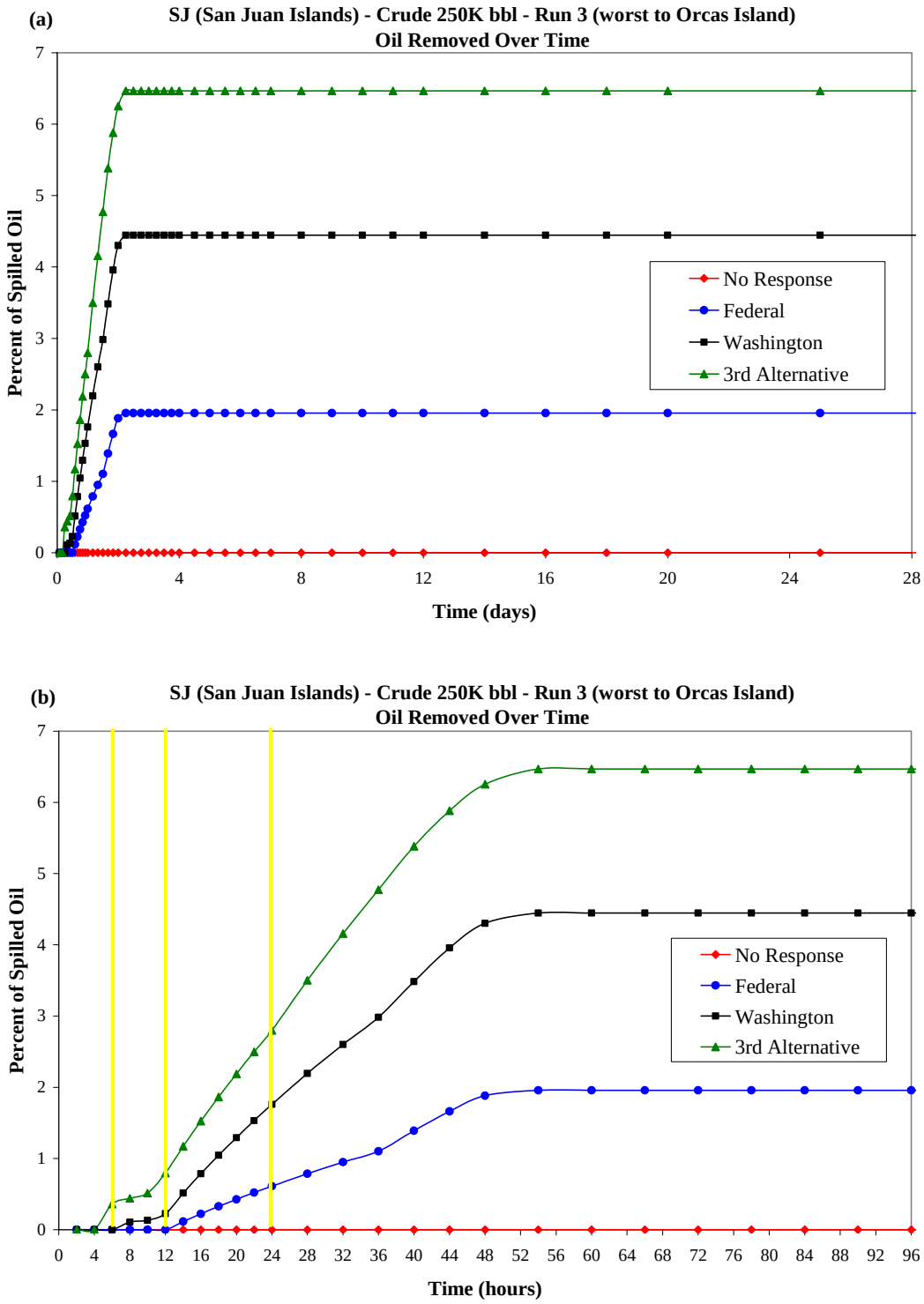
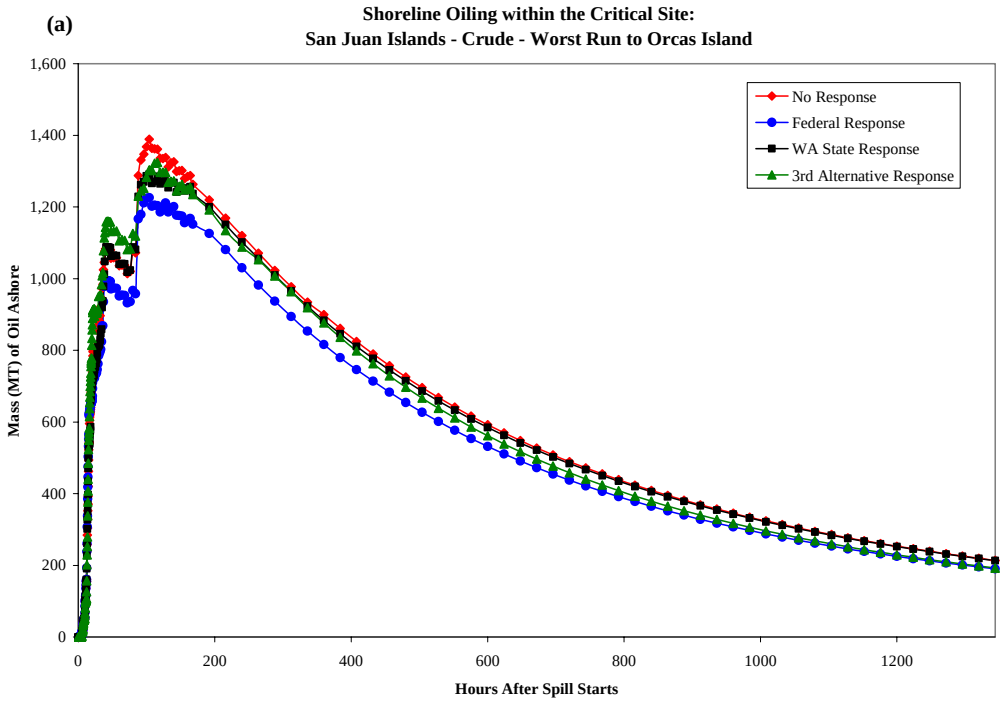


Figure XVII.B-10 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a.



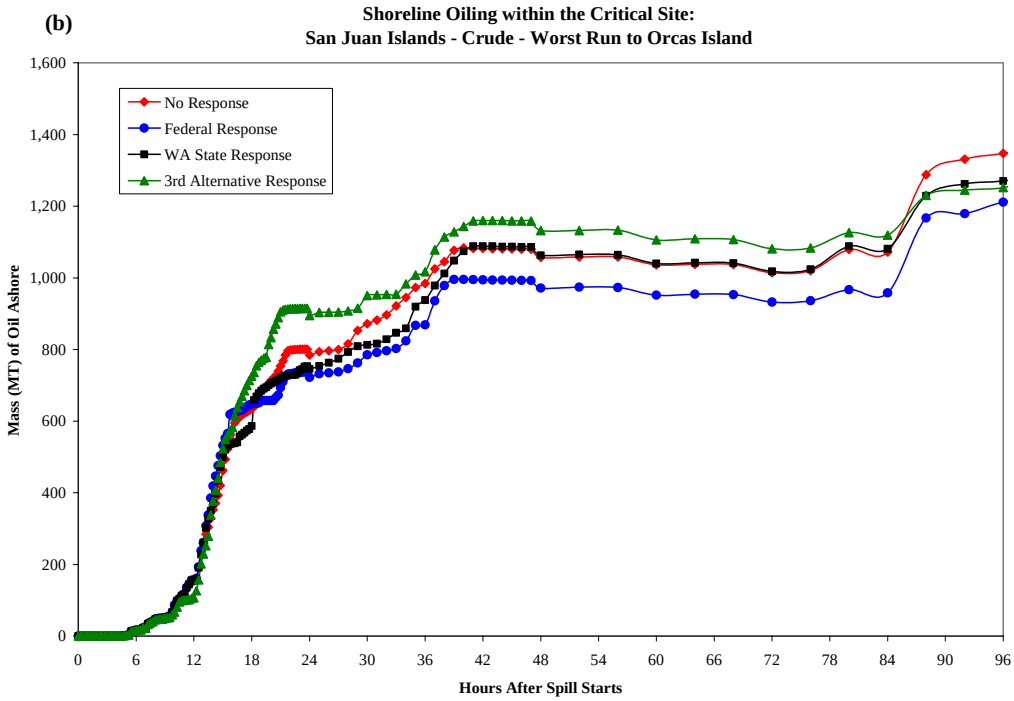
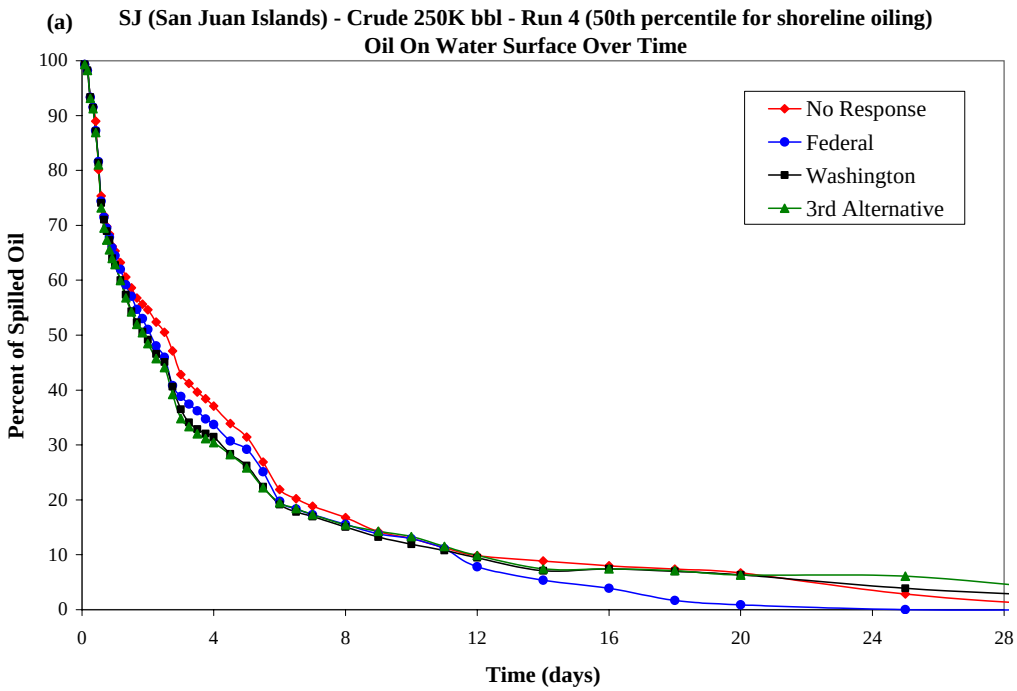


Figure XVII.B-11 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Orcas Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



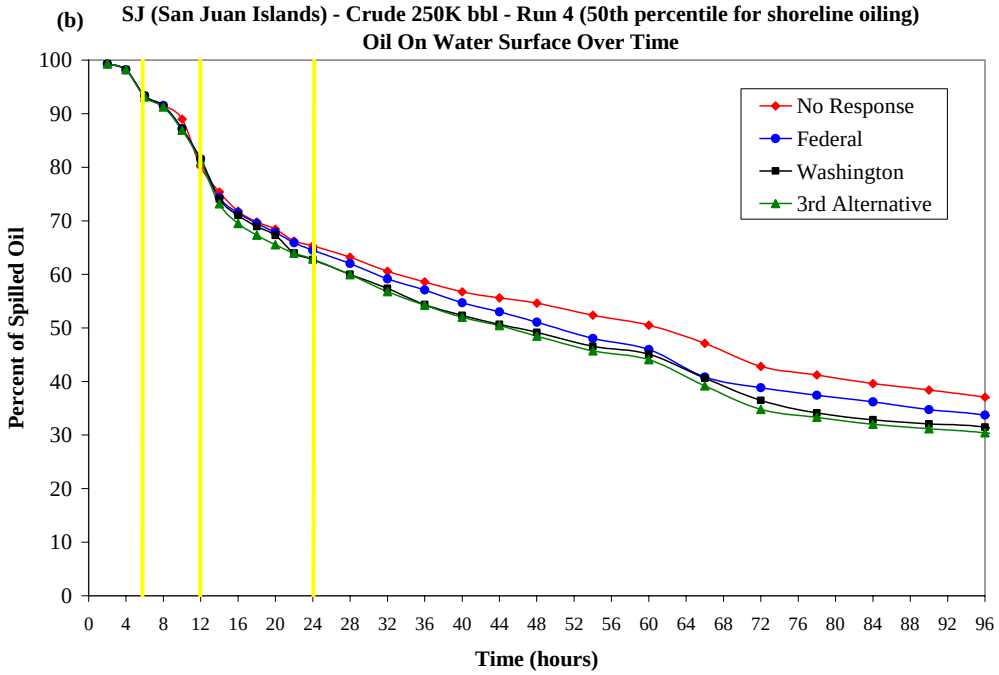


Figure XVII.B-12 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

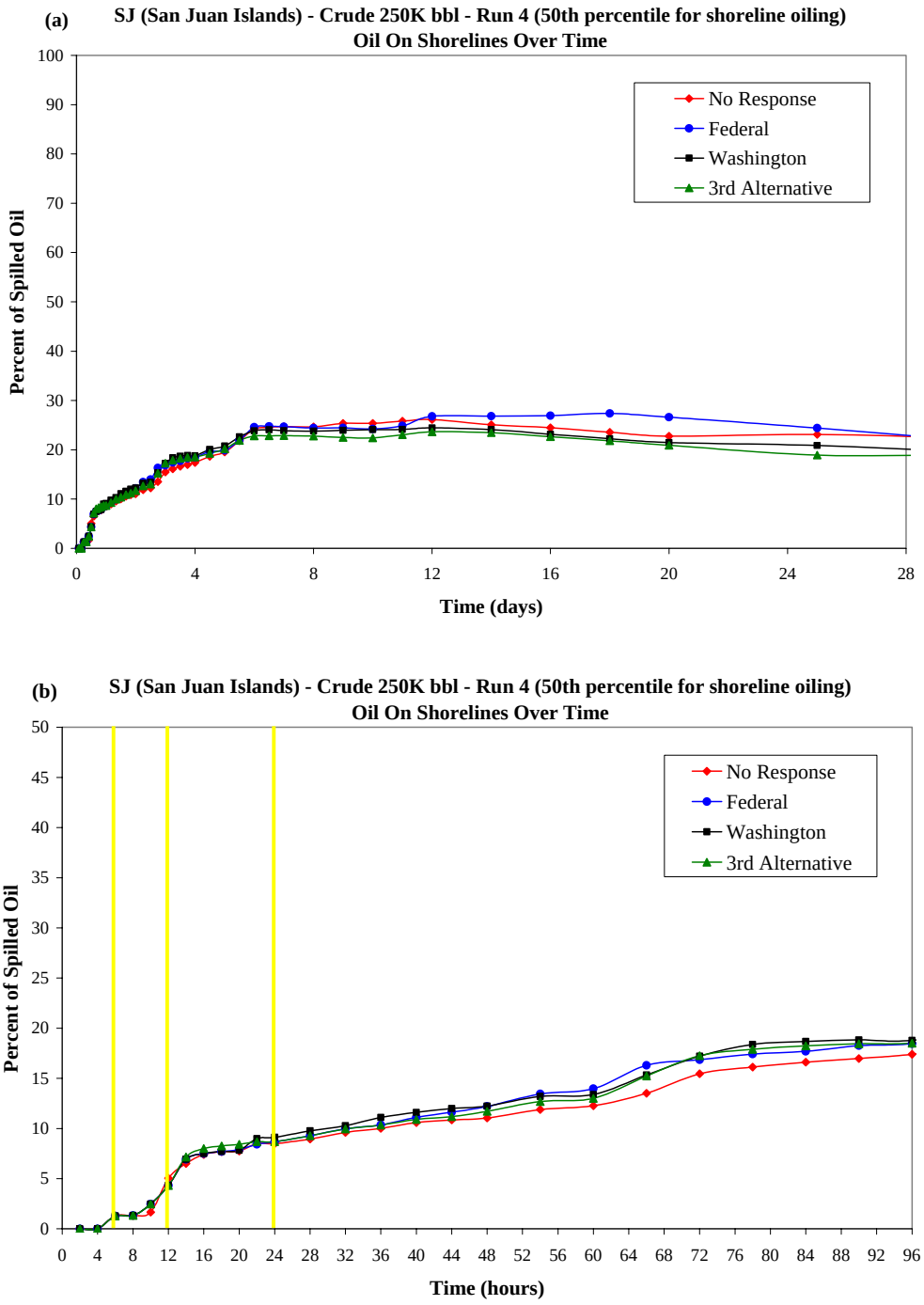


Figure XVII.B-13 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

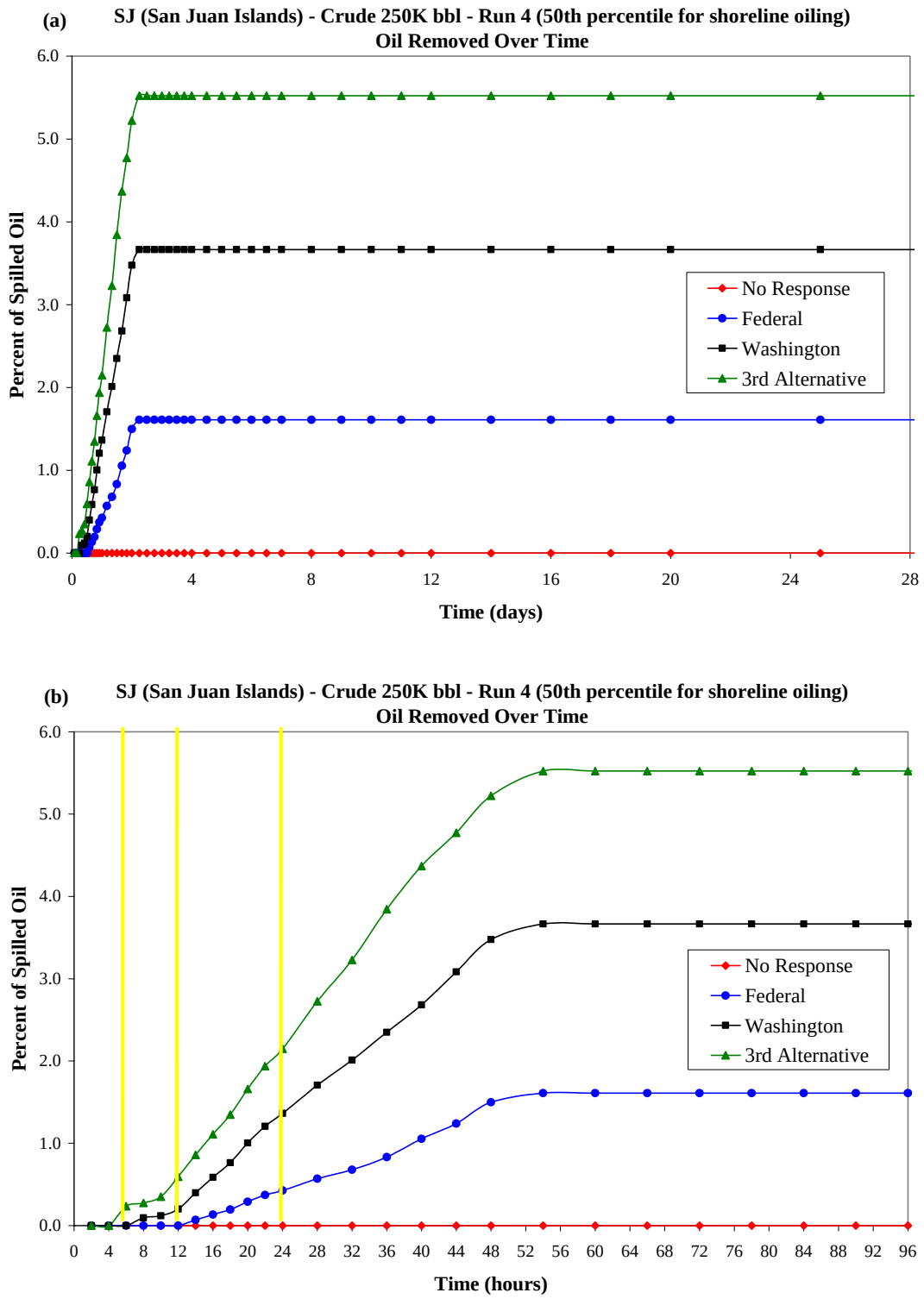
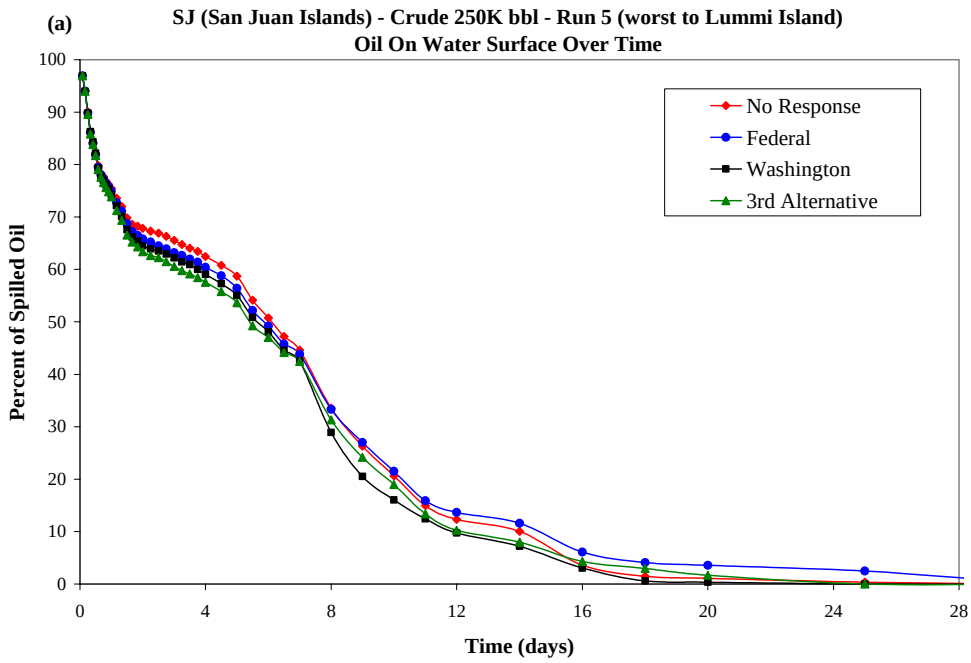


Figure XVII.B-14 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 50th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



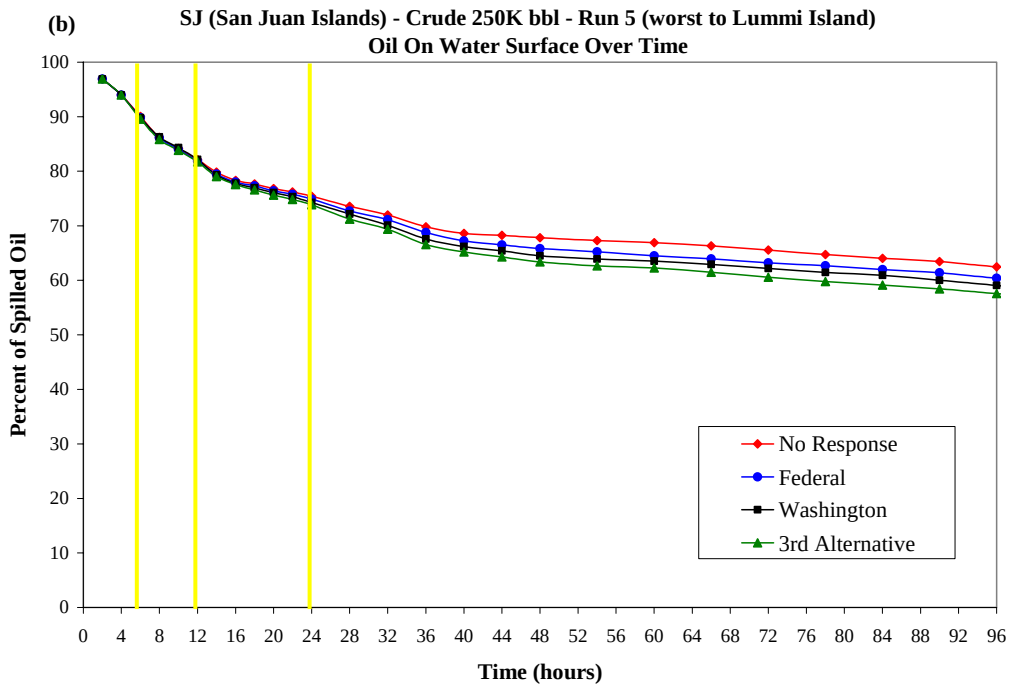
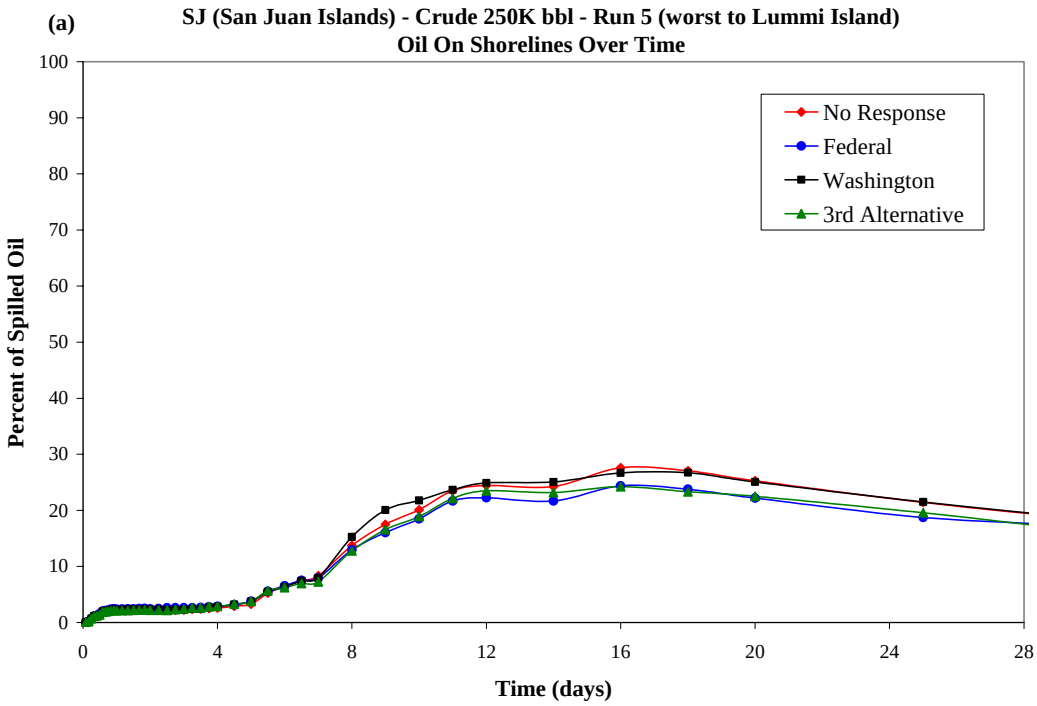


Figure XVII.B-15 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



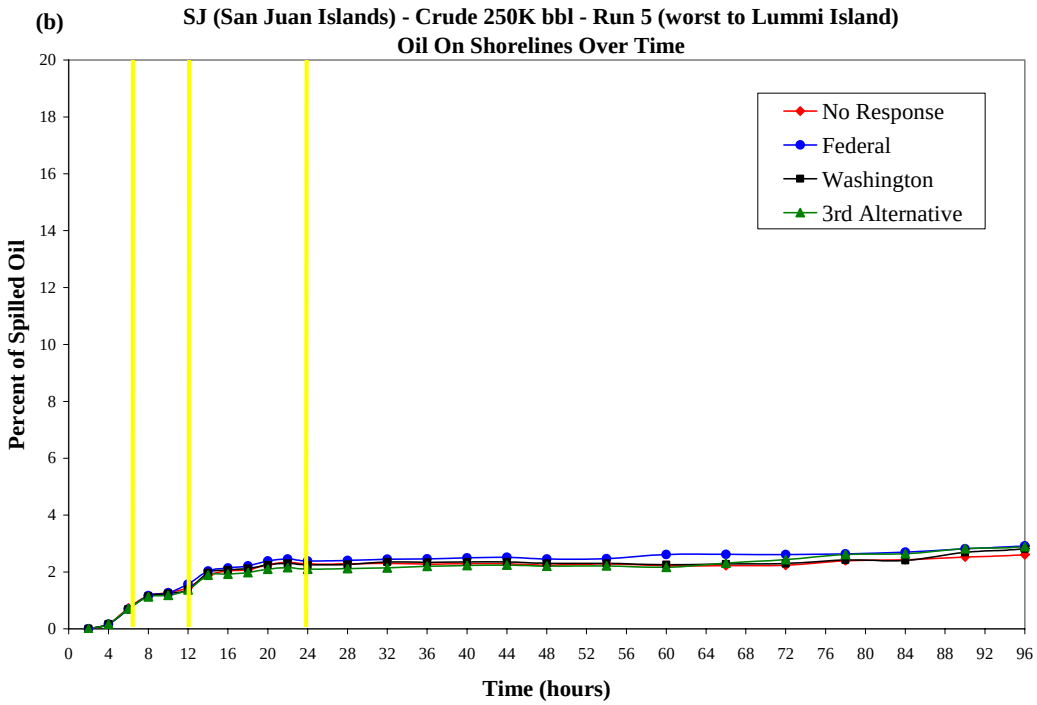


Figure XVII.B-16 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

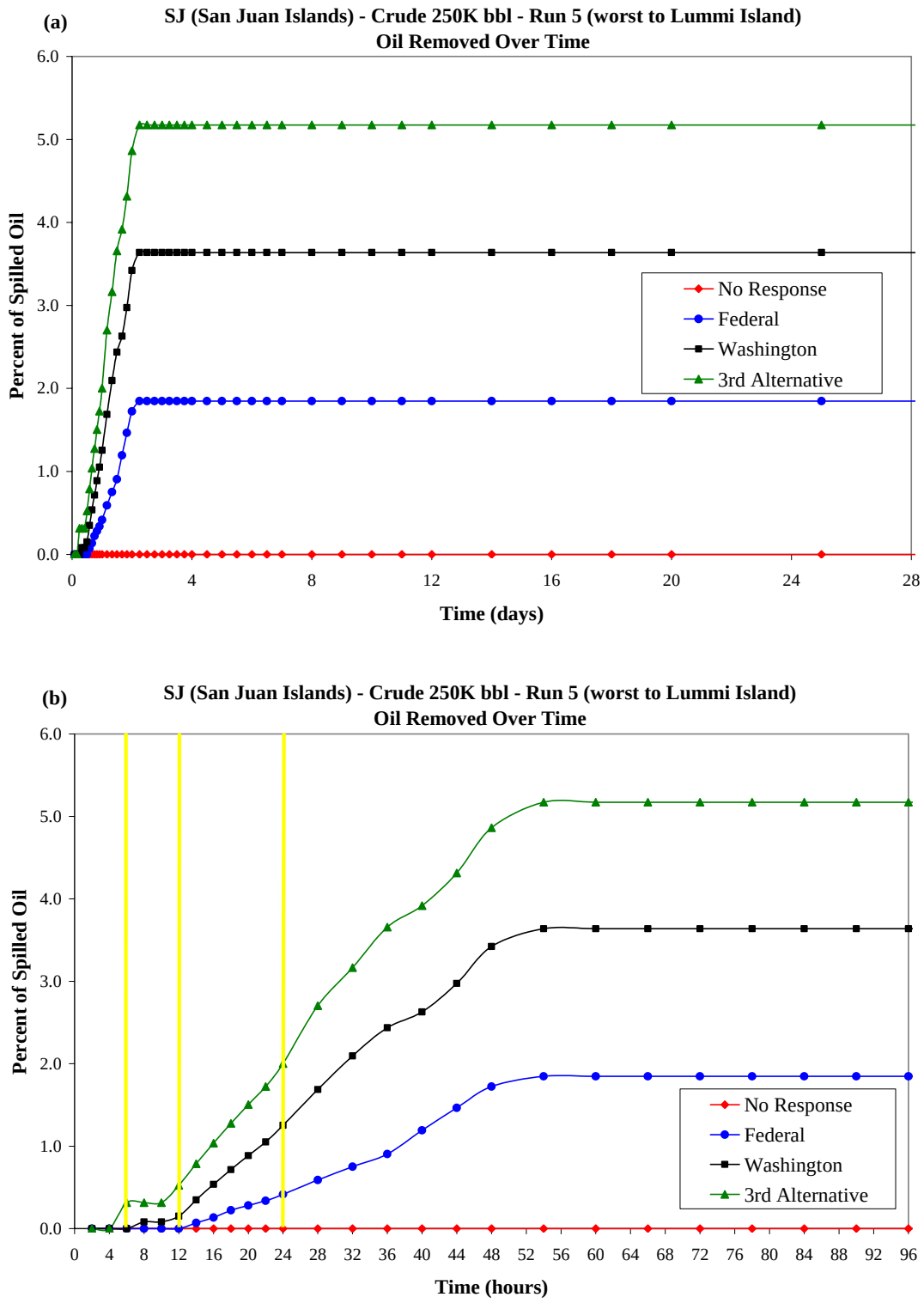
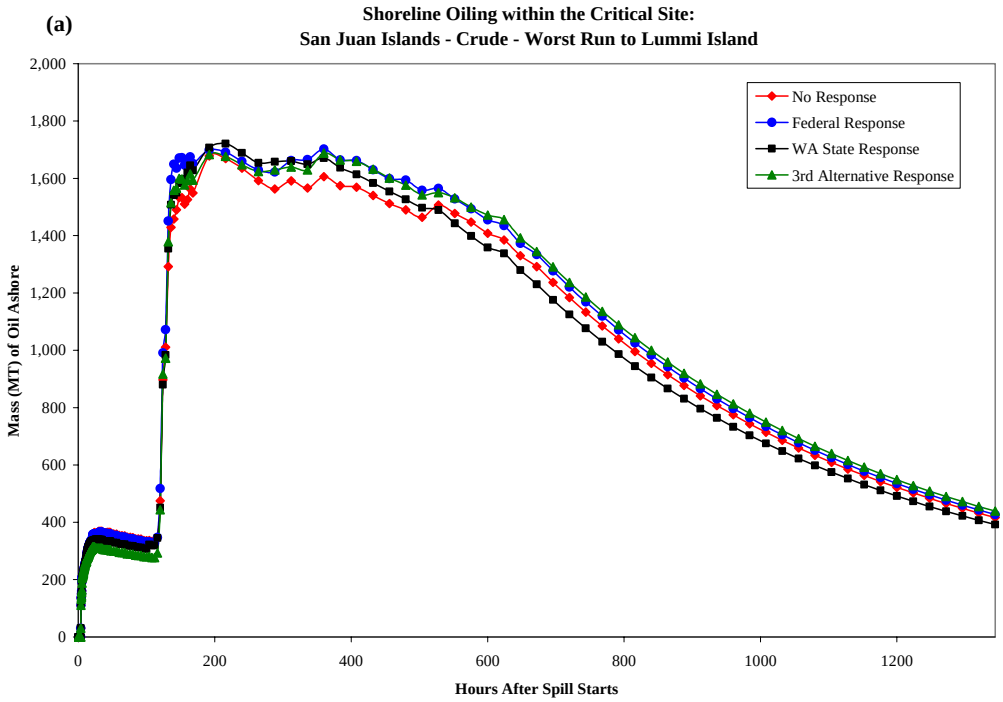


Figure XVII.B-17 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a.



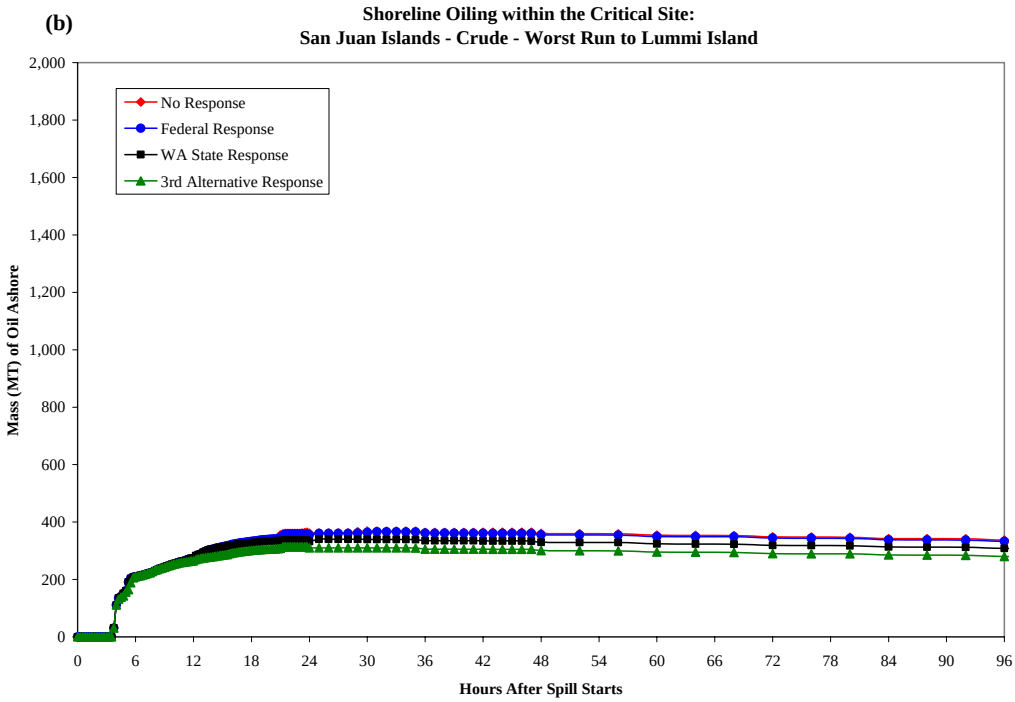


Figure XVII.B-18 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Lummi Island. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

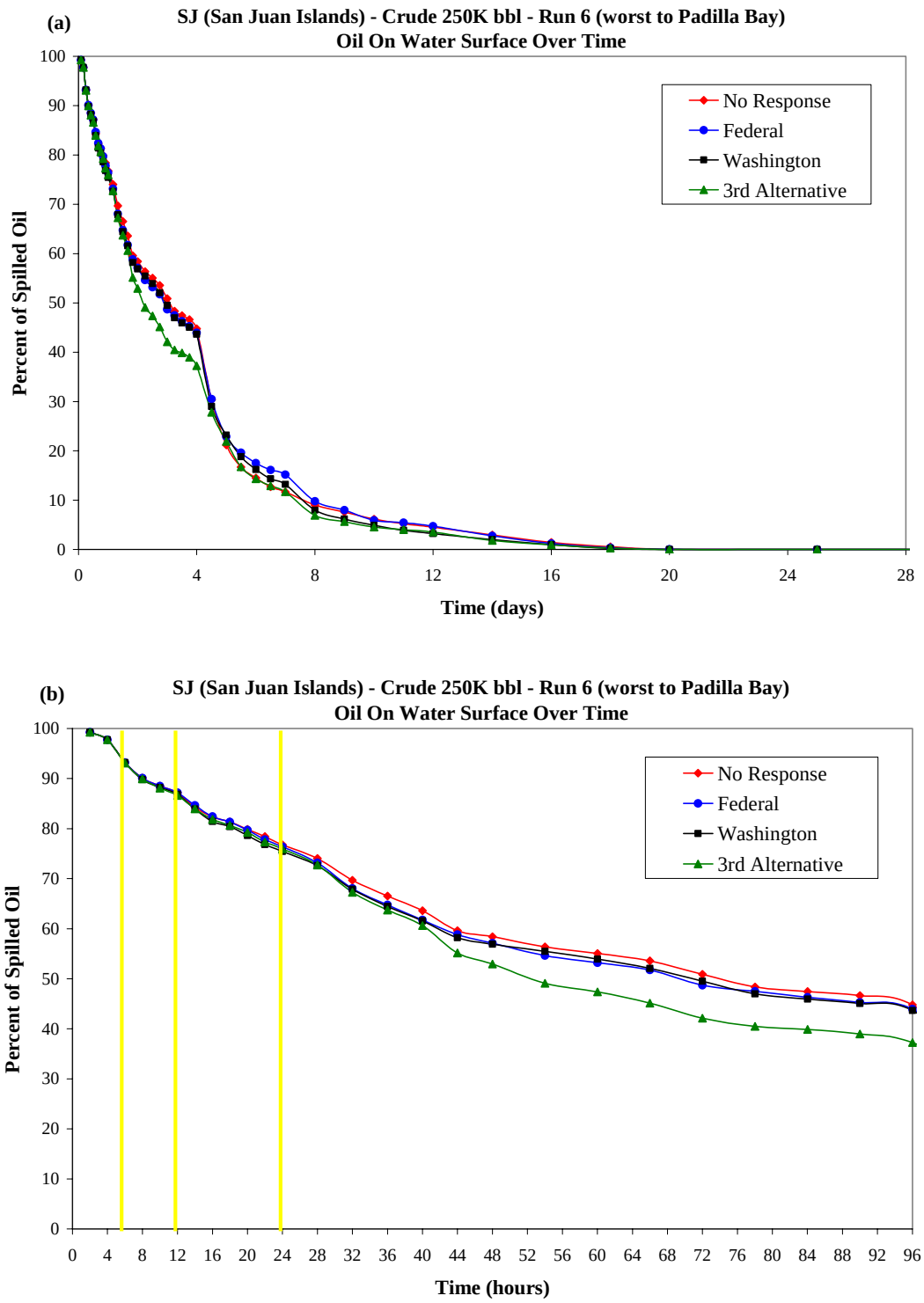
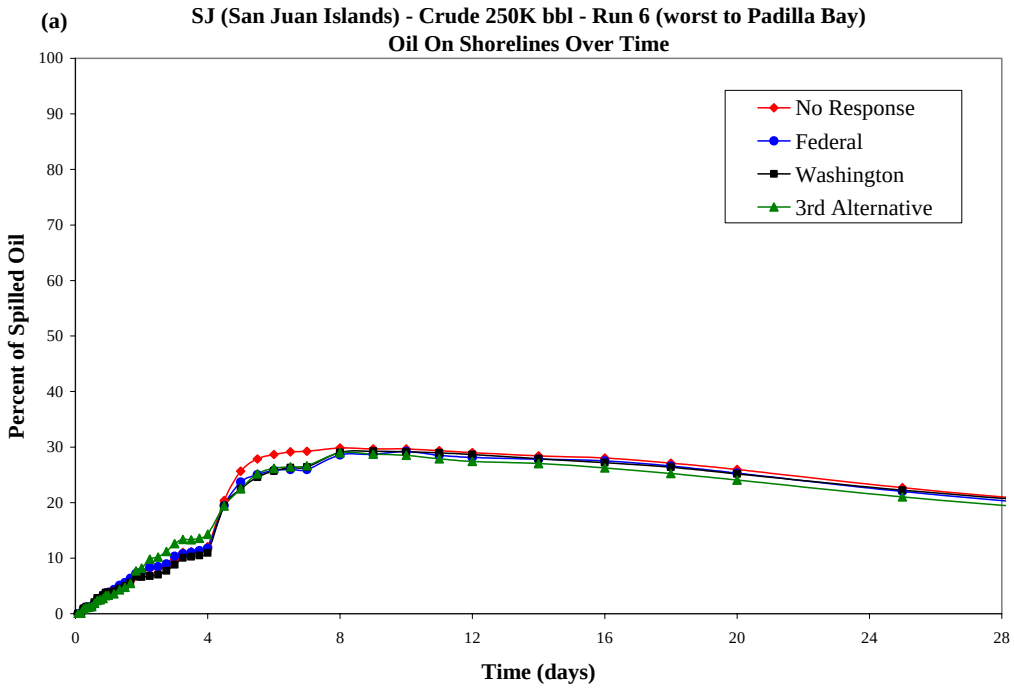


Figure XVII.B-19 San Juan Islands - Alaskan North Slope Crude: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



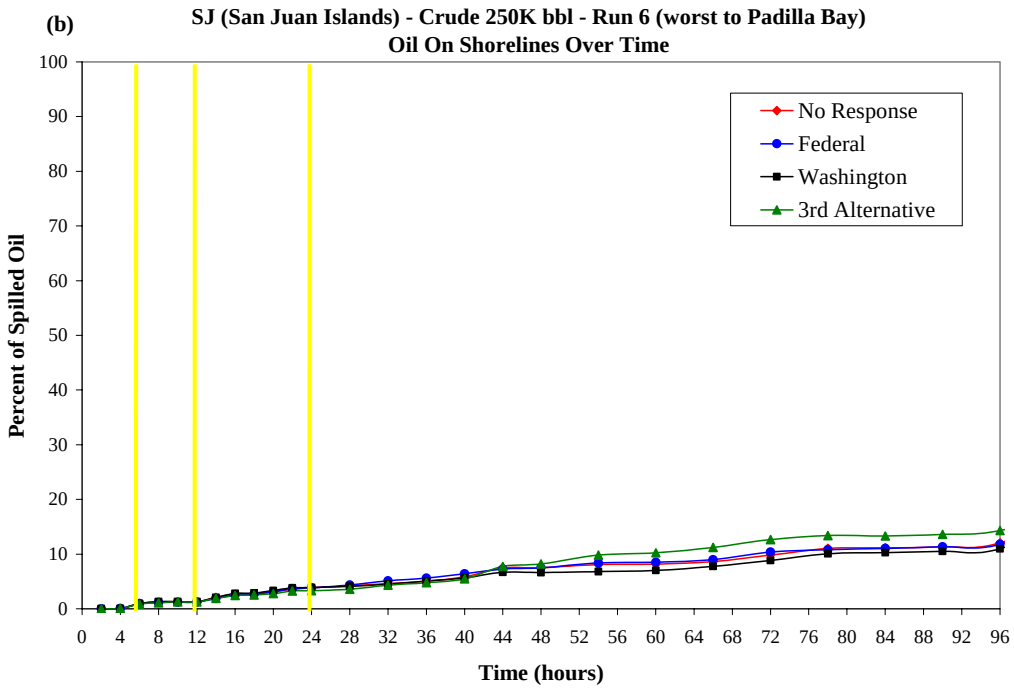


Figure XVII.B-20 San Juan Islands - Alaskan North Slope Crude: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

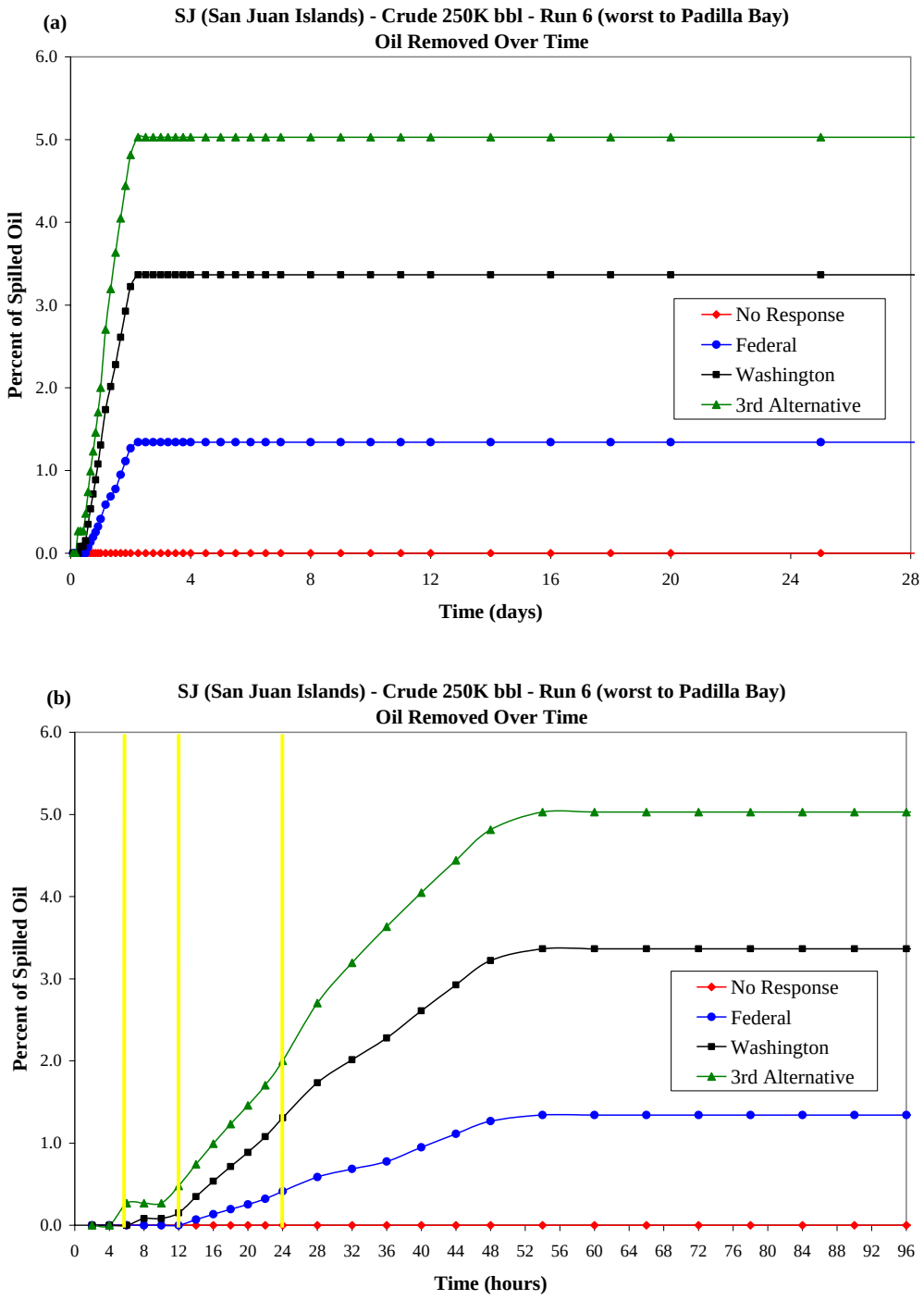
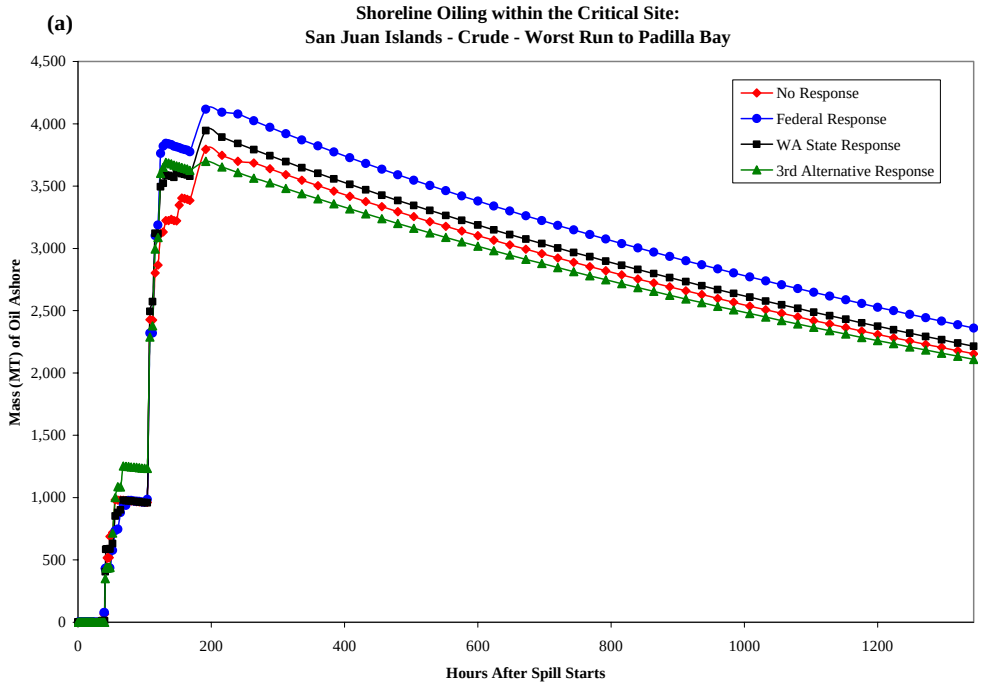


Figure XVII.B-21 San Juan Islands - Alaskan North Slope Crude: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



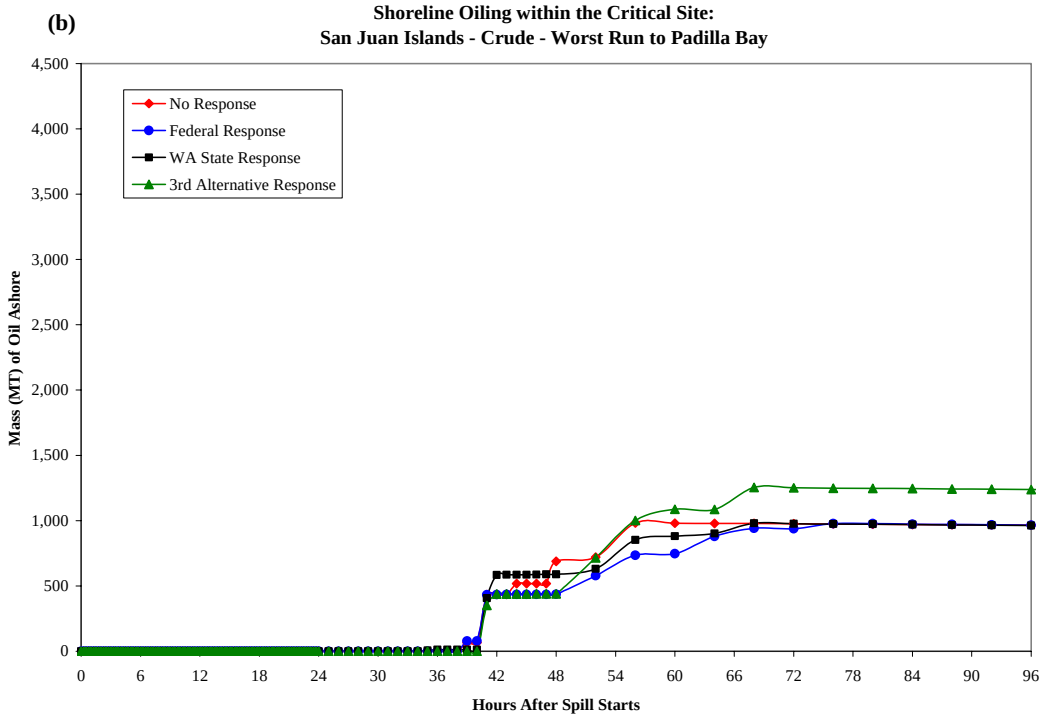


Figure XVII.B-22 San Juan Islands - Alaskan North Slope Crude: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Padilla Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

Table XVII.B-1 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.71	2.99	2.19	0.00	0.08	0.05	0.00	0.00	94.71
4	0.17	92.25	4.75	2.84	0.00	0.07	0.09	0.00	0.00	92.25
6	0.25	88.71	8.62	2.33	0.00	0.18	0.16	0.00	0.00	88.71
8	0.33	85.27	12.25	2.01	0.00	0.24	0.24	0.00	0.00	85.27
10	0.42	82.55	15.05	1.79	0.00	0.30	0.31	0.00	0.00	82.55
12	0.50	81.26	16.80	1.27	0.00	0.30	0.38	0.00	0.00	81.26
14	0.58	80.74	17.53	0.97	0.00	0.31	0.45	0.00	0.00	80.74
16	0.67	80.10	18.29	0.77	0.00	0.32	0.51	0.00	0.00	80.10
18	0.75	79.37	19.04	0.61	0.00	0.40	0.58	0.00	0.00	79.37
20	0.83	78.13	20.04	0.78	0.00	0.40	0.65	0.00	0.00	78.13
22	0.92	77.04	20.90	0.94	0.00	0.41	0.71	0.00	0.00	77.04
24	1.00	76.46	21.55	0.79	0.00	0.42	0.78	0.00	0.00	76.46
28	1.17	75.04	22.73	0.60	0.00	0.72	0.91	0.00	0.00	75.04
32	1.33	73.44	23.94	0.62	0.00	0.96	1.03	0.00	0.00	73.44
36	1.50	71.17	25.18	1.19	0.00	1.30	1.16	0.00	0.00	71.17
40	1.67	70.38	26.14	0.71	0.01	1.48	1.28	0.00	0.00	70.38
44	1.83	68.70	27.21	0.72	0.02	1.95	1.40	0.00	0.00	68.70
48	2.00	56.08	32.67	0.47	0.02	9.25	1.51	0.00	0.00	56.08
54	2.25	54.70	33.45	0.26	0.04	9.88	1.68	0.00	0.00	54.70
60	2.50	53.61	34.07	0.25	0.05	10.17	1.84	0.00	0.00	53.61
66	2.75	49.99	35.70	0.23	0.09	11.98	2.00	0.00	0.00	49.99
72	3.00	49.22	36.15	0.28	0.11	12.08	2.16	0.00	0.00	49.22
78	3.25	48.06	36.76	0.22	0.16	12.49	2.32	0.00	0.00	48.06
84	3.50	45.77	37.79	0.31	0.19	13.47	2.47	0.00	0.00	45.77
90	3.75	43.47	38.89	0.58	0.28	14.16	2.62	0.00	0.00	43.47

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	40.30	40.50	0.90	0.31	15.22	2.77	0.00	0.00	40.30
108	4.50	37.93	41.91	0.33	0.41	16.37	3.05	0.00	0.00	37.93
120	5.00	35.77	42.84	0.35	0.51	17.20	3.33	0.00	0.00	35.77
132	5.50	33.70	43.70	0.38	0.63	17.98	3.60	0.00	0.00	33.70
144	6.00	30.12	45.14	0.45	0.80	19.61	3.87	0.00	0.00	30.12
156	6.50	27.30	46.45	0.77	1.00	20.36	4.12	0.00	0.00	27.30
168	7.00	19.53	49.27	1.37	1.20	24.26	4.37	0.00	0.00	19.53
192	8.00	7.14	53.25	0.66	1.64	32.50	4.82	0.00	0.00	7.14
216	9.00	3.55	54.17	0.62	2.28	34.14	5.24	0.00	0.00	3.55
240	10.00	2.84	54.33	0.56	2.93	33.70	5.65	0.00	0.00	2.84
264	11.00	1.40	54.56	0.81	3.60	33.60	6.05	0.00	0.00	1.40
288	12.00	1.15	54.65	0.54	4.14	33.09	6.43	0.00	0.00	1.15
336	14.00	0.92	54.68	0.49	5.26	31.49	7.16	0.00	0.00	0.92
384	16.00	0.77	54.70	0.43	6.29	29.96	7.86	0.00	0.00	0.77
432	18.00	0.58	54.73	0.41	7.17	28.60	8.52	0.00	0.00	0.58
480	20.00	0.04	54.80	0.34	8.01	27.66	9.14	0.00	0.02	0.05
600	25.00	0.00	54.80	0.28	9.65	24.69	10.56	0.00	0.02	0.02
720	30.00	0.00	54.80	0.23	10.88	22.24	11.82	0.00	0.02	0.02
840	35.00	0.00	54.80	0.21	11.79	20.21	12.96	0.00	0.02	0.02
1080	45.00	0.00	54.80	0.16	13.05	17.06	14.91	0.00	0.02	0.02
1200	50.00	0.00	54.80	0.14	13.47	15.80	15.76	0.00	0.02	0.02
1320	55.00	0.00	54.80	0.14	13.78	14.71	16.55	0.00	0.02	0.02
Maximum	56.00	95.68	54.80	2.84	13.85	34.14	16.70	0.00	0.02	95.68

Table XVII.B-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	89.17	8.64	1.81	0.00	0.22	0.16	0.00	0.00	89.17
8	0.33	85.32	12.21	1.98	0.00	0.25	0.24	0.00	0.00	85.32
10	0.42	82.47	15.00	1.94	0.00	0.29	0.31	0.00	0.00	82.47
12	0.50	81.34	16.74	1.24	0.00	0.30	0.38	0.00	0.00	81.34
14	0.58	80.92	17.48	0.78	0.00	0.31	0.45	0.07	0.00	80.92
16	0.67	80.20	18.24	0.54	0.00	0.32	0.51	0.18	0.00	80.20
18	0.75	79.47	18.93	0.38	0.00	0.35	0.58	0.29	0.00	79.47
20	0.83	78.20	19.93	0.49	0.00	0.35	0.65	0.37	0.00	78.20
22	0.92	77.16	20.80	0.52	0.00	0.36	0.71	0.45	0.00	77.16
24	1.00	76.41	21.44	0.46	0.00	0.36	0.78	0.54	0.00	76.41
28	1.17	74.59	22.71	0.33	0.00	0.76	0.91	0.71	0.00	74.59
32	1.33	72.51	24.03	0.40	0.00	1.15	1.03	0.87	0.00	72.51
36	1.50	70.86	25.07	0.66	0.00	1.23	1.15	1.03	0.00	70.86
40	1.67	69.66	25.99	0.38	0.01	1.36	1.27	1.32	0.00	69.66
44	1.83	67.99	26.86	0.57	0.01	1.58	1.39	1.59	0.00	67.99
48	2.00	54.76	32.55	0.29	0.01	9.13	1.50	1.75	0.00	54.76
54	2.25	53.59	33.15	0.23	0.03	9.50	1.66	1.82	0.00	53.59
60	2.50	52.66	33.69	0.26	0.05	9.70	1.82	1.82	0.00	52.66
66	2.75	49.20	35.27	0.18	0.08	11.47	1.98	1.82	0.00	49.20
72	3.00	48.36	35.73	0.23	0.09	11.62	2.14	1.82	0.00	48.36
78	3.25	47.27	36.30	0.18	0.14	11.99	2.29	1.82	0.00	47.27
84	3.50	45.22	37.24	0.27	0.17	12.84	2.44	1.82	0.00	45.22
90	3.75	43.50	38.10	0.56	0.27	13.17	2.59	1.82	0.00	43.50
96	4.00	41.10	39.39	0.97	0.29	13.69	2.73	1.82	0.00	41.10

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	37.67	41.16	0.41	0.39	15.54	3.01	1.82	0.00	37.67
120	5.00	35.73	42.01	0.42	0.48	16.26	3.28	1.82	0.00	35.73
132	5.50	33.47	42.91	0.44	0.60	17.20	3.55	1.82	0.00	33.47
144	6.00	30.16	44.26	0.45	0.77	18.72	3.81	1.82	0.00	30.16
156	6.50	27.71	45.44	0.74	0.97	19.26	4.06	1.82	0.00	27.71
168	7.00	20.81	48.00	1.46	1.17	22.44	4.30	1.82	0.00	20.81
192	8.00	8.11	52.18	0.55	1.59	31.01	4.75	1.82	0.00	8.11
216	9.00	4.03	53.27	0.55	2.18	32.99	5.16	1.82	0.00	4.03
240	10.00	3.02	53.51	0.53	2.78	32.77	5.56	1.82	0.00	3.02
264	11.00	1.93	53.69	0.92	3.42	32.27	5.95	1.82	0.00	1.93
288	12.00	1.28	53.87	0.54	3.94	32.22	6.32	1.82	0.00	1.28
336	14.00	0.81	53.95	0.52	5.00	30.85	7.04	1.82	0.00	0.82
384	16.00	0.71	53.96	0.45	6.00	29.33	7.72	1.82	0.01	0.71
432	18.00	0.35	54.00	0.39	6.84	28.10	8.36	1.82	0.13	0.48
480	20.00	0.00	54.04	0.32	7.64	26.94	8.97	1.82	0.28	0.28
600	25.00	0.00	54.04	0.27	9.18	24.07	10.35	1.82	0.28	0.28
720	30.00	0.00	54.04	0.22	10.34	21.72	11.59	1.82	0.28	0.28
840	35.00	0.00	54.04	0.20	11.20	19.77	12.69	1.82	0.28	0.28
1080	45.00	0.00	54.04	0.15	12.39	16.71	14.61	1.82	0.28	0.28
1200	50.00	0.00	54.04	0.20	12.78	15.29	15.59	1.82	0.28	0.28
1320	55.00	0.00	54.04	0.21	12.99	14.45	16.20	1.82	0.28	0.28
Maximum	56.00	95.68	54.04	2.67	13.11	32.99	16.50	1.82	0.28	95.68

Table XVII.B-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	89.17	8.64	1.81	0.00	0.22	0.16	0.00	0.00	89.17
8	0.33	85.24	12.21	1.98	0.00	0.25	0.24	0.08	0.00	85.24
10	0.42	82.39	15.00	1.94	0.00	0.29	0.31	0.08	0.00	82.39
12	0.50	81.19	16.74	1.24	0.00	0.30	0.38	0.15	0.00	81.19
14	0.58	80.63	17.48	0.78	0.00	0.31	0.45	0.36	0.00	80.63
16	0.67	79.82	18.23	0.48	0.00	0.32	0.51	0.63	0.00	79.82
18	0.75	78.68	18.96	0.49	0.00	0.39	0.58	0.89	0.00	78.68
20	0.83	77.28	19.96	0.58	0.00	0.39	0.65	1.14	0.00	77.28
22	0.92	76.23	20.83	0.48	0.00	0.40	0.71	1.34	0.00	76.23
24	1.00	75.43	21.46	0.36	0.00	0.41	0.78	1.57	0.00	75.43
28	1.17	73.40	22.64	0.31	0.00	0.74	0.90	2.00	0.00	73.40
32	1.33	71.49	23.80	0.33	0.00	0.94	1.02	2.41	0.00	71.49
36	1.50	69.28	24.92	0.71	0.00	1.15	1.14	2.79	0.00	69.28
40	1.67	67.88	25.77	0.55	0.01	1.24	1.26	3.29	0.00	67.88
44	1.83	66.03	26.69	0.57	0.02	1.55	1.38	3.77	0.00	66.03
48	2.00	52.71	32.29	0.32	0.02	9.10	1.48	4.08	0.00	52.71
54	2.25	51.62	32.83	0.25	0.03	9.40	1.64	4.22	0.00	51.62
60	2.50	50.78	33.33	0.24	0.05	9.58	1.80	4.22	0.00	50.78
66	2.75	47.13	34.97	0.20	0.08	11.45	1.95	4.22	0.00	47.13
72	3.00	46.13	35.49	0.27	0.09	11.71	2.10	4.22	0.00	46.13
78	3.25	44.95	36.10	0.20	0.14	12.15	2.24	4.22	0.00	44.95
84	3.50	42.93	37.01	0.29	0.17	12.99	2.39	4.22	0.00	42.93
90	3.75	41.07	37.87	0.64	0.27	13.39	2.53	4.22	0.00	41.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	38.47	39.18	1.12	0.30	14.03	2.67	4.22	0.00	38.47
108	4.50	35.67	40.75	0.48	0.41	15.52	2.94	4.22	0.00	35.67
120	5.00	34.14	41.49	0.36	0.52	16.06	3.20	4.22	0.00	34.14
132	5.50	32.66	42.15	0.35	0.65	16.50	3.46	4.22	0.00	32.66
144	6.00	29.52	43.46	0.39	0.82	17.86	3.71	4.22	0.00	29.52
156	6.50	26.05	44.94	0.71	1.03	19.09	3.96	4.22	0.00	26.05
168	7.00	16.55	48.31	1.17	1.23	24.33	4.19	4.22	0.00	16.55
192	8.00	6.91	51.57	0.56	1.64	30.49	4.61	4.22	0.00	6.91
216	9.00	4.43	52.30	0.47	2.16	31.41	5.01	4.22	0.00	4.43
240	10.00	3.34	52.56	0.46	2.68	31.35	5.39	4.22	0.00	3.34
264	11.00	1.84	52.83	0.64	3.22	31.48	5.77	4.22	0.00	1.84
288	12.00	0.66	53.05	0.48	3.66	31.80	6.13	4.22	0.00	0.66
336	14.00	0.31	53.11	0.42	4.56	30.54	6.83	4.22	0.00	0.31
384	16.00	0.18	53.12	0.37	5.41	29.19	7.49	4.22	0.00	0.18
432	18.00	0.10	53.13	0.35	6.13	27.92	8.12	4.22	0.01	0.11
480	20.00	0.00	53.14	0.30	6.82	26.74	8.72	4.22	0.05	0.05
600	25.00	0.00	53.14	0.25	8.14	24.09	10.10	4.22	0.05	0.05
720	30.00	0.00	53.14	0.21	9.15	21.89	11.34	4.22	0.05	0.05
840	35.00	0.00	53.14	0.19	9.89	20.04	12.46	4.22	0.05	0.05
1080	45.00	0.00	53.14	0.14	10.93	17.09	14.41	4.22	0.06	0.06
1200	50.00	0.00	53.14	0.13	11.28	15.90	15.27	4.22	0.06	0.06
1320	55.00	0.00	53.14	0.13	11.54	14.85	16.06	4.22	0.06	0.06
Maximum	56.00	95.68	53.14	2.67	11.60	31.80	16.21	4.22	0.06	95.68

Table XVII.B-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	94.74	2.99	2.15	0.00	0.08	0.05	0.00	0.00	94.74
4	0.17	92.42	4.76	2.67	0.00	0.07	0.09	0.00	0.00	92.42
6	0.25	88.90	8.64	1.81	0.00	0.22	0.16	0.27	0.00	88.90
8	0.33	85.06	12.20	1.98	0.00	0.25	0.24	0.27	0.00	85.06
10	0.42	82.21	14.99	1.94	0.00	0.29	0.31	0.27	0.00	82.21
12	0.50	80.87	16.73	1.24	0.00	0.30	0.38	0.48	0.00	80.87
14	0.58	80.32	17.46	0.73	0.00	0.31	0.45	0.74	0.00	80.32
16	0.67	79.52	18.21	0.44	0.00	0.32	0.51	0.99	0.00	79.52
18	0.75	78.50	18.88	0.41	0.00	0.33	0.58	1.29	0.00	78.50
20	0.83	77.17	19.88	0.45	0.00	0.33	0.64	1.52	0.00	77.17
22	0.92	75.93	20.73	0.54	0.00	0.33	0.71	1.75	0.00	75.93
24	1.00	74.99	21.36	0.49	0.00	0.33	0.77	2.05	0.00	74.99
28	1.17	72.66	22.62	0.33	0.00	0.74	0.90	2.75	0.00	72.66
32	1.33	70.14	23.93	0.35	0.00	1.15	1.02	3.41	0.00	70.14
36	1.50	67.95	24.94	0.70	0.00	1.24	1.14	4.03	0.00	67.95
40	1.67	66.31	25.84	0.55	0.01	1.41	1.25	4.64	0.00	66.31
44	1.83	64.16	26.75	0.74	0.02	1.75	1.37	5.22	0.00	64.16
48	2.00	51.00	32.28	0.41	0.02	9.12	1.47	5.70	0.00	51.00
54	2.25	49.54	32.94	0.31	0.04	9.60	1.62	5.95	0.00	49.54
60	2.50	48.78	33.41	0.33	0.05	9.72	1.77	5.95	0.00	48.78
66	2.75	45.96	34.72	0.25	0.08	11.12	1.92	5.95	0.00	45.96
72	3.00	44.90	35.27	0.29	0.10	11.43	2.07	5.95	0.00	44.90
78	3.25	43.89	35.81	0.21	0.15	11.79	2.21	5.95	0.00	43.89
84	3.50	41.60	36.82	0.28	0.17	12.83	2.35	5.95	0.00	41.60
90	3.75	40.08	37.55	0.62	0.26	13.05	2.49	5.95	0.00	40.08

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	37.77	38.78	0.98	0.29	13.61	2.63	5.95	0.00	37.77
108	4.50	36.48	39.78	0.36	0.37	14.17	2.89	5.95	0.00	36.48
120	5.00	35.57	40.29	0.30	0.46	14.28	3.15	5.95	0.00	35.57
132	5.50	33.90	41.02	0.32	0.55	14.86	3.41	5.95	0.00	33.90
144	6.00	30.76	42.33	0.34	0.69	16.28	3.65	5.95	0.00	30.76
156	6.50	27.93	43.63	0.69	0.85	17.06	3.89	5.95	0.00	27.93
168	7.00	20.40	46.49	1.26	1.00	20.78	4.13	5.95	0.00	20.40
192	8.00	8.10	50.51	0.69	1.36	28.85	4.54	5.95	0.00	8.10
216	9.00	4.75	51.50	0.47	1.87	30.53	4.94	5.95	0.00	4.75
240	10.00	3.83	51.73	0.46	2.40	30.32	5.32	5.95	0.00	3.83
264	11.00	2.44	51.93	1.09	2.96	29.94	5.69	5.95	0.00	2.44
288	12.00	2.63	52.01	0.47	3.40	29.50	6.04	5.95	0.00	2.63
336	14.00	2.16	52.08	0.43	4.32	28.33	6.73	5.95	0.00	2.16
384	16.00	1.73	52.14	0.38	5.20	27.22	7.38	5.95	0.00	1.73
432	18.00	1.38	52.18	0.37	5.96	26.12	8.00	5.95	0.05	1.43
480	20.00	0.00	52.32	0.39	6.68	25.66	8.58	5.95	0.43	0.43
600	25.00	0.00	52.32	0.34	8.08	22.99	9.90	5.95	0.43	0.43
720	30.00	0.00	52.32	0.29	9.14	20.79	11.09	5.95	0.43	0.43
840	35.00	0.00	52.32	0.27	9.93	18.95	12.15	5.95	0.43	0.43
1080	45.00	0.00	52.32	0.15	11.03	16.05	14.00	5.95	0.50	0.50
1200	50.00	0.00	52.32	0.13	11.41	14.89	14.80	5.95	0.50	0.50
1320	55.00	0.00	52.32	0.13	11.69	13.87	15.54	5.95	0.50	0.50
Maximum	56.00	95.68	52.32	2.67	11.75	30.53	15.68	5.95	0.50	95.68

Table XVII.B-5 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	85.14	10.84	0.84	0.00	3.01	0.16	0.00	0.00	85.14
8	0.33	79.71	15.30	0.58	0.00	4.17	0.24	0.00	0.00	79.71
10	0.42	76.38	18.18	0.96	0.00	4.18	0.30	0.00	0.00	76.38
12	0.50	74.77	20.36	0.32	0.00	4.18	0.37	0.00	0.00	74.77
14	0.58	72.72	22.29	0.36	0.01	4.19	0.44	0.00	0.00	72.72
16	0.67	70.56	24.04	0.69	0.01	4.20	0.50	0.00	0.00	70.56
18	0.75	69.48	25.35	0.37	0.01	4.23	0.56	0.00	0.00	69.48
20	0.83	67.57	26.42	1.06	0.01	4.31	0.62	0.00	0.00	67.57
22	0.92	67.04	27.36	0.54	0.01	4.37	0.69	0.00	0.00	67.04
24	1.00	65.91	28.10	0.87	0.01	4.36	0.75	0.00	0.00	65.91
28	1.17	64.13	29.31	1.28	0.03	4.39	0.86	0.00	0.00	64.13
32	1.33	63.71	30.20	0.66	0.03	4.42	0.98	0.00	0.00	63.71
36	1.50	62.34	31.10	0.38	0.03	5.06	1.09	0.00	0.00	62.34
40	1.67	61.41	31.63	0.31	0.04	5.40	1.21	0.00	0.00	61.41
44	1.83	59.56	32.52	0.35	0.05	6.20	1.32	0.00	0.00	59.56
48	2.00	58.33	33.17	0.25	0.05	6.77	1.43	0.00	0.00	58.33
54	2.25	56.03	34.24	0.18	0.09	7.88	1.59	0.00	0.00	56.03
60	2.50	54.16	35.10	0.20	0.11	8.69	1.75	0.00	0.00	54.16
66	2.75	52.32	35.98	0.17	0.16	9.47	1.91	0.00	0.00	52.32
72	3.00	51.09	36.60	0.23	0.18	9.83	2.07	0.00	0.00	51.09
78	3.25	50.21	37.03	0.14	0.23	10.17	2.22	0.00	0.00	50.21
84	3.50	47.74	38.05	0.22	0.26	11.36	2.38	0.00	0.00	47.74
90	3.75	46.99	38.50	0.13	0.34	11.52	2.53	0.00	0.00	46.99
96	4.00	46.39	38.87	0.23	0.37	11.46	2.67	0.00	0.00	46.39

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	43.46	40.24	0.87	0.49	11.97	2.97	0.00	0.00	43.46
120	5.00	42.47	41.23	0.39	0.60	12.07	3.25	0.00	0.00	42.47
132	5.50	41.51	41.95	0.27	0.71	12.03	3.53	0.00	0.00	41.51
144	6.00	40.48	42.43	0.25	0.79	12.24	3.80	0.00	0.00	40.48
156	6.50	39.10	43.03	0.24	0.90	12.66	4.07	0.00	0.00	39.10
168	7.00	38.28	43.54	0.21	1.03	12.61	4.33	0.00	0.00	38.28
192	8.00	36.05	45.01	0.44	1.25	12.39	4.84	0.00	0.00	36.05
216	9.00	33.44	46.77	0.80	1.46	12.19	5.33	0.00	0.00	33.44
240	10.00	32.54	47.81	0.22	1.64	11.99	5.80	0.00	0.00	32.54
264	11.00	27.27	49.42	0.38	1.87	14.82	6.24	0.00	0.00	27.27
288	12.00	21.43	50.76	1.04	2.18	17.93	6.67	0.00	0.00	21.43
336	14.00	12.94	52.27	1.37	3.15	22.79	7.48	0.00	0.00	12.94
384	16.00	9.19	52.98	0.61	4.36	24.61	8.24	0.00	0.00	9.19
432	18.00	7.13	53.32	0.93	5.02	24.64	8.95	0.00	0.02	7.15
480	20.00	6.23	53.44	1.30	5.70	23.68	9.63	0.00	0.02	6.25
600	25.00	4.59	53.66	1.21	8.03	21.31	11.18	0.00	0.02	4.61
720	30.00	2.99	53.79	0.97	10.01	19.09	12.51	0.00	0.63	3.63
840	35.00	1.92	53.86	1.02	11.31	17.12	13.64	0.00	1.12	3.04
1080	45.00	0.90	53.95	0.70	13.54	13.96	15.49	0.00	1.46	2.36
1200	50.00	0.79	53.96	0.56	14.34	12.63	16.25	0.00	1.46	2.25
1320	55.00	0.59	53.98	0.46	14.97	11.56	16.93	0.00	1.51	2.10
Maximum	56.00	97.47	53.98	1.39	15.08	24.89	17.06	0.00	1.57	97.47

Table XVII.B-6 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	87.52	9.57	0.78	0.00	1.96	0.16	0.00	0.00	87.52
8	0.33	83.62	13.15	0.69	0.00	2.30	0.24	0.00	0.00	83.62
10	0.42	80.74	16.11	0.53	0.00	2.31	0.31	0.00	0.00	80.74
12	0.50	78.57	18.39	0.34	0.00	2.32	0.38	0.00	0.00	78.57
14	0.58	75.26	20.89	0.43	0.01	2.86	0.44	0.11	0.00	75.26
16	0.67	72.86	22.81	0.61	0.01	2.98	0.51	0.22	0.00	72.86
18	0.75	71.26	24.21	0.58	0.01	3.03	0.57	0.33	0.00	71.26
20	0.83	70.03	25.33	0.44	0.01	3.12	0.63	0.43	0.00	70.03
22	0.92	68.41	26.31	0.86	0.01	3.19	0.69	0.52	0.00	68.41
24	1.00	67.96	27.07	0.40	0.01	3.19	0.75	0.61	0.00	67.96
28	1.17	65.42	28.50	0.93	0.03	3.47	0.87	0.79	0.00	65.42
32	1.33	64.56	29.52	0.26	0.03	3.69	0.99	0.95	0.00	64.56
36	1.50	62.60	30.47	0.32	0.03	4.38	1.10	1.10	0.00	62.60
40	1.67	61.31	31.05	0.19	0.05	4.80	1.21	1.39	0.00	61.31
44	1.83	59.23	31.92	0.24	0.06	5.57	1.32	1.66	0.00	59.23
48	2.00	57.02	32.82	0.20	0.07	6.54	1.43	1.92	0.00	57.02
54	2.25	54.68	33.85	0.13	0.11	7.59	1.59	2.04	0.00	54.68
60	2.50	53.95	34.26	0.19	0.13	7.68	1.75	2.04	0.00	53.95
66	2.75	52.00	35.18	0.15	0.18	8.54	1.90	2.04	0.00	52.00
72	3.00	51.43	35.57	0.17	0.20	8.52	2.06	2.04	0.00	51.43
78	3.25	50.81	35.89	0.13	0.24	8.68	2.21	2.04	0.00	50.81
84	3.50	47.80	37.11	0.19	0.27	10.23	2.36	2.04	0.00	47.80
90	3.75	47.00	37.58	0.12	0.33	10.42	2.51	2.04	0.00	47.00
96	4.00	46.50	37.93	0.20	0.35	10.32	2.65	2.04	0.00	46.50

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	43.75	39.26	0.83	0.45	10.74	2.94	2.04	0.00	43.75
120	5.00	42.93	40.20	0.33	0.53	10.75	3.22	2.04	0.00	42.93
132	5.50	41.40	41.09	0.23	0.62	11.13	3.49	2.04	0.00	41.40
144	6.00	40.61	41.48	0.24	0.69	11.17	3.75	2.04	0.00	40.61
156	6.50	39.81	41.91	0.24	0.79	11.20	4.02	2.04	0.00	39.81
168	7.00	38.80	42.48	0.19	0.89	11.31	4.28	2.04	0.00	38.80
192	8.00	36.32	43.99	0.54	1.10	11.23	4.78	2.04	0.00	36.32
216	9.00	33.95	45.79	0.60	1.27	11.08	5.26	2.04	0.00	33.95
240	10.00	32.72	46.88	0.26	1.43	10.95	5.72	2.04	0.00	32.72
264	11.00	27.61	48.39	0.36	1.64	13.81	6.15	2.04	0.00	27.61
288	12.00	22.24	49.80	0.96	1.92	16.47	6.57	2.04	0.00	22.24
336	14.00	13.91	51.34	1.43	2.80	21.12	7.37	2.04	0.00	13.91
384	16.00	10.72	51.97	0.58	3.90	22.67	8.11	2.04	0.00	10.72
432	18.00	7.67	52.44	0.88	4.50	23.52	8.81	2.04	0.15	7.81
480	20.00	6.84	52.54	1.24	5.15	22.56	9.48	2.04	0.15	6.99
600	25.00	4.71	52.84	1.19	7.39	20.68	11.00	2.04	0.15	4.86
720	30.00	3.27	52.98	0.97	9.36	18.56	12.31	2.04	0.51	3.78
840	35.00	2.14	53.08	1.04	10.67	16.72	13.43	2.04	0.88	3.02
1080	45.00	0.99	53.18	0.72	12.97	13.57	15.26	2.04	1.27	2.27
1200	50.00	0.81	53.20	0.58	13.80	12.28	16.00	2.04	1.27	2.09
1320	55.00	0.44	53.23	0.48	14.46	11.22	16.66	2.04	1.47	1.90
Maximum	56.00	97.47	53.23	1.43	14.57	23.52	16.79	2.04	1.48	97.47

Table XVII.B-7 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	85.14	10.84	0.84	0.00	3.01	0.16	0.00	0.00	85.14
8	0.33	79.38	15.30	0.80	0.00	4.18	0.24	0.11	0.00	79.38
10	0.42	76.76	18.21	0.39	0.00	4.20	0.30	0.13	0.00	76.76
12	0.50	74.53	20.37	0.31	0.00	4.19	0.37	0.23	0.00	74.53
14	0.58	71.96	22.29	0.59	0.01	4.20	0.44	0.51	0.00	71.96
16	0.67	69.58	24.01	0.91	0.01	4.21	0.50	0.78	0.00	69.58
18	0.75	68.33	25.33	0.49	0.01	4.24	0.56	1.04	0.00	68.33
20	0.83	67.01	26.32	0.51	0.01	4.24	0.62	1.29	0.00	67.01
22	0.92	65.69	27.20	0.65	0.01	4.23	0.68	1.53	0.00	65.69
24	1.00	64.50	27.92	0.84	0.01	4.23	0.74	1.76	0.00	64.50
28	1.17	61.85	29.36	1.07	0.02	4.64	0.85	2.19	0.00	61.85
32	1.33	60.74	30.18	0.83	0.03	4.65	0.97	2.60	0.00	60.74
36	1.50	59.21	30.95	0.61	0.02	5.14	1.08	2.98	0.00	59.21
40	1.67	58.16	31.46	0.19	0.04	5.49	1.19	3.48	0.00	58.16
44	1.83	55.94	32.25	0.33	0.05	6.20	1.29	3.96	0.00	55.94
48	2.00	53.45	33.18	0.27	0.05	7.26	1.40	4.41	0.00	53.45
54	2.25	51.90	33.88	0.15	0.08	7.83	1.55	4.62	0.00	51.90
60	2.50	50.76	34.44	0.17	0.10	8.21	1.70	4.62	0.00	50.76
66	2.75	49.56	35.05	0.19	0.14	8.59	1.85	4.62	0.00	49.56
72	3.00	49.00	35.43	0.18	0.16	8.61	2.00	4.62	0.00	49.00
78	3.25	48.59	35.66	0.13	0.20	8.65	2.14	4.62	0.00	48.59
84	3.50	45.89	36.73	0.22	0.23	10.02	2.29	4.62	0.00	45.89
90	3.75	44.59	37.37	0.13	0.29	10.58	2.43	4.62	0.00	44.59

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	44.00	37.71	0.28	0.32	10.51	2.57	4.62	0.00	44.00
108	4.50	41.27	38.90	1.10	0.42	10.85	2.84	4.62	0.00	41.27
120	5.00	40.70	39.81	0.31	0.51	10.95	3.11	4.62	0.00	40.70
132	5.50	39.60	40.50	0.28	0.60	11.04	3.37	4.62	0.00	39.60
144	6.00	38.77	40.90	0.25	0.67	11.16	3.63	4.62	0.00	38.77
156	6.50	37.50	41.45	0.21	0.76	11.57	3.88	4.62	0.00	37.50
168	7.00	36.56	41.97	0.19	0.86	11.66	4.13	4.62	0.00	36.56
192	8.00	34.29	43.33	0.58	1.05	11.50	4.62	4.62	0.00	34.29
216	9.00	32.19	45.01	0.56	1.22	11.31	5.08	4.62	0.00	32.19
240	10.00	31.01	46.09	0.25	1.37	11.13	5.52	4.62	0.00	31.01
264	11.00	25.00	47.80	0.35	1.58	14.70	5.95	4.62	0.00	25.00
288	12.00	19.54	49.15	0.93	1.91	17.50	6.35	4.62	0.00	19.54
336	14.00	12.39	50.63	0.76	2.85	21.63	7.11	4.62	0.00	12.39
384	16.00	8.84	51.23	0.65	4.00	22.84	7.82	4.62	0.00	8.84
432	18.00	6.84	51.59	0.89	4.62	22.95	8.49	4.62	0.00	6.84
480	20.00	5.85	51.72	1.25	5.28	22.14	9.13	4.62	0.00	5.85
600	25.00	4.03	51.98	1.18	7.53	20.08	10.58	4.62	0.00	4.03
720	30.00	3.03	52.09	0.94	9.46	17.91	11.83	4.62	0.12	3.15
840	35.00	1.63	52.25	1.01	10.73	16.43	12.90	4.62	0.43	2.06
1080	45.00	0.84	52.34	0.69	12.96	13.34	14.67	4.62	0.54	1.38
1200	50.00	0.68	52.36	0.56	13.75	12.09	15.39	4.62	0.54	1.22
1320	55.00	0.44	52.39	0.47	14.38	11.12	16.04	4.62	0.54	0.97
Maximum	56.00	97.47	52.40	1.39	14.50	23.13	16.16	4.62	0.54	97.47

Table XVII.B-8 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lopez Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.74	2.25	0.96	0.00	0.00	0.05	0.00	0.00	96.74
4	0.17	94.44	4.05	1.39	0.00	0.04	0.09	0.00	0.00	94.44
6	0.25	84.79	10.84	0.84	0.00	3.01	0.16	0.36	0.00	84.79
8	0.33	79.06	15.29	0.80	0.00	4.18	0.23	0.44	0.00	79.06
10	0.42	76.40	18.18	0.39	0.00	4.20	0.30	0.51	0.00	76.40
12	0.50	73.99	20.34	0.31	0.00	4.19	0.37	0.79	0.00	73.99
14	0.58	71.53	22.25	0.41	0.01	4.20	0.43	1.17	0.00	71.53
16	0.67	69.23	23.97	0.57	0.01	4.20	0.50	1.52	0.00	69.23
18	0.75	67.61	25.26	0.48	0.01	4.22	0.56	1.86	0.00	67.61
20	0.83	66.18	26.28	0.45	0.01	4.27	0.62	2.19	0.00	66.18
22	0.92	64.51	27.17	0.84	0.01	4.29	0.68	2.50	0.00	64.51
24	1.00	63.57	27.92	0.62	0.01	4.35	0.74	2.80	0.00	63.57
28	1.17	61.01	29.06	1.18	0.03	4.38	0.85	3.50	0.00	61.01
32	1.33	59.40	30.01	0.81	0.03	4.64	0.96	4.16	0.00	59.40
36	1.50	58.21	30.55	0.56	0.03	4.81	1.07	4.77	0.00	58.21
40	1.67	56.69	31.10	0.38	0.04	5.23	1.17	5.38	0.00	56.69
44	1.83	54.65	31.84	0.36	0.04	5.87	1.28	5.96	0.00	54.65
48	2.00	50.61	33.34	0.30	0.04	7.83	1.38	6.51	0.00	50.61
54	2.25	48.91	34.05	0.16	0.08	8.45	1.52	6.82	0.00	48.91
60	2.50	47.53	34.70	0.17	0.09	9.02	1.67	6.82	0.00	47.53
66	2.75	46.39	35.28	0.18	0.13	9.39	1.81	6.82	0.00	46.39
72	3.00	45.44	35.79	0.18	0.15	9.67	1.95	6.82	0.00	45.44
78	3.25	45.06	36.01	0.12	0.18	9.71	2.09	6.82	0.00	45.06
84	3.50	42.45	37.08	0.19	0.20	11.03	2.23	6.82	0.00	42.45
90	3.75	40.80	37.82	0.12	0.25	11.81	2.37	6.82	0.00	40.80

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	40.37	38.11	0.22	0.27	11.71	2.50	6.82	0.00	40.37
108	4.50	37.94	39.30	0.61	0.35	12.21	2.76	6.82	0.00	37.94
120	5.00	37.27	40.07	0.24	0.43	12.15	3.02	6.82	0.00	37.27
132	5.50	36.48	40.67	0.20	0.50	12.06	3.27	6.82	0.00	36.48
144	6.00	35.33	41.17	0.19	0.56	12.42	3.52	6.82	0.00	35.33
156	6.50	34.56	41.56	0.18	0.63	12.49	3.76	6.82	0.00	34.56
168	7.00	33.86	42.01	0.17	0.72	12.43	4.00	6.82	0.00	33.86
192	8.00	31.92	43.33	0.40	0.86	12.20	4.47	6.82	0.00	31.92
216	9.00	29.51	44.99	0.62	1.00	12.15	4.92	6.82	0.00	29.51
240	10.00	28.59	45.97	0.20	1.12	11.96	5.34	6.82	0.00	28.59
264	11.00	23.68	47.48	0.33	1.28	14.66	5.75	6.82	0.00	23.68
288	12.00	18.07	48.75	0.98	1.53	17.72	6.14	6.82	0.00	18.07
336	14.00	10.24	50.26	1.06	2.39	22.36	6.88	6.82	0.00	10.24
384	16.00	7.26	50.78	0.80	3.47	23.30	7.57	6.82	0.00	7.26
432	18.00	5.35	51.11	0.82	4.04	23.62	8.22	6.82	0.01	5.36
480	20.00	4.58	51.21	1.14	4.64	22.75	8.84	6.82	0.01	4.58
600	25.00	3.47	51.35	1.07	6.67	20.35	10.26	6.82	0.01	3.48
720	30.00	2.50	51.41	0.85	8.39	18.10	11.50	6.82	0.44	2.94
840	35.00	1.75	51.45	0.89	9.51	16.24	12.55	6.82	0.79	2.53
1080	45.00	0.88	51.51	0.60	11.40	13.36	14.30	6.82	1.12	2.00
1200	50.00	0.72	51.53	0.49	12.07	12.21	15.03	6.82	1.12	1.84
1320	55.00	0.53	51.55	0.40	12.61	11.23	15.68	6.82	1.18	1.71
Maximum	56.00	97.47	51.55	1.39	12.70	24.05	15.81	6.82	1.20	97.47

Table XVII.B-9 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.52	5.98	0.02	0.00	0.23	0.25	0.00	0.00	93.52
10	0.42	89.33	9.22	0.02	0.00	1.10	0.32	0.00	0.00	89.33
12	0.50	86.29	11.64	0.05	0.00	1.62	0.40	0.00	0.00	86.29
14	0.58	83.38	13.97	0.04	0.01	2.13	0.47	0.00	0.00	83.38
16	0.67	80.35	16.50	0.04	0.02	2.55	0.54	0.00	0.00	80.35
18	0.75	77.46	18.90	0.04	0.03	2.96	0.61	0.00	0.00	77.46
20	0.83	75.49	20.78	0.05	0.03	2.98	0.68	0.00	0.00	75.49
22	0.92	73.04	22.80	0.07	0.03	3.33	0.74	0.00	0.00	73.04
24	1.00	71.50	24.10	0.13	0.03	3.44	0.80	0.00	0.00	71.50
28	1.17	69.28	26.06	0.09	0.08	3.56	0.93	0.00	0.00	69.28
32	1.33	68.12	27.05	0.06	0.10	3.62	1.05	0.00	0.00	68.12
36	1.50	67.17	27.80	0.12	0.11	3.63	1.17	0.00	0.00	67.17
40	1.67	64.26	29.16	0.08	0.13	5.08	1.29	0.00	0.00	64.26
44	1.83	61.99	30.49	0.10	0.18	5.85	1.40	0.00	0.00	61.99
48	2.00	59.95	31.85	0.25	0.19	6.25	1.51	0.00	0.00	59.95
54	2.25	57.43	33.41	0.14	0.28	7.06	1.68	0.00	0.00	57.43
60	2.50	55.90	34.22	0.19	0.29	7.56	1.84	0.00	0.00	55.90
66	2.75	53.30	35.39	0.10	0.36	8.86	2.00	0.00	0.00	53.30
72	3.00	51.32	36.26	0.21	0.39	9.66	2.16	0.00	0.00	51.32
78	3.25	48.88	37.47	0.10	0.52	10.72	2.31	0.00	0.00	48.88
84	3.50	47.44	38.22	0.21	0.56	11.12	2.46	0.00	0.00	47.44
90	3.75	43.91	39.81	0.10	0.70	12.87	2.61	0.00	0.00	43.91
96	4.00	41.41	41.10	0.28	0.74	13.71	2.75	0.00	0.00	41.41

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	36.73	43.28	0.29	0.95	15.72	3.03	0.00	0.00	36.73
120	5.00	33.72	44.84	0.40	1.19	16.55	3.30	0.00	0.00	33.72
132	5.50	31.40	46.33	0.33	1.46	16.93	3.55	0.00	0.00	31.40
144	6.00	17.99	50.43	0.39	1.72	25.68	3.80	0.00	0.00	17.99
156	6.50	13.88	51.94	0.32	1.99	27.85	4.02	0.00	0.00	13.88
168	7.00	12.43	52.44	0.33	2.23	28.32	4.24	0.00	0.00	12.43
192	8.00	9.71	53.14	0.38	2.72	29.38	4.67	0.00	0.00	9.71
216	9.00	7.33	53.67	0.46	3.24	30.21	5.09	0.00	0.00	7.33
240	10.00	5.48	54.08	0.39	3.93	30.64	5.49	0.00	0.00	5.48
264	11.00	3.41	54.46	0.46	4.49	31.30	5.88	0.00	0.00	3.41
288	12.00	2.07	54.70	0.43	5.18	31.37	6.25	0.00	0.00	2.07
336	14.00	1.16	54.86	0.36	6.49	30.16	6.96	0.00	0.00	1.16
384	16.00	0.82	54.91	0.36	7.61	28.67	7.63	0.00	0.00	0.82
432	18.00	0.40	54.97	0.29	8.70	27.39	8.25	0.00	0.00	0.40
480	20.00	0.05	55.02	0.28	9.62	26.19	8.84	0.00	0.00	0.05
600	25.00	0.00	55.02	0.20	11.59	23.01	10.18	0.00	0.00	0.00
720	30.00	0.00	55.02	0.15	13.05	20.44	11.34	0.00	0.00	0.00
840	35.00	0.00	55.02	0.15	14.11	18.35	12.37	0.00	0.00	0.00
1080	45.00	0.00	55.02	0.07	15.60	15.18	14.12	0.00	0.00	0.00
1200	50.00	0.00	55.02	0.08	16.07	13.96	14.87	0.00	0.00	0.00
1320	55.00	0.00	55.02	0.06	16.45	12.92	15.55	0.00	0.00	0.00
Maximum	56.00	99.18	55.02	0.46	16.52	31.37	15.68	0.00	0.00	99.18

Table XVII.B-10 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.52	5.98	0.02	0.00	0.23	0.25	0.00	0.00	93.52
10	0.42	89.33	9.22	0.02	0.00	1.10	0.32	0.00	0.00	89.33
12	0.50	86.29	11.64	0.05	0.00	1.62	0.40	0.00	0.00	86.29
14	0.58	83.27	13.96	0.04	0.01	2.13	0.47	0.11	0.00	83.27
16	0.67	80.14	16.49	0.04	0.02	2.55	0.54	0.22	0.00	80.14
18	0.75	77.14	18.89	0.05	0.03	2.95	0.61	0.33	0.00	77.14
20	0.83	75.06	20.77	0.07	0.03	2.98	0.67	0.43	0.00	75.06
22	0.92	72.45	22.82	0.07	0.03	3.37	0.74	0.52	0.00	72.45
24	1.00	70.84	24.10	0.14	0.03	3.47	0.80	0.61	0.00	70.84
28	1.17	68.28	26.12	0.13	0.08	3.67	0.92	0.79	0.00	68.28
32	1.33	66.96	27.12	0.07	0.10	3.75	1.04	0.95	0.00	66.96
36	1.50	65.95	27.83	0.14	0.11	3.71	1.16	1.10	0.00	65.95
40	1.67	64.21	28.59	0.09	0.14	4.32	1.28	1.39	0.00	64.21
44	1.83	61.61	29.94	0.11	0.18	5.11	1.39	1.66	0.00	61.61
48	2.00	59.52	31.22	0.30	0.20	5.38	1.50	1.88	0.00	59.52
54	2.25	57.30	32.66	0.12	0.28	6.02	1.66	1.96	0.00	57.30
60	2.50	55.78	33.46	0.15	0.29	6.54	1.82	1.96	0.00	55.78
66	2.75	53.63	34.46	0.08	0.35	7.54	1.98	1.96	0.00	53.63
72	3.00	52.41	35.04	0.18	0.38	7.90	2.13	1.96	0.00	52.41
78	3.25	50.65	36.02	0.07	0.49	8.53	2.28	1.96	0.00	50.65
84	3.50	49.18	36.77	0.18	0.52	8.96	2.43	1.96	0.00	49.18
90	3.75	46.28	38.16	0.09	0.64	10.30	2.58	1.96	0.00	46.28
96	4.00	44.17	39.34	0.25	0.68	10.88	2.72	1.96	0.00	44.17

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	39.32	41.61	0.30	0.86	12.96	3.00	1.96	0.00	39.32
120	5.00	35.40	43.52	0.38	1.08	14.40	3.26	1.96	0.00	35.40
132	5.50	32.66	45.17	0.30	1.32	15.08	3.51	1.96	0.00	32.66
144	6.00	15.26	50.35	0.39	1.56	26.74	3.75	1.96	0.00	15.26
156	6.50	11.46	51.69	0.36	1.82	28.74	3.97	1.96	0.00	11.46
168	7.00	10.14	52.14	0.35	2.06	29.17	4.19	1.96	0.00	10.14
192	8.00	7.74	52.75	0.36	2.53	30.07	4.60	1.96	0.00	7.74
216	9.00	5.91	53.16	0.42	3.01	30.53	5.01	1.96	0.00	5.91
240	10.00	3.82	53.58	0.36	3.64	31.23	5.40	1.96	0.00	3.82
264	11.00	2.06	53.90	0.44	4.17	31.69	5.78	1.96	0.00	2.06
288	12.00	1.30	54.04	0.39	4.81	31.37	6.14	1.96	0.00	1.30
336	14.00	0.49	54.17	0.33	5.99	30.23	6.84	1.96	0.00	0.49
384	16.00	0.19	54.21	0.33	7.00	28.83	7.49	1.96	0.00	0.19
432	18.00	0.07	54.23	0.26	7.96	27.42	8.11	1.96	0.00	0.07
480	20.00	0.00	54.24	0.25	8.77	26.10	8.69	1.96	0.00	0.00
600	25.00	0.00	54.24	0.18	10.46	23.14	10.03	1.96	0.00	0.00
720	30.00	0.00	54.24	0.13	11.72	20.75	11.20	1.96	0.00	0.00
840	35.00	0.00	54.24	0.13	12.63	18.79	12.25	1.96	0.00	0.00
1080	45.00	0.00	54.24	0.06	13.90	15.78	14.06	1.96	0.00	0.00
1200	50.00	0.00	54.24	0.07	14.30	14.60	14.84	1.96	0.00	0.00
1320	55.00	0.00	54.24	0.05	14.62	13.58	15.56	1.96	0.00	0.00
Maximum	56.00	99.18	54.24	0.44	14.68	31.69	15.70	1.96	0.00	99.18

Table XVII.B-11 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	96.12	3.64	0.01	0.00	0.06	0.17	0.00	0.00	96.12
8	0.33	93.42	5.98	0.02	0.00	0.23	0.25	0.11	0.00	93.42
10	0.42	89.20	9.22	0.02	0.00	1.10	0.32	0.13	0.00	89.20
12	0.50	86.12	11.61	0.05	0.00	1.59	0.40	0.23	0.00	86.12
14	0.58	82.89	13.95	0.05	0.01	2.12	0.47	0.51	0.00	82.89
16	0.67	79.37	16.59	0.04	0.02	2.66	0.54	0.78	0.00	79.37
18	0.75	76.43	18.89	0.04	0.03	2.96	0.61	1.04	0.00	76.43
20	0.83	74.03	20.84	0.06	0.03	3.08	0.67	1.29	0.00	74.03
22	0.92	71.61	22.71	0.10	0.03	3.28	0.74	1.53	0.00	71.61
24	1.00	70.04	23.93	0.14	0.03	3.31	0.80	1.76	0.00	70.04
28	1.17	67.37	25.89	0.10	0.08	3.45	0.92	2.19	0.00	67.37
32	1.33	65.67	26.93	0.05	0.10	3.61	1.04	2.60	0.00	65.67
36	1.50	64.30	27.70	0.11	0.10	3.66	1.15	2.98	0.00	64.30
40	1.67	61.72	28.70	0.08	0.13	4.62	1.26	3.48	0.00	61.72
44	1.83	59.34	29.88	0.09	0.17	5.20	1.37	3.96	0.00	59.34
48	2.00	56.99	31.20	0.27	0.19	5.58	1.48	4.30	0.00	56.99
54	2.25	54.75	32.59	0.12	0.27	6.19	1.64	4.45	0.00	54.75
60	2.50	53.35	33.34	0.15	0.28	6.64	1.79	4.45	0.00	53.35
66	2.75	51.19	34.33	0.08	0.34	7.66	1.94	4.45	0.00	51.19
72	3.00	49.63	35.04	0.19	0.38	8.22	2.09	4.45	0.00	49.63
78	3.25	47.65	36.08	0.08	0.49	9.02	2.23	4.45	0.00	47.65
84	3.50	46.29	36.78	0.20	0.53	9.38	2.38	4.45	0.00	46.29
90	3.75	43.23	38.20	0.11	0.66	10.84	2.52	4.45	0.00	43.23

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	41.21	39.32	0.28	0.70	11.38	2.65	4.45	0.00	41.21
108	4.50	36.08	41.65	0.29	0.89	13.73	2.92	4.45	0.00	36.08
120	5.00	32.69	43.33	0.42	1.13	14.82	3.17	4.45	0.00	32.69
132	5.50	30.46	44.77	0.33	1.41	15.17	3.41	4.45	0.00	30.46
144	6.00	15.02	49.38	0.42	1.66	25.43	3.64	4.45	0.00	15.02
156	6.50	10.46	50.93	0.38	1.94	27.99	3.85	4.45	0.00	10.46
168	7.00	8.39	51.52	0.35	2.20	29.04	4.05	4.45	0.00	8.39
192	8.00	6.15	52.07	0.40	2.71	29.77	4.45	4.45	0.00	6.15
216	9.00	4.39	52.45	0.46	3.25	30.16	4.84	4.45	0.00	4.39
240	10.00	3.01	52.74	0.38	3.94	30.29	5.21	4.45	0.00	3.01
264	11.00	1.60	52.98	0.45	4.48	30.47	5.57	4.45	0.00	1.60
288	12.00	0.51	53.16	0.40	5.14	30.42	5.92	4.45	0.00	0.51
336	14.00	0.14	53.22	0.33	6.36	28.92	6.58	4.45	0.00	0.14
384	16.00	0.03	53.24	0.33	7.37	27.39	7.20	4.45	0.00	0.03
432	18.00	0.01	53.24	0.26	8.35	25.92	7.78	4.45	0.00	0.01
480	20.00	0.00	53.24	0.25	9.15	24.58	8.33	4.45	0.00	0.00
600	25.00	0.00	53.24	0.17	10.85	21.70	9.58	4.45	0.00	0.00
720	30.00	0.00	53.24	0.13	12.10	19.39	10.68	4.45	0.00	0.00
840	35.00	0.00	53.24	0.13	13.01	17.51	11.66	4.45	0.00	0.00
1080	45.00	0.00	53.24	0.06	14.27	14.64	13.34	4.45	0.00	0.00
1200	50.00	0.00	53.24	0.06	14.66	13.52	14.07	4.45	0.00	0.00
1320	55.00	0.00	53.24	0.05	14.98	12.55	14.73	4.45	0.00	0.00
Maximum	56.00	99.18	53.24	0.46	15.04	30.47	14.86	4.45	0.00	99.18

Table XVII.B-12 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Orcas Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	98.66	1.26	0.03	0.00	0.00	0.05	0.00	0.00	98.66
4	0.17	98.18	1.72	0.01	0.00	0.00	0.09	0.00	0.00	98.18
6	0.25	95.76	3.64	0.01	0.00	0.06	0.17	0.36	0.00	95.76
8	0.33	93.12	5.96	0.02	0.00	0.21	0.25	0.44	0.00	93.12
10	0.42	88.74	9.26	0.02	0.00	1.14	0.32	0.51	0.00	88.74
12	0.50	85.55	11.61	0.05	0.00	1.61	0.40	0.79	0.00	85.55
14	0.58	82.54	13.78	0.05	0.01	1.99	0.47	1.17	0.00	82.54
16	0.67	79.20	16.29	0.05	0.02	2.38	0.54	1.52	0.00	79.20
18	0.75	76.22	18.57	0.04	0.03	2.67	0.60	1.86	0.00	76.22
20	0.83	73.89	20.44	0.07	0.03	2.71	0.67	2.19	0.00	73.89
22	0.92	71.45	22.32	0.07	0.03	2.90	0.73	2.50	0.00	71.45
24	1.00	69.92	23.48	0.11	0.03	2.87	0.79	2.80	0.00	69.92
28	1.17	66.93	25.45	0.11	0.07	3.03	0.91	3.50	0.00	66.93
32	1.33	65.03	26.47	0.07	0.09	3.15	1.03	4.16	0.00	65.03
36	1.50	63.45	27.23	0.11	0.09	3.20	1.14	4.77	0.00	63.45
40	1.67	61.29	28.01	0.08	0.12	3.87	1.25	5.38	0.00	61.29
44	1.83	58.88	29.19	0.08	0.15	4.45	1.36	5.88	0.00	58.88
48	2.00	55.98	30.71	0.24	0.17	5.18	1.47	6.25	0.00	55.98
54	2.25	53.64	32.10	0.11	0.24	5.83	1.62	6.47	0.00	53.64
60	2.50	51.62	33.07	0.18	0.25	6.65	1.77	6.47	0.00	51.62
66	2.75	49.88	33.92	0.07	0.30	7.45	1.91	6.47	0.00	49.88
72	3.00	48.23	34.66	0.17	0.33	8.09	2.06	6.47	0.00	48.23
78	3.25	46.29	35.68	0.07	0.44	8.86	2.20	6.47	0.00	46.29
84	3.50	45.06	36.33	0.18	0.47	9.16	2.34	6.47	0.00	45.06
90	3.75	42.07	37.72	0.08	0.59	10.60	2.47	6.47	0.00	42.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	39.57	39.00	0.25	0.62	11.48	2.61	6.47	0.00	39.57
108	4.50	33.71	41.53	0.29	0.81	14.33	2.86	6.47	0.00	33.71
120	5.00	30.11	43.25	0.39	1.05	15.62	3.11	6.47	0.00	30.11
132	5.50	27.84	44.64	0.34	1.31	16.06	3.34	6.47	0.00	27.84
144	6.00	15.20	48.47	0.39	1.57	24.35	3.56	6.47	0.00	15.20
156	6.50	10.91	49.94	0.34	1.85	26.73	3.77	6.47	0.00	10.91
168	7.00	9.71	50.35	0.35	2.09	27.07	3.97	6.47	0.00	9.71
192	8.00	6.86	51.03	0.38	2.59	28.32	4.36	6.47	0.00	6.86
216	9.00	5.71	51.31	0.43	3.10	28.25	4.73	6.47	0.00	5.71
240	10.00	3.68	51.72	0.37	3.75	28.92	5.10	6.47	0.00	3.68
264	11.00	2.27	51.98	0.43	4.28	29.13	5.45	6.47	0.00	2.27
288	12.00	1.12	52.17	0.39	4.92	29.15	5.79	6.47	0.00	1.12
336	14.00	0.44	52.28	0.32	6.11	27.94	6.43	6.47	0.00	0.44
384	16.00	0.16	52.33	0.33	7.12	26.57	7.04	6.47	0.00	0.16
432	18.00	0.05	52.34	0.26	8.09	25.19	7.61	6.47	0.00	0.05
480	20.00	0.02	52.34	0.25	8.90	23.88	8.14	6.47	0.00	0.02
600	25.00	0.00	52.35	0.18	10.62	21.03	9.36	6.47	0.00	0.00
720	30.00	0.00	52.35	0.13	11.90	18.73	10.42	6.47	0.00	0.00
840	35.00	0.00	52.35	0.13	12.83	16.85	11.37	6.47	0.00	0.00
1080	45.00	0.00	52.35	0.07	14.15	13.99	12.98	6.47	0.00	0.00
1200	50.00	0.00	52.35	0.07	14.57	12.88	13.67	6.47	0.00	0.00
1320	55.00	0.00	52.35	0.05	14.91	11.93	14.30	6.47	0.00	0.00
Maximum	56.00	99.18	52.35	0.43	14.97	29.15	14.42	6.47	0.00	99.18

Table XVII.B-13 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.34	5.20	0.00	0.00	1.29	0.17	0.00	0.00	93.34
8	0.33	91.55	6.89	0.00	0.00	1.31	0.25	0.00	0.00	91.55
10	0.42	88.99	9.03	0.00	0.00	1.67	0.32	0.00	0.00	88.99
12	0.50	80.14	14.41	0.01	0.00	5.05	0.39	0.00	0.00	80.14
14	0.58	75.36	17.65	0.01	0.00	6.51	0.46	0.00	0.00	75.36
16	0.67	71.81	20.24	0.01	0.00	7.41	0.53	0.00	0.00	71.81
18	0.75	69.77	21.93	0.01	0.00	7.69	0.60	0.00	0.00	69.77
20	0.83	68.43	23.13	0.01	0.00	7.76	0.66	0.00	0.00	68.43
22	0.92	66.23	24.55	0.00	0.00	8.49	0.73	0.00	0.00	66.23
24	1.00	65.32	25.33	0.06	0.00	8.49	0.79	0.00	0.00	65.32
28	1.17	63.22	26.85	0.04	0.02	8.95	0.91	0.00	0.00	63.22
32	1.33	60.57	28.73	0.02	0.04	9.61	1.03	0.00	0.00	60.57
36	1.50	58.60	30.10	0.09	0.05	10.01	1.15	0.00	0.00	58.60
40	1.67	56.74	31.26	0.07	0.07	10.59	1.26	0.00	0.00	56.74
44	1.83	55.62	32.01	0.04	0.10	10.86	1.38	0.00	0.00	55.62
48	2.00	54.61	32.61	0.13	0.11	11.05	1.49	0.00	0.00	54.61
54	2.25	52.37	33.86	0.07	0.17	11.88	1.65	0.00	0.00	52.37
60	2.50	50.51	35.04	0.16	0.21	12.27	1.82	0.00	0.00	50.51
66	2.75	47.13	36.98	0.08	0.32	13.51	1.97	0.00	0.00	47.13
72	3.00	42.81	39.09	0.17	0.34	15.46	2.13	0.00	0.00	42.81
78	3.25	41.21	39.89	0.09	0.42	16.12	2.27	0.00	0.00	41.21
84	3.50	39.62	40.68	0.20	0.46	16.61	2.42	0.00	0.00	39.62
90	3.75	38.43	41.38	0.08	0.57	16.98	2.56	0.00	0.00	38.43
96	4.00	37.07	42.00	0.22	0.61	17.40	2.71	0.00	0.00	37.07
108	4.50	33.90	43.44	0.24	0.76	18.67	2.98	0.00	0.00	33.90

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
120	5.00	31.43	44.57	0.27	0.93	19.54	3.25	0.00	0.00	31.43
132	5.50	26.91	46.37	0.29	1.13	21.80	3.51	0.00	0.00	26.91
144	6.00	21.88	48.53	0.26	1.38	24.19	3.76	0.00	0.00	21.88
156	6.50	20.21	49.36	0.28	1.58	24.56	4.00	0.00	0.00	20.21
168	7.00	18.84	50.15	0.26	1.81	24.70	4.24	0.00	0.00	18.84
192	8.00	16.78	51.35	0.26	2.27	24.64	4.69	0.00	0.00	16.78
216	9.00	14.20	52.37	0.27	2.70	25.34	5.12	0.00	0.00	14.20
240	10.00	12.94	52.78	0.30	3.09	25.36	5.53	0.00	0.00	12.94
264	11.00	11.29	53.17	0.28	3.53	25.80	5.94	0.00	0.00	11.29
288	12.00	9.85	53.45	0.33	3.92	26.12	6.33	0.00	0.00	9.85
336	14.00	8.87	53.69	0.44	4.86	25.06	7.08	0.00	0.00	8.87
384	16.00	8.00	53.84	0.30	5.58	24.49	7.79	0.00	0.00	8.00
432	18.00	7.40	53.90	0.26	6.40	23.56	8.47	0.00	0.00	7.40
480	20.00	6.68	53.97	0.36	7.10	22.77	9.12	0.00	0.00	6.68
600	25.00	2.85	54.48	0.25	8.71	23.11	10.61	0.00	0.00	2.85
720	30.00	0.73	54.76	0.19	10.14	22.25	11.92	0.00	0.00	0.73
840	35.00	0.17	54.83	0.15	11.46	20.32	13.08	0.00	0.00	0.17
1080	45.00	0.04	54.85	0.09	13.23	16.74	15.04	0.00	0.00	0.04
1200	50.00	0.01	54.85	0.08	13.83	15.35	15.87	0.00	0.00	0.01
1320	55.00	0.00	54.86	0.06	14.30	14.15	16.63	0.00	0.00	0.00
Maximum	56.00	99.57	54.86	0.57	14.39	26.12	16.77	0.00	0.00	99.57

Table XVII.B-14 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.36	5.19	0.00	0.00	1.28	0.17	0.00	0.00	93.36
8	0.33	91.53	6.90	0.00	0.00	1.32	0.25	0.00	0.00	91.53
10	0.42	87.24	9.97	0.00	0.00	2.47	0.32	0.00	0.00	87.24
12	0.50	81.62	13.64	0.01	0.00	4.33	0.39	0.00	0.00	81.62
14	0.58	74.40	18.12	0.01	0.00	6.93	0.46	0.07	0.00	74.40
16	0.67	71.47	20.36	0.01	0.00	7.49	0.53	0.13	0.00	71.47
18	0.75	69.50	21.99	0.01	0.01	7.71	0.60	0.20	0.00	69.50
20	0.83	67.86	23.29	0.00	0.01	7.90	0.66	0.29	0.00	67.86
22	0.92	65.93	24.54	0.00	0.01	8.42	0.72	0.37	0.00	65.93
24	1.00	64.51	25.54	0.07	0.01	8.67	0.79	0.43	0.00	64.51
28	1.17	62.01	27.17	0.05	0.02	9.27	0.91	0.57	0.00	62.01
32	1.33	59.17	29.08	0.02	0.04	9.98	1.03	0.68	0.00	59.17
36	1.50	57.09	30.42	0.11	0.05	10.36	1.14	0.83	0.00	57.09
40	1.67	54.71	31.70	0.07	0.08	11.12	1.26	1.06	0.00	54.71
44	1.83	53.02	32.61	0.04	0.11	11.62	1.37	1.24	0.00	53.02
48	2.00	51.06	33.49	0.15	0.12	12.20	1.47	1.50	0.00	51.06
54	2.25	48.04	35.01	0.08	0.19	13.44	1.63	1.61	0.00	48.04
60	2.50	45.96	36.24	0.19	0.24	13.96	1.79	1.61	0.00	45.96
66	2.75	40.83	38.83	0.12	0.38	16.30	1.94	1.61	0.00	40.83
72	3.00	38.83	39.99	0.22	0.40	16.86	2.09	1.61	0.00	38.83
78	3.25	37.44	40.72	0.10	0.49	17.42	2.23	1.61	0.00	37.44
84	3.50	36.19	41.36	0.22	0.54	17.71	2.37	1.61	0.00	36.19
90	3.75	34.75	42.14	0.09	0.66	18.25	2.51	1.61	0.00	34.75
96	4.00	33.72	42.63	0.24	0.70	18.46	2.64	1.61	0.00	33.72

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.69	43.99	0.27	0.87	19.66	2.91	1.61	0.00	30.69
120	5.00	29.22	44.76	0.29	1.06	19.90	3.17	1.61	0.00	29.22
132	5.50	25.12	46.38	0.30	1.27	21.91	3.42	1.61	0.00	25.12
144	6.00	19.74	48.61	0.27	1.53	24.57	3.66	1.61	0.00	19.74
156	6.50	18.35	49.33	0.30	1.75	24.76	3.89	1.61	0.00	18.35
168	7.00	17.30	50.00	0.29	2.00	24.69	4.12	1.61	0.00	17.30
192	8.00	15.56	51.08	0.31	2.48	24.41	4.56	1.61	0.00	15.56
216	9.00	13.81	51.92	0.32	2.92	24.45	4.97	1.61	0.00	13.81
240	10.00	12.94	52.24	0.29	3.32	24.22	5.37	1.61	0.00	12.94
264	11.00	11.11	52.64	0.27	3.76	24.85	5.76	1.61	0.00	11.11
288	12.00	7.81	53.19	0.32	4.15	26.77	6.14	1.61	0.00	7.81
336	14.00	5.35	53.56	0.73	5.08	26.81	6.87	1.61	0.00	5.35
384	16.00	3.90	53.83	0.33	5.85	26.94	7.55	1.61	0.00	3.90
432	18.00	1.69	54.12	0.25	6.76	27.38	8.20	1.61	0.00	1.69
480	20.00	0.89	54.22	0.30	7.56	26.60	8.82	1.61	0.00	0.89
600	25.00	0.00	54.34	0.17	9.25	24.41	10.22	1.61	0.00	0.00
720	30.00	0.00	54.34	0.15	10.49	21.94	11.47	1.61	0.00	0.00
840	35.00	0.00	54.34	0.10	11.44	19.92	12.58	1.61	0.00	0.00
1080	45.00	0.00	54.34	0.07	12.67	16.81	14.51	1.61	0.00	0.00
1200	50.00	0.00	54.34	0.05	13.07	15.58	15.34	1.61	0.00	0.00
1320	55.00	0.00	54.34	0.05	13.37	14.52	16.11	1.61	0.00	0.00
Maximum	56.00	99.57	54.34	0.73	13.42	27.80	16.26	1.61	0.00	99.57

Table XVII.B-15 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.36	5.19	0.00	0.00	1.28	0.17	0.00	0.00	93.36
8	0.33	91.43	6.90	0.00	0.00	1.32	0.25	0.09	0.00	91.43
10	0.42	87.13	9.97	0.00	0.00	2.47	0.32	0.12	0.00	87.13
12	0.50	81.42	13.64	0.01	0.00	4.33	0.39	0.20	0.00	81.42
14	0.58	74.07	18.12	0.01	0.00	6.93	0.46	0.40	0.00	74.07
16	0.67	71.03	20.35	0.01	0.00	7.49	0.53	0.59	0.00	71.03
18	0.75	68.94	21.97	0.01	0.01	7.71	0.60	0.77	0.00	68.94
20	0.83	67.30	23.20	0.00	0.01	7.83	0.66	1.00	0.00	67.30
22	0.92	64.00	25.06	0.00	0.01	9.01	0.72	1.21	0.00	64.00
24	1.00	62.75	25.92	0.06	0.01	9.12	0.78	1.36	0.00	62.75
28	1.17	60.00	27.56	0.04	0.02	9.76	0.90	1.71	0.00	60.00
32	1.33	57.35	29.27	0.02	0.04	10.28	1.02	2.01	0.00	57.35
36	1.50	54.36	30.92	0.10	0.05	11.09	1.13	2.35	0.00	54.36
40	1.67	52.33	31.99	0.07	0.08	11.61	1.24	2.68	0.00	52.33
44	1.83	50.64	32.79	0.04	0.11	11.99	1.35	3.08	0.00	50.64
48	2.00	49.16	33.41	0.14	0.12	12.24	1.45	3.48	0.00	49.16
54	2.25	46.56	34.71	0.07	0.18	13.20	1.61	3.66	0.00	46.56
60	2.50	45.10	35.68	0.17	0.23	13.39	1.76	3.66	0.00	45.10
66	2.75	40.63	38.00	0.11	0.35	15.34	1.91	3.66	0.00	40.63
72	3.00	36.49	40.00	0.21	0.37	17.21	2.05	3.66	0.00	36.49
78	3.25	34.12	41.08	0.11	0.46	18.39	2.19	3.66	0.00	34.12
84	3.50	32.86	41.72	0.24	0.51	18.68	2.32	3.66	0.00	32.86
90	3.75	32.07	42.23	0.10	0.64	18.83	2.45	3.66	0.00	32.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	31.49	42.56	0.24	0.68	18.78	2.59	3.66	0.00	31.49
108	4.50	28.35	43.95	0.27	0.85	20.07	2.84	3.66	0.00	28.35
120	5.00	26.21	44.93	0.30	1.04	20.76	3.09	3.66	0.00	26.21
132	5.50	22.36	46.45	0.30	1.26	22.63	3.34	3.66	0.00	22.36
144	6.00	19.17	47.95	0.27	1.52	23.86	3.57	3.66	0.00	19.17
156	6.50	17.79	48.67	0.30	1.73	24.06	3.79	3.66	0.00	17.79
168	7.00	16.93	49.27	0.27	1.97	23.89	4.01	3.66	0.00	16.93
192	8.00	15.05	50.37	0.29	2.41	23.77	4.44	3.66	0.00	15.05
216	9.00	13.23	51.20	0.28	2.84	23.95	4.84	3.66	0.00	13.23
240	10.00	11.92	51.58	0.30	3.23	24.08	5.23	3.66	0.00	11.92
264	11.00	10.79	51.85	0.28	3.67	24.14	5.61	3.66	0.00	10.79
288	12.00	9.45	52.10	0.31	4.05	24.45	5.98	3.66	0.00	9.45
336	14.00	7.08	52.40	1.15	4.93	24.09	6.69	3.66	0.00	7.08
384	16.00	7.42	52.47	0.32	5.61	23.16	7.36	3.66	0.00	7.42
432	18.00	6.97	52.51	0.28	6.35	22.23	8.00	3.66	0.00	6.97
480	20.00	6.33	52.56	0.37	6.99	21.47	8.61	3.66	0.00	6.33
600	25.00	3.89	52.88	0.24	8.45	20.86	10.02	3.66	0.00	3.89
720	30.00	2.37	53.07	0.18	9.87	19.58	11.26	3.66	0.00	2.37
840	35.00	0.94	53.22	0.34	11.12	18.34	12.36	3.66	0.00	0.94
1080	45.00	0.17	53.34	0.12	13.11	15.39	14.20	3.66	0.00	0.17
1200	50.00	0.00	53.36	0.09	13.83	14.07	14.97	3.66	0.00	0.00
1320	55.00	0.00	53.36	0.08	14.40	12.84	15.66	3.66	0.00	0.00
Maximum	56.00	99.57	53.36	1.15	14.50	24.61	15.79	3.66	0.00	99.57

Table XVII.B-16 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 50th percentile run (based on shore cost).

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.31	0.65	0.00	0.00	0.00	0.05	0.00	0.00	99.31
4	0.17	98.22	1.69	0.00	0.00	0.00	0.09	0.00	0.00	98.22
6	0.25	93.13	5.19	0.00	0.00	1.28	0.17	0.24	0.00	93.13
8	0.33	91.25	6.90	0.00	0.00	1.32	0.25	0.28	0.00	91.25
10	0.42	86.90	9.96	0.00	0.00	2.47	0.32	0.35	0.00	86.90
12	0.50	81.03	13.64	0.01	0.00	4.33	0.39	0.60	0.00	81.03
14	0.58	73.18	18.33	0.01	0.00	7.15	0.46	0.86	0.00	73.18
16	0.67	69.49	20.85	0.01	0.00	8.01	0.53	1.11	0.00	69.49
18	0.75	67.32	22.47	0.01	0.00	8.26	0.59	1.35	0.00	67.32
20	0.83	65.54	23.71	0.00	0.01	8.42	0.66	1.66	0.00	65.54
22	0.92	63.96	24.69	0.00	0.01	8.68	0.72	1.94	0.00	63.96
24	1.00	62.86	25.46	0.07	0.01	8.68	0.78	2.15	0.00	62.86
28	1.17	59.95	27.08	0.05	0.02	9.28	0.90	2.73	0.00	59.95
32	1.33	56.78	28.94	0.03	0.04	9.96	1.01	3.23	0.00	56.78
36	1.50	54.25	30.27	0.11	0.05	10.36	1.12	3.84	0.00	54.25
40	1.67	51.98	31.36	0.07	0.08	10.90	1.23	4.37	0.00	51.98
44	1.83	50.44	32.10	0.04	0.11	11.20	1.34	4.77	0.00	50.44
48	2.00	48.46	32.91	0.14	0.12	11.71	1.44	5.22	0.00	48.46
54	2.25	45.73	34.21	0.07	0.18	12.69	1.59	5.52	0.00	45.73
60	2.50	44.07	35.26	0.17	0.23	13.01	1.74	5.52	0.00	44.07
66	2.75	39.17	37.74	0.11	0.35	15.23	1.88	5.52	0.00	39.17
72	3.00	34.80	39.81	0.22	0.37	17.26	2.02	5.52	0.00	34.80
78	3.25	33.32	40.54	0.12	0.45	17.90	2.15	5.52	0.00	33.32
84	3.50	32.03	41.19	0.23	0.50	18.25	2.29	5.52	0.00	32.03
90	3.75	31.15	41.73	0.11	0.62	18.46	2.41	5.52	0.00	31.15

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	30.44	42.10	0.23	0.66	18.51	2.54	5.52	0.00	30.44
108	4.50	28.22	43.15	0.25	0.82	19.24	2.79	5.52	0.00	28.22
120	5.00	25.80	44.22	0.27	0.99	20.16	3.04	5.52	0.00	25.80
132	5.50	22.18	45.66	0.27	1.19	21.90	3.28	5.52	0.00	22.18
144	6.00	19.47	47.01	0.26	1.43	22.81	3.50	5.52	0.00	19.47
156	6.50	18.42	47.64	0.27	1.61	22.82	3.72	5.52	0.00	18.42
168	7.00	17.31	48.32	0.24	1.82	22.85	3.94	5.52	0.00	17.31
192	8.00	15.44	49.43	0.29	2.22	22.74	4.36	5.52	0.00	15.44
216	9.00	14.28	50.16	0.24	2.58	22.46	4.75	5.52	0.00	14.28
240	10.00	13.29	50.50	0.25	2.91	22.39	5.14	5.52	0.00	13.29
264	11.00	11.51	50.89	0.24	3.28	23.05	5.51	5.52	0.00	11.51
288	12.00	9.89	51.19	0.28	3.61	23.64	5.88	5.52	0.00	9.89
336	14.00	7.43	51.50	1.08	4.42	23.47	6.57	5.52	0.00	7.43
384	16.00	7.43	51.57	0.53	5.06	22.65	7.24	5.52	0.00	7.43
432	18.00	7.12	51.62	0.31	5.76	21.80	7.87	5.52	0.00	7.12
480	20.00	6.30	51.66	0.77	6.36	20.91	8.48	5.52	0.00	6.30
600	25.00	6.10	51.74	0.21	7.63	18.92	9.88	5.52	0.00	6.10
720	30.00	3.63	52.05	0.14	8.63	18.88	11.14	5.52	0.00	3.63
840	35.00	2.26	52.19	0.36	9.58	17.81	12.28	5.52	0.00	2.26
1080	45.00	1.32	52.31	0.11	11.01	15.50	14.22	5.52	0.00	1.32
1200	50.00	0.72	52.39	0.11	11.54	14.66	15.06	5.52	0.00	0.72
1320	55.00	0.56	52.41	0.08	12.01	13.60	15.82	5.52	0.00	0.56
Maximum	56.00	99.57	52.42	1.08	12.10	23.87	15.96	5.52	0.00	99.57

Table XVII.B-17 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.91	1.89	1.14	0.00	0.00	0.05	0.00	0.00	96.91
4	0.17	94.00	4.13	1.62	0.00	0.17	0.09	0.00	0.00	94.00
6	0.25	90.05	8.29	0.76	0.00	0.73	0.16	0.00	0.00	90.05
8	0.33	86.22	11.72	0.66	0.00	1.16	0.24	0.00	0.00	86.22
10	0.42	84.16	13.80	0.45	0.00	1.27	0.31	0.00	0.00	84.16
12	0.50	82.16	15.62	0.39	0.00	1.45	0.38	0.00	0.00	82.16
14	0.58	79.82	17.49	0.35	0.01	1.88	0.45	0.00	0.00	79.82
16	0.67	78.32	18.77	0.33	0.02	2.04	0.52	0.00	0.00	78.32
18	0.75	77.67	19.45	0.20	0.03	2.07	0.59	0.00	0.00	77.67
20	0.83	76.84	20.04	0.19	0.03	2.26	0.65	0.00	0.00	76.84
22	0.92	76.21	20.54	0.17	0.03	2.33	0.72	0.00	0.00	76.21
24	1.00	75.42	21.28	0.20	0.03	2.28	0.78	0.00	0.00	75.42
28	1.17	73.56	22.91	0.27	0.07	2.28	0.91	0.00	0.00	73.56
32	1.33	71.99	24.26	0.33	0.09	2.30	1.04	0.00	0.00	71.99
36	1.50	69.83	25.90	0.74	0.09	2.28	1.16	0.00	0.00	69.83
40	1.67	68.58	27.09	0.63	0.14	2.29	1.28	0.00	0.00	68.58
44	1.83	68.25	27.62	0.29	0.15	2.29	1.40	0.00	0.00	68.25
48	2.00	67.82	28.00	0.27	0.15	2.24	1.52	0.00	0.00	67.82
54	2.25	67.29	28.35	0.21	0.17	2.28	1.69	0.00	0.00	67.29
60	2.50	66.90	28.60	0.22	0.19	2.22	1.87	0.00	0.00	66.90
66	2.75	66.33	29.02	0.16	0.23	2.22	2.04	0.00	0.00	66.33
72	3.00	65.53	29.58	0.18	0.25	2.23	2.21	0.00	0.00	65.53
78	3.25	64.73	30.07	0.13	0.29	2.39	2.38	0.00	0.00	64.73
84	3.50	64.05	30.50	0.16	0.30	2.43	2.55	0.00	0.00	64.05
90	3.75	63.45	30.85	0.13	0.33	2.52	2.72	0.00	0.00	63.45
96	4.00	62.48	31.51	0.16	0.36	2.60	2.88	0.00	0.00	62.48

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	60.79	32.54	0.16	0.41	2.89	3.21	0.00	0.00	60.79
120	5.00	58.71	33.82	0.16	0.47	3.31	3.52	0.00	0.00	58.71
132	5.50	54.13	36.06	0.20	0.54	5.24	3.83	0.00	0.00	54.13
144	6.00	50.72	37.82	0.25	0.64	6.45	4.12	0.00	0.00	50.72
156	6.50	47.20	39.83	0.31	0.77	7.49	4.41	0.00	0.00	47.20
168	7.00	44.60	41.18	0.31	0.91	8.32	4.68	0.00	0.00	44.60
192	8.00	33.54	45.73	0.51	1.28	13.74	5.20	0.00	0.00	33.54
216	9.00	26.29	48.44	0.40	1.68	17.51	5.67	0.00	0.00	26.29
240	10.00	20.66	50.35	0.64	2.15	20.08	6.12	0.00	0.00	20.66
264	11.00	14.96	51.78	0.55	2.68	23.49	6.54	0.00	0.00	14.96
288	12.00	12.31	52.41	0.56	3.32	24.45	6.94	0.00	0.00	12.31
336	14.00	10.06	52.80	0.49	4.68	24.25	7.71	0.00	0.00	10.06
384	16.00	3.61	53.70	0.69	6.01	27.58	8.42	0.00	0.00	3.61
432	18.00	1.48	53.99	0.57	7.80	27.08	9.08	0.00	0.00	1.48
480	20.00	1.09	54.05	0.51	9.37	25.28	9.69	0.00	0.00	1.09
600	25.00	0.35	54.15	0.43	12.65	21.42	11.00	0.00	0.00	0.35
720	30.00	0.01	54.20	0.34	15.03	18.33	12.09	0.00	0.00	0.01
840	35.00	0.00	54.20	0.25	16.84	15.70	13.01	0.00	0.00	0.00
1080	45.00	0.00	54.20	0.16	19.13	12.04	14.46	0.00	0.00	0.00
1200	50.00	0.00	54.20	0.12	19.86	10.76	15.05	0.00	0.00	0.00
1320	55.00	0.00	54.20	0.11	20.39	9.72	15.58	0.00	0.00	0.00
Maximum	56.00	97.75	54.20	1.62	20.47	27.58	15.67	0.00	0.00	97.75

Table XVII.B-18 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.81	8.19	1.15	0.00	0.69	0.16	0.00	0.00	89.81
8	0.33	86.12	11.64	0.84	0.00	1.16	0.24	0.00	0.00	86.12
10	0.42	84.05	13.72	0.65	0.00	1.27	0.31	0.00	0.00	84.05
12	0.50	81.85	15.64	0.56	0.00	1.57	0.38	0.00	0.00	81.85
14	0.58	79.50	17.53	0.40	0.01	2.03	0.45	0.07	0.00	79.50
16	0.67	78.01	18.77	0.41	0.02	2.14	0.52	0.13	0.00	78.01
18	0.75	77.29	19.48	0.18	0.03	2.21	0.59	0.22	0.00	77.29
20	0.83	76.42	20.06	0.17	0.03	2.38	0.65	0.28	0.00	76.42
22	0.92	75.77	20.57	0.12	0.03	2.45	0.72	0.34	0.00	75.77
24	1.00	74.88	21.30	0.20	0.04	2.39	0.78	0.42	0.00	74.88
28	1.17	72.74	22.94	0.34	0.07	2.41	0.91	0.59	0.00	72.74
32	1.33	71.12	24.30	0.25	0.09	2.45	1.04	0.75	0.00	71.12
36	1.50	68.77	25.97	0.64	0.10	2.46	1.16	0.91	0.00	68.77
40	1.67	67.24	27.16	0.50	0.15	2.50	1.28	1.19	0.00	67.24
44	1.83	66.48	27.69	0.29	0.16	2.52	1.39	1.47	0.00	66.48
48	2.00	65.84	28.05	0.26	0.16	2.46	1.51	1.72	0.00	65.84
54	2.25	65.24	28.37	0.21	0.19	2.47	1.68	1.85	0.00	65.24
60	2.50	64.51	28.75	0.23	0.20	2.61	1.85	1.85	0.00	64.51
66	2.75	63.94	29.16	0.17	0.25	2.62	2.02	1.85	0.00	63.94
72	3.00	63.22	29.68	0.19	0.27	2.61	2.18	1.85	0.00	63.22
78	3.25	62.68	30.05	0.13	0.30	2.64	2.35	1.85	0.00	62.68
84	3.50	61.98	30.48	0.16	0.32	2.69	2.51	1.85	0.00	61.98
90	3.75	61.36	30.83	0.12	0.35	2.81	2.67	1.85	0.00	61.36
96	4.00	60.40	31.48	0.15	0.38	2.92	2.83	1.85	0.00	60.40

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	58.78	32.45	0.15	0.44	3.18	3.15	1.85	0.00	58.78
120	5.00	56.40	33.83	0.17	0.50	3.80	3.46	1.85	0.00	56.40
132	5.50	52.16	35.92	0.20	0.57	5.55	3.76	1.85	0.00	52.16
144	6.00	49.18	37.48	0.24	0.67	6.54	4.04	1.85	0.00	49.18
156	6.50	45.77	39.40	0.34	0.80	7.53	4.32	1.85	0.00	45.77
168	7.00	43.84	40.54	0.31	0.93	7.95	4.59	1.85	0.00	43.84
192	8.00	33.33	44.97	0.51	1.29	12.96	5.09	1.85	0.00	33.33
216	9.00	27.01	47.48	0.39	1.68	16.03	5.56	1.85	0.00	27.01
240	10.00	21.51	49.41	0.57	2.17	18.50	5.99	1.85	0.00	21.51
264	11.00	15.89	50.87	0.57	2.75	21.67	6.41	1.85	0.00	15.89
288	12.00	13.64	51.47	0.60	3.43	22.22	6.80	1.85	0.00	13.64
336	14.00	11.57	51.81	0.69	4.85	21.68	7.54	1.85	0.00	11.57
384	16.00	6.08	52.61	0.67	6.19	24.37	8.23	1.85	0.00	6.08
432	18.00	4.10	52.88	0.60	7.94	23.76	8.87	1.85	0.00	4.10
480	20.00	3.57	52.96	0.53	9.46	22.19	9.46	1.85	0.00	3.57
600	25.00	2.49	53.10	0.45	12.65	18.73	10.73	1.85	0.00	2.49
720	30.00	0.47	53.37	0.37	15.09	17.08	11.78	1.85	0.00	0.47
840	35.00	0.00	53.42	0.28	17.17	14.63	12.65	1.85	0.00	0.00
1080	45.00	0.00	53.42	0.18	19.83	10.73	13.98	1.85	0.00	0.00
1200	50.00	0.00	53.42	0.13	20.69	9.40	14.51	1.85	0.00	0.00
1320	55.00	0.00	53.42	0.12	21.30	8.35	14.96	1.85	0.00	0.00
Maximum	56.00	97.75	53.42	1.67	21.39	24.37	15.04	1.85	0.00	97.75

Table XVII.B-19 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.81	8.19	1.15	0.00	0.69	0.16	0.00	0.00	89.81
8	0.33	86.27	11.61	0.66	0.00	1.15	0.24	0.08	0.00	86.27
10	0.42	84.33	13.66	0.38	0.00	1.24	0.31	0.08	0.00	84.33
12	0.50	82.14	15.43	0.52	0.00	1.38	0.38	0.15	0.00	82.14
14	0.58	79.31	17.45	0.46	0.01	1.97	0.45	0.35	0.00	79.31
16	0.67	77.76	18.67	0.43	0.02	2.07	0.52	0.54	0.00	77.76
18	0.75	76.96	19.36	0.23	0.02	2.13	0.59	0.72	0.00	76.96
20	0.83	76.07	19.90	0.22	0.03	2.25	0.65	0.89	0.00	76.07
22	0.92	75.31	20.39	0.20	0.03	2.30	0.72	1.05	0.00	75.31
24	1.00	74.28	21.12	0.29	0.03	2.25	0.78	1.25	0.00	74.28
28	1.17	72.16	22.74	0.17	0.07	2.26	0.91	1.69	0.00	72.16
32	1.33	70.08	24.14	0.21	0.08	2.35	1.03	2.10	0.00	70.08
36	1.50	67.58	25.77	0.63	0.09	2.34	1.15	2.44	0.00	67.58
40	1.67	66.19	26.92	0.51	0.13	2.35	1.27	2.63	0.00	66.19
44	1.83	65.41	27.44	0.29	0.14	2.35	1.38	2.97	0.00	65.41
48	2.00	64.51	27.79	0.33	0.15	2.30	1.49	3.42	0.00	64.51
54	2.25	63.89	28.09	0.24	0.17	2.30	1.66	3.64	0.00	63.89
60	2.50	63.52	28.34	0.24	0.19	2.25	1.83	3.64	0.00	63.52
66	2.75	62.91	28.75	0.20	0.23	2.28	1.99	3.64	0.00	62.91
72	3.00	62.20	29.28	0.19	0.25	2.29	2.16	3.64	0.00	62.20
78	3.25	61.47	29.72	0.16	0.28	2.42	2.32	3.64	0.00	61.47
84	3.50	60.91	30.09	0.18	0.30	2.41	2.48	3.64	0.00	60.91
90	3.75	60.03	30.53	0.15	0.33	2.69	2.64	3.64	0.00	60.03

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	59.06	31.18	0.16	0.35	2.81	2.79	3.64	0.00	59.06
108	4.50	57.28	32.21	0.16	0.41	3.20	3.10	3.64	0.00	57.28
120	5.00	55.05	33.52	0.18	0.48	3.73	3.40	3.64	0.00	55.05
132	5.50	50.84	35.60	0.21	0.56	5.46	3.69	3.64	0.00	50.84
144	6.00	48.13	37.06	0.24	0.66	6.31	3.97	3.64	0.00	48.13
156	6.50	44.56	39.02	0.31	0.79	7.44	4.24	3.64	0.00	44.56
168	7.00	42.52	40.16	0.31	0.93	7.94	4.50	3.64	0.00	42.52
192	8.00	28.91	45.33	0.56	1.31	15.25	4.99	3.64	0.00	28.91
216	9.00	20.52	48.24	0.37	1.72	20.07	5.44	3.64	0.00	20.52
240	10.00	16.05	49.72	0.75	2.20	21.79	5.86	3.64	0.00	16.05
264	11.00	12.44	50.71	0.59	2.71	23.67	6.25	3.64	0.00	12.44
288	12.00	9.73	51.36	0.48	3.28	24.88	6.63	3.64	0.00	9.73
336	14.00	7.21	51.78	0.45	4.51	25.06	7.36	3.64	0.00	7.21
384	16.00	3.04	52.37	0.58	5.67	26.67	8.04	3.64	0.00	3.04
432	18.00	0.60	52.71	0.48	7.18	26.73	8.66	3.64	0.00	0.60
480	20.00	0.36	52.75	0.44	8.50	25.08	9.24	3.64	0.00	0.36
600	25.00	0.00	52.79	0.32	11.22	21.50	10.52	3.64	0.00	0.00
720	30.00	0.00	52.79	0.29	13.18	18.50	11.61	3.64	0.00	0.00
840	35.00	0.00	52.79	0.22	14.65	16.16	12.54	3.64	0.00	0.00
1080	45.00	0.00	52.79	0.15	16.52	12.84	14.06	3.64	0.00	0.00
1200	50.00	0.00	52.79	0.11	17.12	11.63	14.70	3.64	0.00	0.00
1320	55.00	0.00	52.79	0.10	17.56	10.64	15.27	3.64	0.00	0.00
Maximum	56.00	97.75	52.79	1.67	17.62	26.94	15.37	3.64	0.00	97.75

Table XVII.B-20 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Lummi Island.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	96.92	1.89	1.15	0.00	0.00	0.05	0.00	0.00	96.92
4	0.17	93.99	4.09	1.67	0.00	0.16	0.09	0.00	0.00	93.99
6	0.25	89.56	8.22	1.04	0.00	0.70	0.16	0.31	0.00	89.56
8	0.33	85.82	11.65	0.85	0.00	1.13	0.24	0.31	0.00	85.82
10	0.42	83.83	13.69	0.67	0.00	1.18	0.31	0.31	0.00	83.83
12	0.50	81.71	15.51	0.50	0.00	1.37	0.38	0.52	0.00	81.71
14	0.58	79.02	17.45	0.39	0.01	1.89	0.45	0.79	0.00	79.02
16	0.67	77.55	18.62	0.33	0.02	1.92	0.52	1.04	0.00	77.55
18	0.75	76.58	19.31	0.25	0.02	1.98	0.58	1.28	0.00	76.58
20	0.83	75.63	19.85	0.24	0.03	2.10	0.65	1.51	0.00	75.63
22	0.92	74.82	20.33	0.24	0.03	2.15	0.71	1.72	0.00	74.82
24	1.00	73.85	21.06	0.19	0.03	2.10	0.78	2.00	0.00	73.85
28	1.17	71.22	22.68	0.31	0.06	2.12	0.90	2.70	0.00	71.22
32	1.33	69.37	24.01	0.21	0.08	2.14	1.02	3.17	0.00	69.37
36	1.50	66.56	25.67	0.68	0.09	2.20	1.14	3.66	0.00	66.56
40	1.67	65.18	26.82	0.47	0.13	2.23	1.26	3.92	0.00	65.18
44	1.83	64.29	27.35	0.30	0.14	2.24	1.37	4.31	0.00	64.29
48	2.00	63.38	27.70	0.23	0.14	2.21	1.48	4.86	0.00	63.38
54	2.25	62.64	28.00	0.16	0.16	2.21	1.64	5.17	0.00	62.64
60	2.50	62.26	28.24	0.18	0.18	2.16	1.81	5.17	0.00	62.26
66	2.75	61.47	28.73	0.13	0.21	2.31	1.97	5.17	0.00	61.47
72	3.00	60.56	29.32	0.15	0.23	2.43	2.13	5.17	0.00	60.56
78	3.25	59.76	29.79	0.12	0.26	2.61	2.28	5.17	0.00	59.76
84	3.50	59.12	30.18	0.15	0.28	2.64	2.44	5.17	0.00	59.12
90	3.75	58.43	30.54	0.13	0.31	2.82	2.60	5.17	0.00	58.43

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	57.56	31.14	0.15	0.34	2.89	2.75	5.17	0.00	57.56
108	4.50	55.77	32.16	0.16	0.39	3.30	3.05	5.17	0.00	55.77
120	5.00	53.65	33.39	0.19	0.46	3.79	3.34	5.17	0.00	53.65
132	5.50	49.28	35.50	0.21	0.53	5.67	3.63	5.17	0.00	49.28
144	6.00	47.03	36.78	0.24	0.64	6.23	3.90	5.17	0.00	47.03
156	6.50	44.15	38.52	0.27	0.77	6.96	4.17	5.17	0.00	44.15
168	7.00	42.42	39.53	0.31	0.90	7.24	4.42	5.17	0.00	42.42
192	8.00	31.29	44.05	0.57	1.23	12.77	4.91	5.17	0.00	31.29
216	9.00	24.17	46.68	0.45	1.62	16.56	5.35	5.17	0.00	24.17
240	10.00	18.97	48.48	0.58	2.12	18.90	5.77	5.17	0.00	18.97
264	11.00	13.37	49.88	0.58	2.70	22.14	6.16	5.17	0.00	13.37
288	12.00	10.24	50.60	0.55	3.39	23.51	6.53	5.17	0.00	10.24
336	14.00	7.99	50.99	0.54	4.88	23.19	7.23	5.17	0.00	7.99
384	16.00	4.31	51.54	0.63	6.23	24.24	7.88	5.17	0.00	4.31
432	18.00	2.97	51.71	0.50	7.86	23.31	8.48	5.17	0.00	2.97
480	20.00	1.67	51.89	0.48	9.23	22.52	9.04	5.17	0.00	1.67
600	25.00	0.00	52.12	0.37	12.51	19.59	10.23	5.17	0.00	0.00
720	30.00	0.00	52.12	0.33	14.89	16.28	11.21	5.17	0.00	0.00
840	35.00	0.00	52.12	0.24	16.65	13.80	12.02	5.17	0.00	0.00
1080	45.00	0.00	52.12	0.16	18.83	10.43	13.28	5.17	0.00	0.00
1200	50.00	0.00	52.12	0.12	19.51	9.28	13.79	5.17	0.00	0.00
1320	55.00	0.00	52.12	0.11	20.00	8.36	14.24	5.17	0.00	0.00
Maximum	56.00	97.75	52.12	1.67	20.07	24.24	14.32	5.17	0.00	97.75

Table XVII.B-21 San Juan Islands - Alaskan North Slope Crude, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	90.12	8.37	0.09	0.00	1.17	0.24	0.00	0.00	90.12
10	0.42	88.49	9.92	0.06	0.00	1.20	0.32	0.00	0.00	88.49
12	0.50	87.18	11.14	0.08	0.00	1.21	0.39	0.00	0.00	87.18
14	0.58	84.29	13.10	0.07	0.00	2.07	0.47	0.00	0.00	84.29
16	0.67	82.31	14.44	0.04	0.01	2.66	0.54	0.00	0.00	82.31
18	0.75	81.35	15.23	0.04	0.01	2.77	0.61	0.00	0.00	81.35
20	0.83	79.86	16.26	0.04	0.01	3.16	0.68	0.00	0.00	79.86
22	0.92	78.42	17.24	0.04	0.01	3.54	0.75	0.00	0.00	78.42
24	1.00	76.78	18.42	0.12	0.01	3.85	0.82	0.00	0.00	76.78
28	1.17	74.04	20.65	0.11	0.04	4.21	0.95	0.00	0.00	74.04
32	1.33	69.71	24.43	0.11	0.09	4.59	1.08	0.00	0.00	69.71
36	1.50	66.54	26.92	0.18	0.10	5.06	1.20	0.00	0.00	66.54
40	1.67	63.61	28.89	0.17	0.16	5.85	1.32	0.00	0.00	63.61
44	1.83	59.59	31.18	0.16	0.19	7.45	1.43	0.00	0.00	59.59
48	2.00	58.41	32.09	0.27	0.20	7.50	1.54	0.00	0.00	58.41
54	2.25	56.37	33.41	0.14	0.28	8.08	1.71	0.00	0.00	56.37
60	2.50	55.05	34.40	0.20	0.30	8.18	1.87	0.00	0.00	55.05
66	2.75	53.57	35.32	0.08	0.38	8.63	2.03	0.00	0.00	53.57
72	3.00	50.89	36.55	0.18	0.40	9.80	2.19	0.00	0.00	50.89
78	3.25	48.34	37.71	0.09	0.48	11.04	2.34	0.00	0.00	48.34
84	3.50	47.45	38.20	0.21	0.52	11.13	2.49	0.00	0.00	47.45
90	3.75	46.65	38.68	0.11	0.62	11.30	2.64	0.00	0.00	46.65
96	4.00	44.79	39.46	0.24	0.67	12.07	2.79	0.00	0.00	44.79

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.33	45.04	0.30	0.87	20.39	3.07	0.00	0.00	30.33
120	5.00	21.18	48.42	0.35	1.08	25.65	3.32	0.00	0.00	21.18
132	5.50	16.70	50.14	0.36	1.37	27.86	3.57	0.00	0.00	16.70
144	6.00	14.52	50.97	0.40	1.64	28.67	3.80	0.00	0.00	14.52
156	6.50	12.71	51.73	0.39	1.98	29.16	4.03	0.00	0.00	12.71
168	7.00	11.67	52.16	0.40	2.27	29.24	4.25	0.00	0.00	11.67
192	8.00	9.03	53.10	0.40	2.94	29.85	4.68	0.00	0.00	9.03
216	9.00	7.61	53.65	0.38	3.59	29.67	5.10	0.00	0.00	7.61
240	10.00	6.18	54.04	0.38	4.23	29.68	5.49	0.00	0.00	6.18
264	11.00	5.21	54.28	0.41	4.86	29.36	5.88	0.00	0.00	5.21
288	12.00	4.52	54.41	0.37	5.46	29.00	6.25	0.00	0.00	4.52
336	14.00	2.95	54.60	0.44	6.63	28.42	6.95	0.00	0.00	2.95
384	16.00	1.44	54.82	0.35	7.74	28.04	7.62	0.00	0.00	1.44
432	18.00	0.55	54.93	0.33	8.83	27.12	8.24	0.00	0.00	0.55
480	20.00	0.05	55.00	0.30	9.84	25.98	8.83	0.00	0.00	0.05
600	25.00	0.00	55.01	0.23	11.93	22.68	10.15	0.00	0.00	0.00
720	30.00	0.00	55.01	0.18	13.47	20.05	11.29	0.00	0.00	0.00
840	35.00	0.00	55.01	0.14	14.61	17.93	12.30	0.00	0.00	0.00
1080	45.00	0.00	55.01	0.10	16.09	14.79	14.01	0.00	0.00	0.00
1200	50.00	0.00	55.01	0.08	16.57	13.60	14.74	0.00	0.00	0.00
1320	55.00	0.00	55.01	0.06	16.95	12.59	15.40	0.00	0.00	0.00
Maximum	56.00	99.57	55.01	0.44	17.01	29.85	15.53	0.00	0.00	99.57

Table XVII.B-22 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	90.12	8.37	0.09	0.00	1.17	0.24	0.00	0.00	90.12
10	0.42	88.49	9.92	0.06	0.00	1.20	0.32	0.00	0.00	88.49
12	0.50	87.18	11.14	0.08	0.00	1.21	0.39	0.00	0.00	87.18
14	0.58	84.65	12.88	0.07	0.00	1.86	0.47	0.07	0.00	84.65
16	0.67	82.39	14.32	0.07	0.01	2.54	0.54	0.13	0.00	82.39
18	0.75	81.33	15.13	0.07	0.01	2.66	0.61	0.20	0.00	81.33
20	0.83	79.70	16.20	0.06	0.01	3.09	0.68	0.26	0.00	79.70
22	0.92	77.81	17.37	0.06	0.01	3.68	0.75	0.32	0.00	77.81
24	1.00	76.37	18.41	0.15	0.01	3.83	0.82	0.41	0.00	76.37
28	1.17	73.15	20.79	0.13	0.04	4.36	0.95	0.59	0.00	73.15
32	1.33	68.04	24.86	0.15	0.09	5.11	1.07	0.68	0.00	68.04
36	1.50	64.76	27.33	0.25	0.10	5.59	1.19	0.78	0.00	64.76
40	1.67	61.73	29.27	0.18	0.17	6.40	1.31	0.95	0.00	61.73
44	1.83	58.84	31.00	0.17	0.21	7.25	1.42	1.11	0.00	58.84
48	2.00	57.11	32.06	0.31	0.21	7.51	1.53	1.27	0.00	57.11
54	2.25	54.63	33.53	0.13	0.31	8.36	1.70	1.34	0.00	54.63
60	2.50	53.19	34.52	0.25	0.33	8.50	1.85	1.34	0.00	53.19
66	2.75	51.76	35.41	0.09	0.42	8.96	2.01	1.34	0.00	51.76
72	3.00	48.70	36.78	0.21	0.45	10.36	2.16	1.34	0.00	48.70
78	3.25	47.46	37.44	0.10	0.55	10.79	2.31	1.34	0.00	47.46
84	3.50	46.30	38.03	0.23	0.60	11.03	2.46	1.34	0.00	46.30
90	3.75	45.29	38.58	0.12	0.70	11.37	2.61	1.34	0.00	45.29
96	4.00	43.95	39.16	0.26	0.76	11.78	2.75	1.34	0.00	43.95

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
108	4.50	30.53	44.36	0.31	0.98	19.45	3.03	1.34	0.00	30.53
120	5.00	22.90	47.26	0.33	1.19	23.70	3.28	1.34	0.00	22.90
132	5.50	19.62	48.66	0.34	1.46	25.05	3.52	1.34	0.00	19.62
144	6.00	17.53	49.50	0.37	1.72	25.79	3.76	1.34	0.00	17.53
156	6.50	16.11	50.20	0.36	2.04	25.97	3.98	1.34	0.00	16.11
168	7.00	15.17	50.64	0.38	2.31	25.96	4.21	1.34	0.00	15.17
192	8.00	9.79	52.31	0.40	2.94	28.59	4.63	1.34	0.00	9.79
216	9.00	8.00	52.96	0.40	3.58	28.69	5.04	1.34	0.00	8.00
240	10.00	5.91	53.48	0.39	4.22	29.23	5.43	1.34	0.00	5.91
264	11.00	5.41	53.66	0.40	4.86	28.52	5.80	1.34	0.00	5.41
288	12.00	4.73	53.80	0.36	5.45	28.16	6.17	1.34	0.00	4.73
336	14.00	2.76	54.04	0.52	6.63	27.85	6.86	1.34	0.00	2.76
384	16.00	1.22	54.27	0.37	7.76	27.54	7.51	1.34	0.00	1.22
432	18.00	0.35	54.38	0.34	8.88	26.60	8.12	1.34	0.00	0.35
480	20.00	0.02	54.43	0.30	9.91	25.31	8.69	1.34	0.00	0.02
600	25.00	0.00	54.43	0.23	12.01	22.01	9.97	1.34	0.00	0.00
720	30.00	0.00	54.43	0.18	13.57	19.40	11.08	1.34	0.00	0.00
840	35.00	0.00	54.43	0.14	14.72	17.31	12.06	1.34	0.00	0.00
1080	45.00	0.00	54.43	0.10	16.22	14.21	13.70	1.34	0.00	0.00
1200	50.00	0.00	54.43	0.08	16.71	13.04	14.40	1.34	0.00	0.00
1320	55.00	0.00	54.43	0.06	17.09	12.05	15.04	1.34	0.00	0.00
Maximum	56.00	99.57	54.43	0.52	17.15	29.23	15.16	1.34	0.00	99.57

Table XVII.B-23 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.21	5.59	0.10	0.00	0.93	0.17	0.00	0.00	93.21
8	0.33	89.81	8.49	0.10	0.00	1.28	0.24	0.08	0.00	89.81
10	0.42	88.22	10.02	0.08	0.00	1.29	0.32	0.08	0.00	88.22
12	0.50	86.85	11.22	0.09	0.00	1.29	0.39	0.15	0.00	86.85
14	0.58	83.93	13.10	0.08	0.00	2.07	0.47	0.35	0.00	83.93
16	0.67	81.43	14.61	0.07	0.01	2.82	0.54	0.54	0.00	81.43
18	0.75	80.43	15.32	0.06	0.01	2.86	0.61	0.72	0.00	80.43
20	0.83	78.61	16.43	0.04	0.01	3.34	0.68	0.89	0.00	78.61
22	0.92	76.85	17.48	0.03	0.01	3.80	0.74	1.08	0.00	76.85
24	1.00	75.44	18.43	0.12	0.02	3.88	0.81	1.31	0.00	75.44
28	1.17	72.62	20.48	0.10	0.05	4.08	0.94	1.73	0.00	72.62
32	1.33	67.88	24.28	0.14	0.09	4.53	1.07	2.02	0.00	67.88
36	1.50	64.44	26.77	0.18	0.10	5.04	1.19	2.28	0.00	64.44
40	1.67	61.56	28.56	0.17	0.17	5.64	1.30	2.61	0.00	61.56
44	1.83	58.20	30.43	0.16	0.20	6.67	1.41	2.92	0.00	58.20
48	2.00	56.89	31.26	0.26	0.21	6.63	1.52	3.22	0.00	56.89
54	2.25	55.46	32.27	0.13	0.30	6.79	1.68	3.37	0.00	55.46
60	2.50	53.92	33.32	0.21	0.32	7.02	1.84	3.37	0.00	53.92
66	2.75	52.07	34.36	0.09	0.40	7.73	1.99	3.37	0.00	52.07
72	3.00	49.50	35.54	0.19	0.43	8.84	2.14	3.37	0.00	49.50
78	3.25	47.00	36.66	0.09	0.52	10.07	2.29	3.37	0.00	47.00
84	3.50	45.92	37.22	0.23	0.56	10.27	2.43	3.37	0.00	45.92
90	3.75	45.07	37.70	0.12	0.67	10.50	2.57	3.37	0.00	45.07

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	43.65	38.31	0.26	0.73	10.97	2.71	3.37	0.00	43.65
108	4.50	29.01	43.93	0.33	0.95	19.42	2.99	3.37	0.00	29.01
120	5.00	23.21	46.24	0.33	1.18	22.45	3.23	3.37	0.00	23.21
132	5.50	18.82	47.97	0.34	1.45	24.58	3.47	3.37	0.00	18.82
144	6.00	16.22	48.96	0.36	1.70	25.71	3.69	3.37	0.00	16.22
156	6.50	14.33	49.76	0.35	2.00	26.28	3.91	3.37	0.00	14.33
168	7.00	13.21	50.23	0.37	2.27	26.43	4.13	3.37	0.00	13.21
192	8.00	7.98	51.81	0.38	2.89	29.03	4.54	3.37	0.00	7.98
216	9.00	6.15	52.42	0.37	3.51	29.24	4.93	3.37	0.00	6.15
240	10.00	4.91	52.77	0.38	4.12	29.15	5.31	3.37	0.00	4.91
264	11.00	3.88	53.02	0.36	4.72	28.99	5.68	3.37	0.00	3.88
288	12.00	3.22	53.13	0.34	5.27	28.65	6.03	3.37	0.00	3.22
336	14.00	1.99	53.28	0.40	6.36	27.90	6.70	3.37	0.00	1.99
384	16.00	1.00	53.43	0.30	7.35	27.22	7.34	3.37	0.00	1.00
432	18.00	0.21	53.53	0.29	8.29	26.38	7.94	3.37	0.00	0.21
480	20.00	0.01	53.56	0.24	9.14	25.18	8.50	3.37	0.00	0.01
600	25.00	0.00	53.56	0.19	10.85	22.24	9.79	3.37	0.00	0.00
720	30.00	0.00	53.56	0.15	12.11	19.90	10.92	3.37	0.00	0.00
840	35.00	0.00	53.56	0.12	13.04	17.99	11.92	3.37	0.00	0.00
1080	45.00	0.00	53.56	0.08	14.24	15.09	13.65	3.37	0.00	0.00
1200	50.00	0.00	53.56	0.07	14.63	13.97	14.40	3.37	0.00	0.00
1320	55.00	0.00	53.56	0.05	14.94	13.00	15.09	3.37	0.00	0.00
Maximum	56.00	99.57	53.56	0.40	14.98	29.24	15.22	3.37	0.00	99.57

Table XVII.B-24 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Padilla Bay.

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
2	0.08	99.27	0.68	0.00	0.00	0.00	0.05	0.00	0.00	99.27
4	0.17	97.76	1.97	0.14	0.00	0.04	0.09	0.00	0.00	97.76
6	0.25	93.09	5.50	0.12	0.00	0.86	0.17	0.27	0.00	93.09
8	0.33	89.96	8.28	0.14	0.00	1.10	0.24	0.27	0.00	89.96
10	0.42	88.09	9.98	0.07	0.00	1.27	0.32	0.27	0.00	88.09
12	0.50	86.61	11.18	0.07	0.00	1.27	0.39	0.48	0.00	86.61
14	0.58	83.96	12.88	0.06	0.00	1.88	0.47	0.74	0.00	83.96
16	0.67	81.84	14.15	0.06	0.01	2.42	0.54	0.99	0.00	81.84
18	0.75	80.67	14.92	0.05	0.01	2.51	0.61	1.23	0.00	80.67
20	0.83	79.24	15.80	0.04	0.01	2.76	0.68	1.46	0.00	79.24
22	0.92	77.35	16.89	0.04	0.01	3.27	0.74	1.70	0.00	77.35
24	1.00	75.97	17.79	0.11	0.02	3.30	0.81	2.00	0.00	75.97
28	1.17	72.73	19.91	0.10	0.04	3.58	0.94	2.70	0.00	72.73
32	1.33	67.28	23.95	0.13	0.08	4.30	1.07	3.20	0.00	67.28
36	1.50	63.75	26.39	0.19	0.09	4.76	1.18	3.63	0.00	63.75
40	1.67	60.62	28.24	0.17	0.15	5.47	1.30	4.05	0.00	60.62
44	1.83	55.15	30.93	0.16	0.18	7.73	1.40	4.44	0.00	55.15
48	2.00	52.94	32.08	0.25	0.19	8.21	1.51	4.81	0.00	52.94
54	2.25	49.10	33.99	0.13	0.27	9.83	1.66	5.03	0.00	49.10
60	2.50	47.38	35.05	0.21	0.29	10.23	1.81	5.03	0.00	47.38
66	2.75	45.14	36.19	0.09	0.38	11.22	1.96	5.03	0.00	45.14
72	3.00	42.12	37.51	0.21	0.40	12.64	2.10	5.03	0.00	42.12
78	3.25	40.46	38.30	0.10	0.49	13.38	2.24	5.03	0.00	40.46
84	3.50	39.88	38.65	0.22	0.54	13.31	2.37	5.03	0.00	39.88
90	3.75	38.98	39.13	0.11	0.64	13.60	2.51	5.03	0.00	38.98

Time (hrs)	Time (days)	% On Water Surface	% Evapor-ated	% In Water Column	% In Sediment	% On Shore	% Decayed	% Removed	% Out of Grid	% On Water Surface +Out of Grid
96	4.00	37.26	39.83	0.25	0.69	14.30	2.64	5.03	0.00	37.26
108	4.50	27.83	43.63	0.31	0.90	19.39	2.90	5.03	0.00	27.83
120	5.00	21.92	45.96	0.35	1.11	22.49	3.14	5.03	0.00	21.92
132	5.50	16.76	47.91	0.34	1.39	25.20	3.37	5.03	0.00	16.76
144	6.00	14.34	48.82	0.38	1.64	26.20	3.59	5.03	0.00	14.34
156	6.50	12.91	49.47	0.37	1.97	26.44	3.81	5.03	0.00	12.91
168	7.00	11.70	49.94	0.39	2.25	26.67	4.02	5.03	0.00	11.70
192	8.00	6.89	51.39	0.39	2.91	28.97	4.42	5.03	0.00	6.89
216	9.00	5.65	51.85	0.38	3.56	28.74	4.80	5.03	0.00	5.65
240	10.00	4.56	52.15	0.38	4.19	28.52	5.17	5.03	0.00	4.56
264	11.00	4.02	52.31	0.39	4.81	27.92	5.52	5.03	0.00	4.02
288	12.00	3.54	52.40	0.36	5.37	27.44	5.86	5.03	0.00	3.54
336	14.00	1.83	52.62	0.48	6.49	27.03	6.52	5.03	0.00	1.83
384	16.00	0.95	52.75	0.35	7.55	26.24	7.13	5.03	0.00	0.95
432	18.00	0.28	52.84	0.31	8.57	25.27	7.71	5.03	0.00	0.28
480	20.00	0.00	52.88	0.27	9.50	24.07	8.25	5.03	0.00	0.00
600	25.00	0.00	52.88	0.21	11.39	21.03	9.47	5.03	0.00	0.00
720	30.00	0.00	52.88	0.16	12.76	18.63	10.53	5.03	0.00	0.00
840	35.00	0.00	52.88	0.13	13.78	16.71	11.47	5.03	0.00	0.00
1080	45.00	0.00	52.88	0.09	15.08	13.86	13.06	5.03	0.00	0.00
1200	50.00	0.00	52.88	0.07	15.50	12.77	13.75	5.03	0.00	0.00
1320	55.00	0.00	52.88	0.05	15.82	11.85	14.37	5.03	0.00	0.00
Maximum	56.00	99.57	52.88	0.48	15.87	28.97	14.49	5.03	0.00	99.57

Table XVII.B-25 San Juan Islands - Alaskan North Slope Crude, no removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,777	4,025	786	409	606	372
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,255	3,626	577	293	535	267
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	11,811	4,145	5,783	4,416	7,162	4,106
Shoreline length (km) oiled by > 100 g/m^2	4,542	2,803	3,324	2,544	3,276	2,763
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	9,604,900	2,435,100	3,348,300	2,706,300	5,035,800	2,105,900
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,205,600	1,710,300	2,434,500	1,709,700	2,125,800	1,999,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	514	159	285	203	344	206

Table XVII.B-26 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,760	4,323	577	375	604	250
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,132	3,927	445	259	528	189
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	8,803	5,067	5,544	5,633	5,816	4,775
Shoreline length (km) oiled by > 100 g/m^2	5,131	2,701	3,625	3,177	2,851	2,636
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	6,581,100	3,439,500	3,094,000	3,916,000	4,168,300	2,934,200
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,222,300	1,627,600	2,449,800	1,717,400	1,648,100	1,840,500
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	396	193	285	253	264	228

Table XVII.B-27 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	1,530	2,969	606	508	796	258
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,025	2,658	423	353	597	185
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	9,597	4,351	4,375	3,728	9,386	6,807
Shoreline length (km) oiled by > 100 g/m^2	5,038	2,858	2,959	2,138	3,862	3,058
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	7,501,500	2,854,800	2,367,400	2,397,100	6,951,400	5,038,500
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,095,400	1,496,300	2,007,600	1,331,000	2,434,500	1,768,300
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	430	165	227	162	419	299

Table XVII.B-28 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Water surface area exposed to oil at some time after the spill (i.e., cumulative total area), shoreline oiled to varying degrees, and the per-unit-area component of shoreline cleanup costs.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	2,272	3,981	658	316	600	231
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	1,475	3,451	459	228	515	171
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	9,305	4,108	4,798	3,964	5,669	5,439
Shoreline length (km) oiled by > 100 g/m^2	4,561	2,492	2,831	2,628	2,747	2,409
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	7,149,000	2,615,800	2,748,600	2,463,700	3,732,700	3,638,000
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,156,300	1,491,700	2,049,800	1,500,300	1,936,500	1,800,600
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	415	154	236	184	274	254

XVII.C. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the appropriate seasonal abundance for each of the representative run dates. Impacts are proportional to pre-spill abundance. To allow for comparisons between runs from different seasons, the results were corrected such that annual mean abundances bird and mammals species are presented in the tables below.

Table XVII.C-1 San Juan Islands - Alaskan North Slope Crude, no removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	92,659	14,638	129	8,219	3	0	10	-	115,658	115,649	10
Worst run for Lopez Island	190,946	17,844	111	7,018	3	0	18	-	215,939	215,921	18
Worst run for Orcas Island	64,502	13,720	115	7,327	3	0	8	-	85,674	85,666	8
50th Percentile Run (based on shore cost)	52,685	13,334	107	6,755	3	0	7	-	72,890	72,883	7
Worst run for Lummi Island	62,750	13,663	115	7,291	3	0	7	-	83,829	83,821	7
Worst run for Padilla Bay	51,609	13,299	109	6,915	3	0	7	-	71,942	71,936	7

Table XVII.C-2 San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	87,615	14,474	136	8,650	3	0	9	-	110,887	110,878	9
Worst run for Lopez Island	203,445	18,252	111	7,041	4	0	19	-	228,871	228,852	19
Worst run for Orcas Island	59,035	13,542	119	7,547	3	0	7	-	80,252	80,245	7
50th Percentile Run (based on shore cost)	51,295	13,289	114	7,218	3	0	7	-	71,925	71,919	7
Worst run for Lummi Island	62,436	13,653	110	6,980	3	0	7	-	83,189	83,181	7
Worst run for Padilla Bay	48,380	13,194	108	6,822	3	0	6	-	68,513	68,507	6

Table XVII.C-3 San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	83,180	14,329	135	8,582	3	0	9	-	106,239	106,229	9
Worst run for Lopez Island	150,815	16,535	110	6,985	3	0	14	-	174,462	174,448	14
Worst run for Orcas Island	58,108	13,511	111	7,059	3	0	7	-	78,800	78,793	7
50th Percentile Run (based on shore cost)	55,174	13,416	102	6,458	3	0	7	-	75,159	75,152	7
Worst run for Lummi Island	65,356	13,748	122	7,720	3	0	8	-	86,955	86,948	8
Worst run for Padilla Bay	48,251	13,190	112	7,132	3	0	6	-	68,694	68,688	6

Table XVII.C-4 San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Wildlife injury (as numbers lost).

Statistic	Waterfowl	Seabirds	Wading birds	Shore-birds	Raptors	Ceta-ceans	Pinnipeds (seals)	Sea otters and Other Mammals	Total Wildlife	Total Birds	Total Mammals
99th Percentile Run (based on shore cost)	101,802	14,937	130	8,232	3	0	11	-	125,114	125,103	11
Worst run for Lopez Island	183,674	17,607	116	7,375	4	0	17	-	208,792	208,775	17
Worst run for Orcas Island	59,605	13,560	110	6,965	3	0	7	-	80,250	80,243	7
50th Percentile Run (based on shore cost)	49,996	13,247	108	6,816	3	0	6	-	70,176	70,169	6
Worst run for Lummi Island	61,896	13,635	109	6,904	3	0	7	-	82,554	82,546	7
Worst run for Padilla Bay	47,614	13,169	105	6,656	3	0	6	-	67,553	67,547	6

XVII.D. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates were calculated using the seasonal abundance for each of the spill dates included in the 3 runs (i.e., the data were not corrected to be seasonal means).

Table XVII.D-1. San Juan Islands - Alaskan North Slope Crude, no removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	5,296	9,817	187	54	1,993	623,325	640,672
Worst run for Lopez Island	2,299	4,344	99	26	1,807	242,536	251,112
Worst run for Orcas Island	374	829	43	8	1,689	424,678	427,620
50th Percentile Run (based on shore cost)	584	1,212	49	9.6	1,702	328,406	331,963
Worst run for Lummi Island	2,777	5,218	113	30	1,837	489,324	499,300
Worst run for Padilla Bay	331	750	41	7.2	1,686	364,744	367,559

Table XVII.D-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	724,311	740,627
Worst run for Lopez Island	2,379	4,491	102	26	1,812	229,324	238,135
Worst run for Orcas Island	318	726	41	7.1	1,685	495,463	498,240
50th Percentile Run (based on shore cost)	923	1,830	59	13	1,722	463,373	467,920
Worst run for Lummi Island	2,876	5,398	116	31	1,843	411,935	422,199
Worst run for Padilla Bay	482	1,025	46	8.6	1,695	357,189	360,446

Table XVII.D-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	718,648	734,965
Worst run for Lopez Island	2,299	4,344	99	26	1,807	268,956	277,533
Worst run for Orcas Island	367	815	43	7.6	1,688	399,657	402,577
50th Percentile Run (based on shore cost)	1,788	3,411	84	21	1,776	260,938	268,018
Worst run for Lummi Island	2,876	5,398	116	31	1,843	575,198	585,463
Worst run for Padilla Bay	245	592	39	6.4	1,681	444,972	447,535

Table XVII.D-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg).

Statistic	Total small pelagic fish	Total large pelagic fish	Total demersal fish	Total demersal invertebrates	Total subtidal mollusks	Total intertidal mollusks	Total
99th Percentile Run (based on shore cost)	4,944	9,175	177	50	1,971	620,032	636,349
Worst run for Lopez Island	2,299	4,344	99	26	1,807	214,233	222,809
Worst run for Orcas Island	310	712	41	7.0	1,685	359,083	361,838
50th Percentile Run (based on shore cost)	1,649	3,158	80	20	1,767	366,636	373,310
Worst run for Lummi Island	2,876	5,398	116	31	1,843	400,140	410,404
Worst run for Padilla Bay	413	899	44	8.0	1,691	340,207	343,262

XVII.E. ESTIMATED NRDA COSTS: HABITAT RESTORATION COSTS

NRDA costs were based on the estimated costs of replacement of ecological services by creation of habitat: either wetland (saltmarsh) or seagrass (eelgrass) bed. The scale of the restoration project required for compensation of the total injury to fish, invertebrates, birds, and mammals was calculated using macrophyte primary production and a food chain model. Saltmarsh and eelgrass bed productivity is corrected for less than full functionality during recovery. It is assumed that it takes 15 years for saltmarshes and 3 years for eelgrass beds to develop 99% of full function, after which they remain fully functional, with benefits discounted at 3% per year for 50 years (discount factor = 25.7). All injuries used to calculate habitat restoration costs are expressed as wet weights; dry weight is assumed 22% of wet weight. Saltmarsh creation cost ($46.30/m^2) is from French et al. (1996), corrected to 2004$ assuming 3% inflation per year. Eelgrass bed creation cost ($29.50/m^2) is from Fonseca et al. (1998), corrected to 2004$ assuming 3% inflation per year.

Table XVII.E-1. San Juan Islands - Alaskan North Slope Crude, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	5,296	2,299	374	584	2,777	331
Large pelagic fish	9,817	4,345	829	1,213	5,218	750
Demersal fish	187	99	43	49	113	42
Decapods	54	26	7.6	9.6	30	7.2
Molluscs	625,318	244,343	426,366	330,108	491,162	366,430
Birds:						
Waterfowl (# * kg each)	60,846	125,388	42,356	34,596	41,206	33,890
Seabirds (# * kg each)	17,017	20,744	15,949	15,501	15,883	15,461
Waders (# * kg each)	150	129	134	124	134	127
Shorebirds (# * kg each)	9,554	8,158	8,517	7,852	8,476	8,039
Raptors (# * kg each)	3.0	3.5	3.0	3.0	3.0	3.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	11	20	8.8	7.7	8.6	7.6
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	640,672	251,112	427,620	331,963	499,300	367,559
Subtotal birds	87,571	154,422	66,960	58,077	65,701	57,520
Subtotal other wildlife	11	21	9	8	9	8
Total all species	728,255	405,554	494,588	390,048	565,010	425,087

Table XVII.E-2. San Juan Islands - Alaskan North Slope Crude, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	295	331	213	190	232	192
Saltmarsh Area (acres)	729	818	526	468	574	473
Saltmarsh Cost (millions of 2004$)	136.5	153.3	98.6	87.7	107.6	88.7
Eelgrass Area (m2)	184	207	133	118	145	120
Eelgrass Area (acres)	455	511	329	293	359	296
Eelgrass Cost (millions of 2004$)	54.4	61.0	39.2	34.9	42.8	35.3

Table XVII.E-3. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,379	318	923	2,876	482
Large pelagic fish	9,175	4,491	726	1,830	5,398	1,025
Demersal fish	177	102	41	59	116	46
Decapods	51	26	7	13	31	8.6
Molluscs	726,282	231,137	497,148	465,095	413,778	358,885
Birds:						
Waterfowl (# * kg each)	57,534	133,595	38,766	33,684	41,000	31,770
Seabirds (# * kg each)	16,826	21,218	15,742	15,449	15,871	15,338
Waders (# * kg each)	158	129	138	132	128	125
Shorebirds (# * kg each)	10,056	8,185	8,773	8,391	8,114	7,931
Raptors (# * kg each)	3.0	4.2	3.0	3.0	3.0	3.3
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	10.9	22	8.3	7.6	8.6	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	740,627	238,135	498,240	467,920	422,199	360,446
Subtotal birds	84,577	163,131	63,423	57,659	65,116	55,167
Subtotal other wildlife	11	22	8	8	9	7
Total all species	825,215	401,288	561,671	525,586	487,324	415,620

Table XVII.E-4. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	301	343	216	207	223	188
Saltmarsh Area (acres)	743	847	533	511	551	465
Saltmarsh Cost (millions of 2004$)	139.2	158.7	99.9	95.8	103.2	87.1
Eelgrass Area (m2)	188	214	135	129	139	118
Eelgrass Area (acres)	464	529	333	320	344	290
Eelgrass Cost (millions of 2004$)	55.4	63.2	39.8	38.1	41.1	34.7

Table XVII.E-5. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,299	367	1,788	2,876	245
Large pelagic fish	9,175	4,345	815	3,411	5,398	592
Demersal fish	177	99	43	84	116	39
Decapods	51	26	7.6	21	31	6.4
Molluscs	720,619	270,764	401,345	262,714	577,041	446,653
Birds:						
Waterfowl (# * kg each)	54,622	99,035	38,158	36,231	42,917	31,685
Seabirds (# * kg each)	16,658	19,222	15,707	15,596	15,982	15,333
Waders (# * kg each)	157	128	129	118	141	131
Shorebirds (# * kg each)	9,977	8,120	8,206	7,507	8,975	8,290
Raptors (# * kg each)	3.0	3.6	3.0	2.9	3.0	3.2
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	10.5	17	8.2	7.9	8.9	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	734,965	277,533	402,577	268,018	585,463	447,535
Subtotal birds	81,416	126,509	62,204	59,455	68,018	55,442
Subtotal other wildlife	11	17	8	8	9	7
Total all species	816,392	404,058	464,789	327,481	653,489	502,985

Table XVII.E-6. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	295	293	203	190	247	198
Saltmarsh Area (acres)	729	724	501	470	609	488
Saltmarsh Cost (millions of 2004$)	136.7	135.7	93.9	88.1	114.2	91.5
Eelgrass Area (m2)	185	183	127	119	154	124
Eelgrass Area (acres)	456	453	313	294	381	305
Eelgrass Cost (millions of 2004$)	54.4	54.0	37.4	35.1	45.5	36.4

Table XVII.E-7. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration.

Species Category	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Fish and Invertebrates:						
Small pelagic fish	4,944	2,299	311	1,649	2,876	413
Large pelagic fish	9,175	4,345	712	3,158	5,398	899
Demersal fish	177	99	41	80	116	44
Decapods	51	26	7.0	20	31	8.0
Molluscs	622,003	216,040	360,767	368,403	401,983	341,898
Birds:						
Waterfowl (# * kg each)	66,850	120,612	39,141	32,831	40,645	31,267
Seabirds (# * kg each)	17,364	20,468	15,764	15,399	15,851	15,309
Waders (# * kg each)	151	135	128	125	127	122
Shorebirds (# * kg each)	9,570	8,573	8,097	7,924	8,026	7,738
Raptors (# * kg each)	3.0	4.1	3.0	2.9	2.9	3.1
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	12	20	8.4	7.5	8.6	7.3
Cetaceans	0.0	0.1	0.0	0.0	0.0	0.0
Totals:						
Subtotal fish and invertebrates	636,349	222,809	361,838	373,310	410,404	343,262
Subtotal birds	93,938	149,793	63,132	56,282	64,651	54,439
Subtotal other wildlife	12	20	8	7	9	7
Total all species	730,298	372,622	424,978	429,599	475,064	397,708

Table XVII.E-8. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Saltmarsh Area (ha)	302	321	199	197	221	185
Saltmarsh Area (acres)	746	793	492	488	545	456
Saltmarsh Cost (millions of 2004$)	139.8	148.5	92.2	91.4	102.2	85.5
Eelgrass Area (m2)	189	200	124	123	138	115
Eelgrass Area (acres)	466	495	307	305	341	285
Eelgrass Cost (millions of 2004$)	55.7	59.1	36.7	36.4	40.7	34.0

XVII.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

The Washington Compensation Schedule was applied to the model results for the hypothetical spills simulated. The methods are described in Section 6.2 of Volume I. Note that the Compensation Schedule is designed to be a simplified procedure for small spills. Thus, for spills the size of those considered here, the OPA procedures using restoration costs (listed in Section XVII.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XVII.F-1. San Juan Islands - Alaskan North Slope Crude, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.70	21.74	25.57	21.75	23.69
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	228	238	228	268	228	249

Table XVII.F-2. San Juan Islands - Alaskan North Slope Crude, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.71	25.54	25.58	21.75	23.71
% Removed by 24 hours	0.54	0.61	0.61	0.43	0.42	0.41
Compensation (millions $)	227	237	267	267	227	248

Table XVII.F-3. San Juan Islands - Alaskan North Slope Crude, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	25.55	25.54	25.56	21.76	23.71
% Removed by 24 hours	1.57	1.76	1.76	1.36	1.25	1.31
Compensation (millions $)	225	264	263	265	226	246

Table XVII.F-4. San Juan Islands - Alaskan North Slope Crude, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule.

Statistic	99th Percentile Run (based on shore cost)	Worst run for Lopez Island	Worst run for Orcas Island	50th Percentile Run (based on shore cost)	Worst run for Lummi Island	Worst run for Padilla Bay
Vulnerability Score ($/gal.)	21.74	22.71	25.54	22.72	21.75	23.70
% Removed by 24 hours	2.05	2.80	2.80	2.15	2.00	2.00
Compensation (millions $)	224	232	261	233	224	244

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 XVIII: Model Inputs for Lower Columbia River – Bunker C

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

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.... 8
XVIII.D: Oil Properties 10
XVIII.E: Inputs to the SIMAP Physical Fates Model..... 13

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.C.1-1 Grid used for the hydrodynamic model-generated current data. 7
Figure XVIII.C.1-2 Grid used for the hydrodynamic model-generated current data. 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 dominant tidal component (M_2) at Astoria. 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 dominant tidal component (M_2) at Astoria. 9
Figure XVIII.E-1 Varied range of spill site from 3 miles off the entrance to Columbia River to Astoria..... 16
Figure XVIII.E-2. Wind Station Locations..... 20

List of Tables

Table XVIII.D-1. Oil properties for Bunker C assumed in the modeling. 10
Table XVIII.D-2. Aromatic concentrations (mg/kg) for Bunker C. 11
Table XVIII.E-1. Inputs to the Fates Model for Stochastic Scenarios 13
Table XVIII.E-2. Time, date and location inputs for each of the 100 stochastic runs. 17
Table XVIII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 19
Table XVIII.E-4. Water temperature by month of the year (from French et al., 1996b). 19
Table XVIII.E-5. Wind data sources and records used. 20

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 was 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

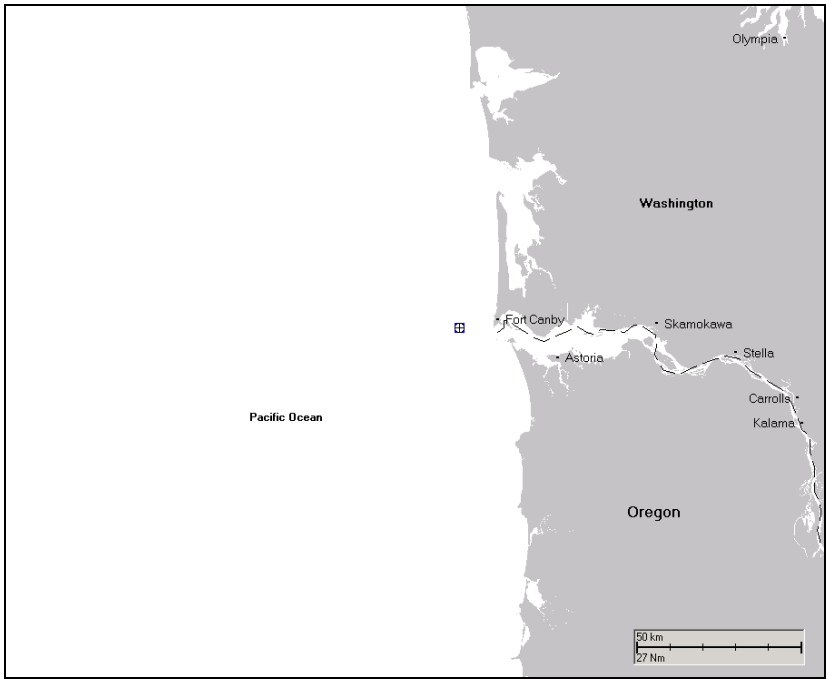


Figure XVIII.B.1-1 Map of the vicinity of the potential spill locations.

XVIII.B.2. Gridded Habitat Mapping

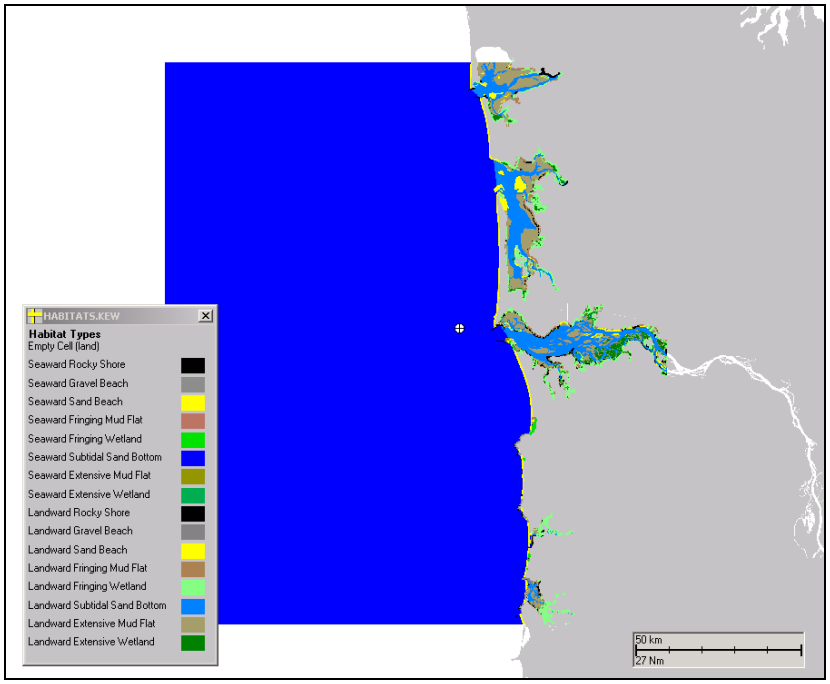


Figure XVIII.B.2-1 Habitat grid used for modeling the potential spills.

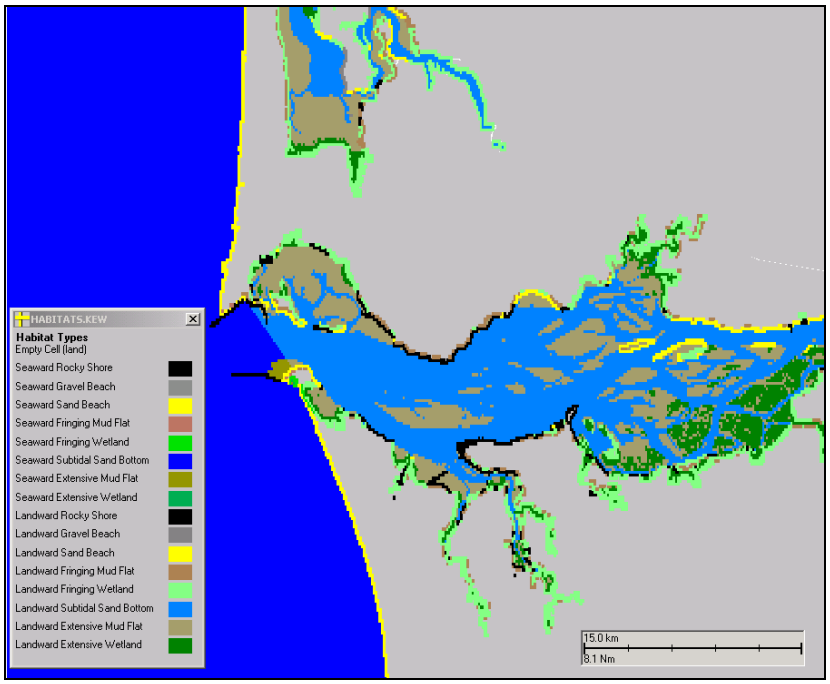


Figure XVIII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XVIII.B-3. Gridded Depth Data

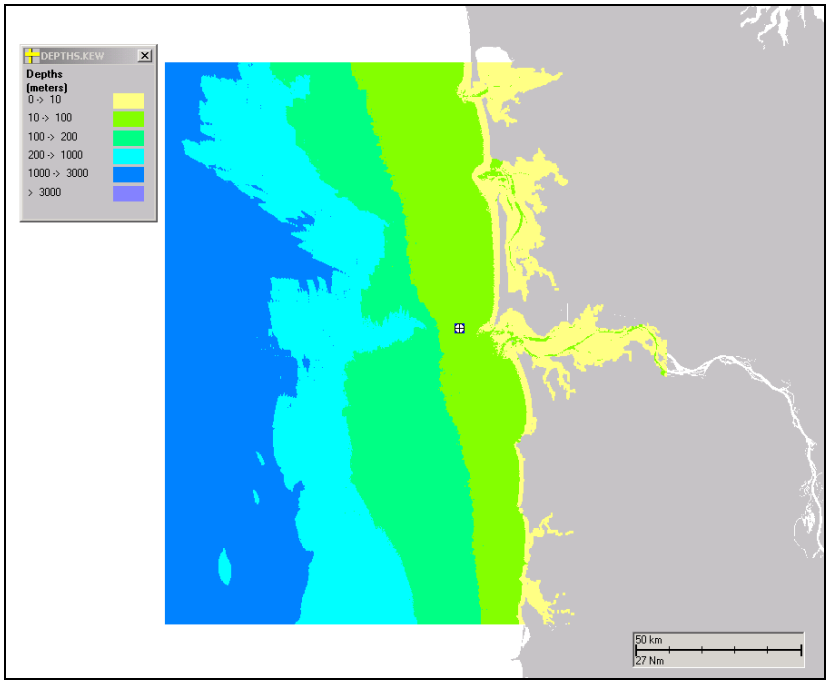


Figure XVIII.B.3-1 Depth grid used for modeling the potential spills.

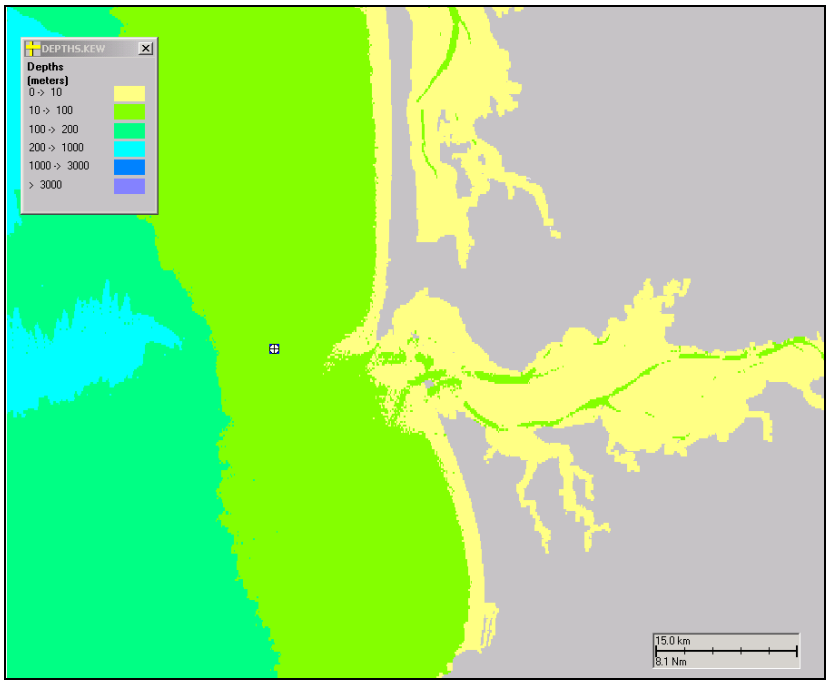


Figure XVIII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XVIII.B-4. Areas Where Response Actions Assumed

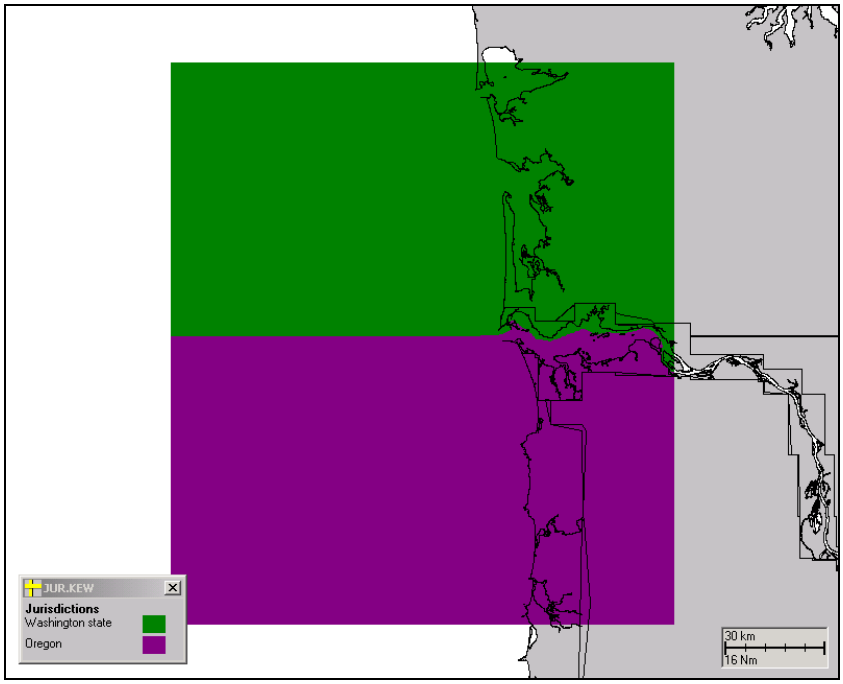


Figure XVIII.B.4-1 Jurisdictions in the area of the potential spills.

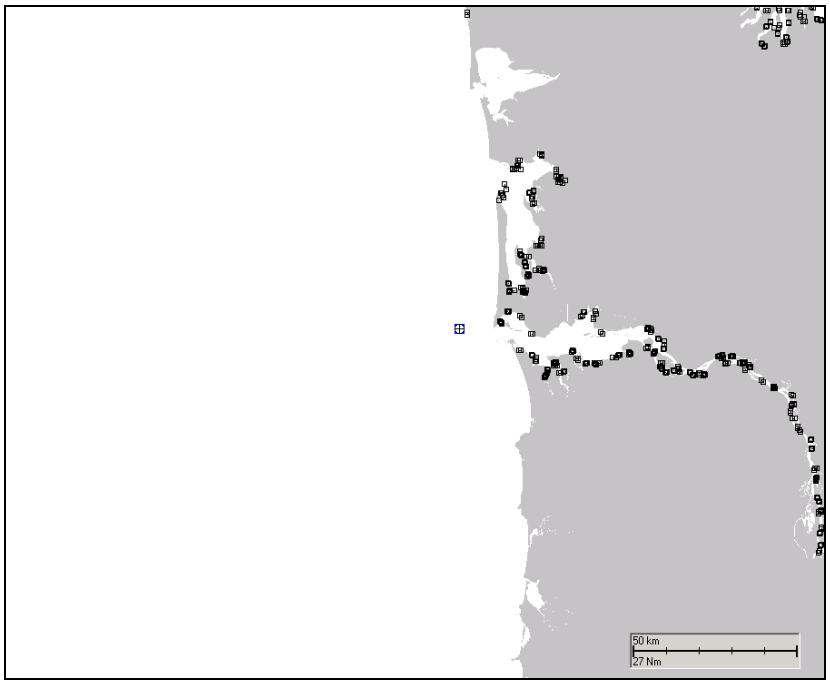


Figure XVIII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

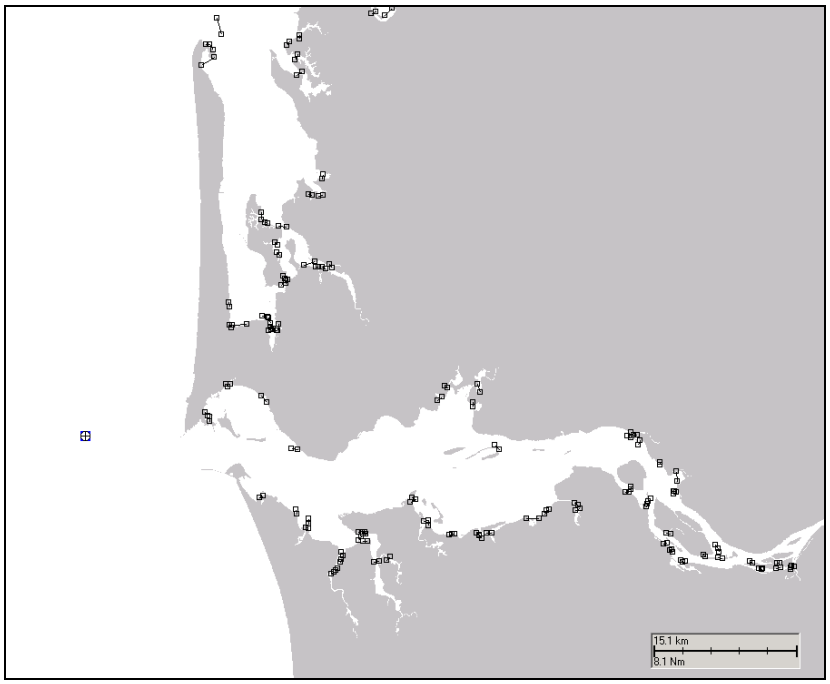


Figure XVIII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

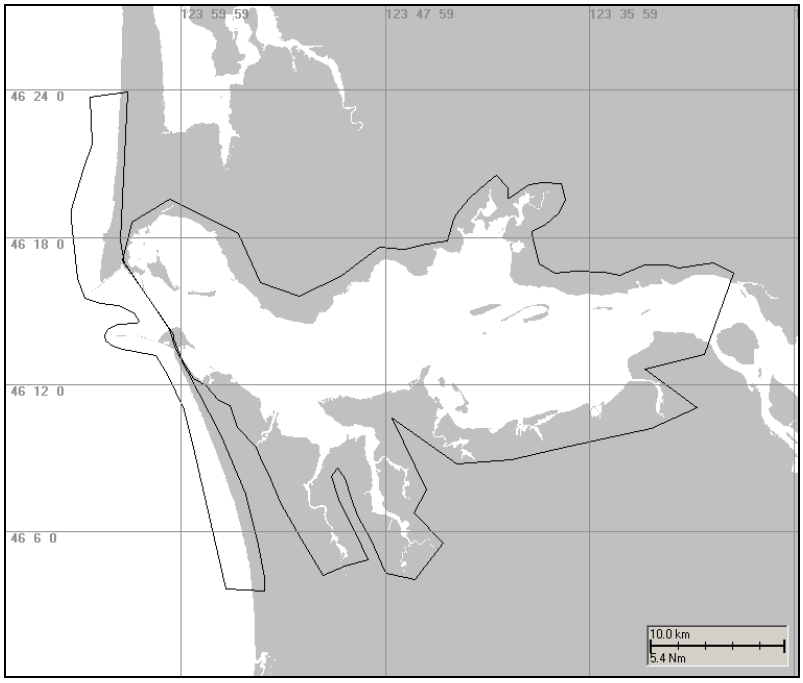


Figure XVIII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

XVIII.C. CURRENT DATA

XVIII.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 two-dimensional current data set for the area surrounding the potential spill locations. The grid used in this study consists of 150 x 150 square water segments (630 x 630 m) with 14378 water cells. The model forcing function consists of surface elevations along the open boundaries. 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 boundaries, while the tidal forcing for the six major harmonic constituents at Astoria, obtained from the NOAA were applied along the open boundary in the Columbia River.

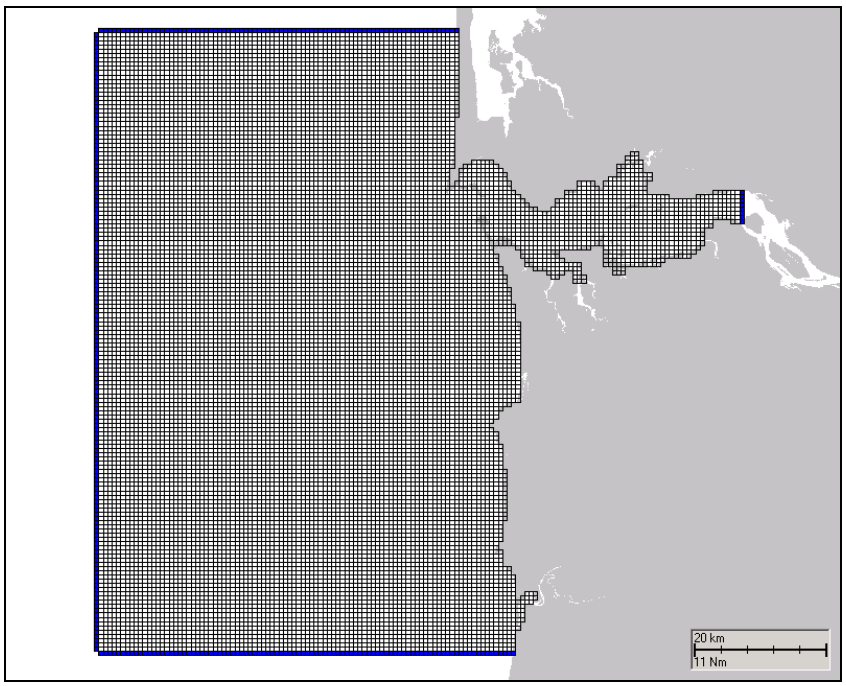


Figure XVIII.C.1-1 Grid used for the hydrodynamic model-generated current data.

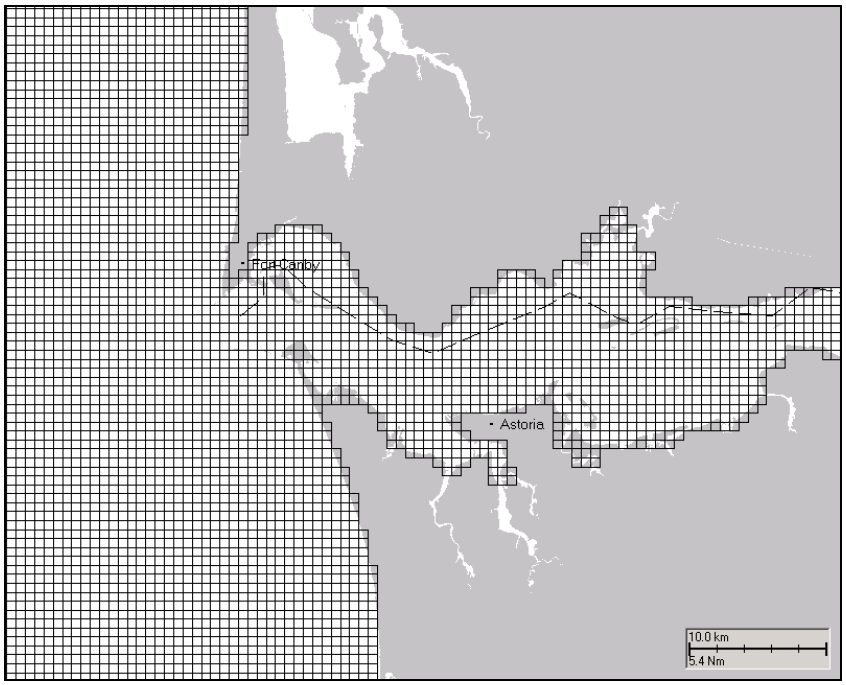


Figure XVIII.C.1-2 Grid used for the hydrodynamic model-generated current data.

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 dominant component, the M_2. Note that 0.5 m/sec = 1 knot.

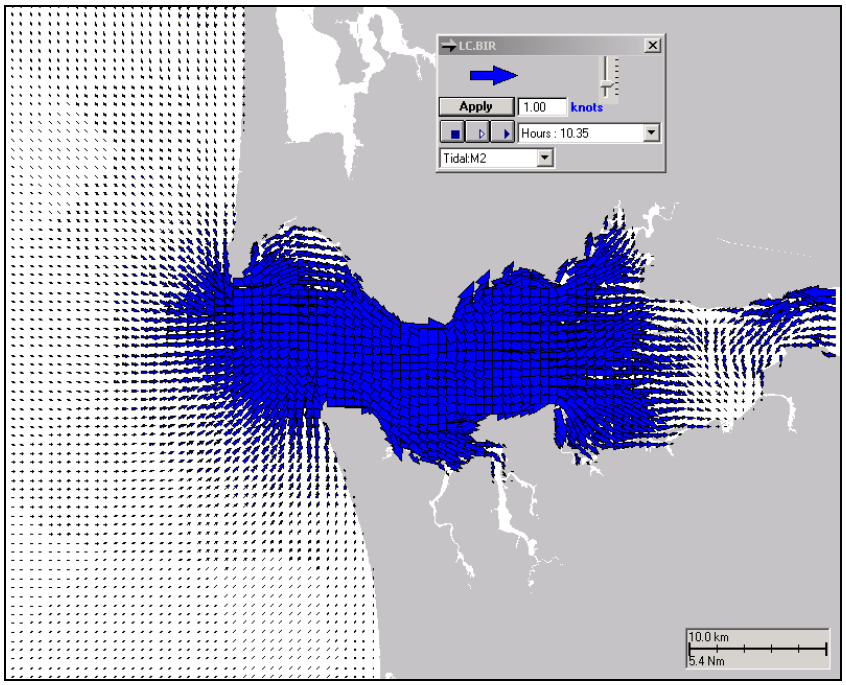


Figure XVIII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the dominant tidal component (M_2) at Astoria.

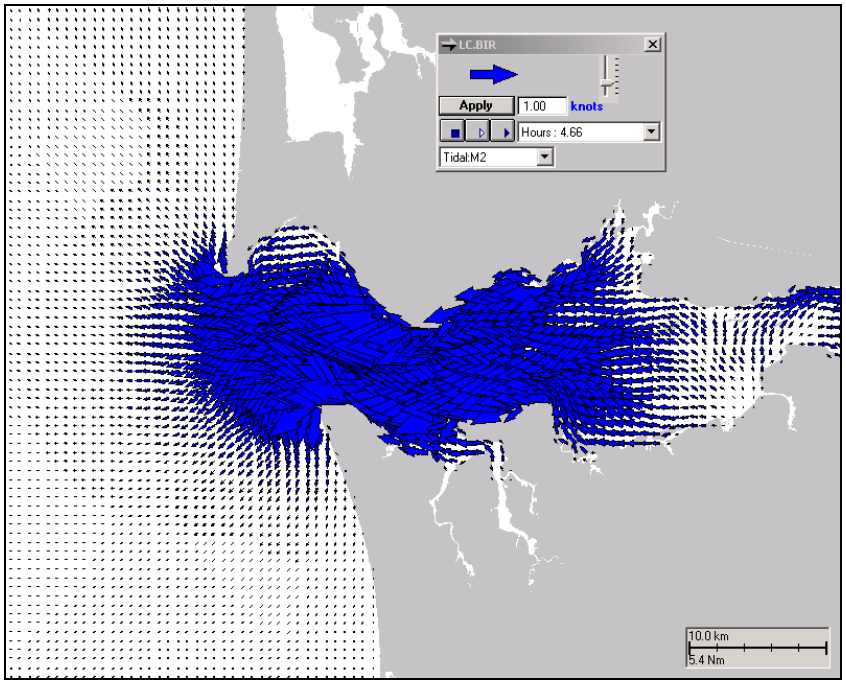


Figure XVIII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the dominant tidal component (M_2) at Astoria.

XVIII.D: OIL PROPERTIES

Table XVIII.D-1. Oil properties for Bunker C assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.9749	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	3180	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27	Jokuty et al. (1999)
Pour Point (deg. C)	7	Whiticar et al. (1994)
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)	0.00	Ostazeski et al. (1997)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.036093	Ostazeski et al. (1997)
Fraction 2-ring aromatics (included in PAHs above)	0.011987	Ostazeski et al. (1997)
Fraction 3-ring aromatics (included in PAHs above)	0.024106	Ostazeski et al. (1997)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.010000	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.037013	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.088894	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	30	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] – Jokuty 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 Bunker C.

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	752
C1-naphthalenes	3.87	4,100
C2-naphthalenes	4.37	7,135
C3-naphthalenes	5.00	5,509
C4-naphthalenes	5.55	2,746
biphenyls	3.9	74
acenaphthylene	4.07	2
acenaphthene	3.92	219
dibenzofuran	4.31	76
Fluorene	4.18	239
C1-fluorenes	4.97	659
C2-fluorenes	5.20	1,144
C3-fluorenes	5.50	1,077

*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 Bunker C (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	346
C1-dibenzothiophene	4.86	1,072
C2-dibenzothiophene	5.50	1,489
C3-dibenzothiophene	5.73	1,176
phenanthrene	4.57	743
anthracene	4.54	88
C1-phenanthrenes/anthracenes	5.14	2,031
C2-phenanthrenes/anthracenes	5.25	2,661
C3-phenanthrenes/anthracenes	6.00	1,825
C4-phenanthrenes/anthracenes	6.51	930
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total $\log(K_{ow}) \leq 5.6$	-	32,162.3

*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	Varied 3 miles off the entrance to Columbia River to Astoria
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	25,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	56 days

Table 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	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table 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 48	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 48	monthly means (see Table XVIII.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 48	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

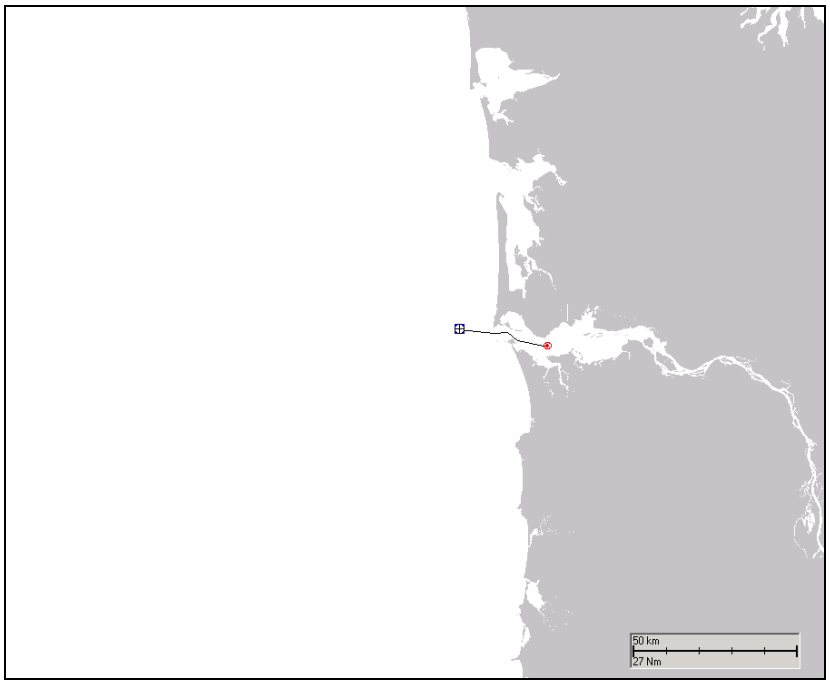


Figure XVIII.E-1 Varied range of spill site from 3 miles off the entrance to Columbia River to Astoria.

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	1992	4	27	7	46.25899	124.14
2	2003	6	2	15	46.25695	124.0241
3	1998	9	21	22	46.25669	124.1068
4	1999	5	14	23	46.2621	124.1848
5	1998	6	7	3	46.24703	124.0073
6	1992	10	15	12	46.2195	123.8852
7	1992	10	10	6	46.22726	123.94
8	1996	8	25	6	46.26409	124.2136
9	1995	6	8	19	46.22235	123.9053
10	1999	5	16	3	46.23129	123.9684
11	1995	7	14	10	46.26252	124.1909
12	1998	8	9	6	46.22681	123.9368
13	1999	7	19	22	46.25677	124.0317
14	1992	11	23	10	46.2634	124.2036
15	1998	7	26	1	46.22501	123.9241
16	2003	8	5	19	46.25501	124.0826
17	1996	8	16	20	46.25542	124.0639
18	1992	8	15	21	46.26431	124.2168
19	1998	10	7	21	46.26283	124.1953
20	1992	10	23	12	46.2361	123.9889
21	1997	5	21	12	46.26326	124.2016
22	1993	8	11	19	46.26248	124.1903
23	2003	11	26	4	46.24379	124.0019
24	1995	8	20	13	46.25746	124.1179
25	1995	9	25	1	46.26085	124.1668
26	2000	8	12	1	46.25863	124.1348
27	2001	8	9	17	46.21856	123.8786
28	1992	11	14	17	46.23075	123.9646
29	1999	6	9	16	46.25178	124.0153
30	1998	8	24	21	46.2607	124.1646
31	1993	12	26	10	46.26389	124.2106
32	1994	6	23	21	46.229	123.9523
33	1998	8	16	15	46.22458	123.9211
34	2002	3	28	0	46.26428	124.2163
35	1996	6	9	9	46.2442	124.0026
36	2003	12	29	7	46.23028	123.9613
37	1995	7	11	22	46.25526	124.0212
38	1994	3	29	20	46.25543	124.0887
39	2001	10	12	5	46.26102	124.1693
40	1993	6	17	23	46.22631	123.9333
41	1996	5	5	23	46.21649	123.864
42	1993	8	21	23	46.22592	123.9305
43	1992	1	30	17	46.22404	123.9172
44	2002	6	4	18	46.25539	124.0646
45	2000	8	25	23	46.25573	124.0929
46	1998	6	30	23	46.25189	124.0155
47	2002	4	22	20	46.25772	124.1217
48	1999	5	16	10	46.26142	124.175
49	1995	11	22	11	46.25658	124.1051
50	1995	11	22	22	46.25574	124.0932

51	2002	3	16	23	46.25531	124.0869
52	1993	10	18	14	46.26202	124.1838
53	1994	8	4	0	46.23925	123.9942
54	1992	1	12	16	46.25826	124.1294
55	1997	2	9	15	46.22852	123.9488
56	2001	7	24	20	46.22318	123.9112
57	2003	12	25	10	46.21848	123.878
58	1999	4	4	7	46.2208	123.8944
59	1998	7	5	23	46.21952	123.8854
60	1995	7	5	10	46.26413	124.2141
61	1995	8	6	7	46.26058	124.163
62	1999	6	14	20	46.24409	124.0024
63	1998	7	15	10	46.23915	123.994
64	1997	8	8	13	46.2449	124.0037
65	1998	10	12	23	46.25489	124.0809
66	1993	10	29	2	46.22201	123.9029
67	1995	12	21	16	46.25525	124.0681
68	1997	9	18	9	46.25705	124.1121
69	1998	5	10	10	46.22297	123.9097
70	2003	1	6	19	46.26426	124.216
71	2000	9	7	16	46.25507	124.0834
72	1994	4	2	17	46.25684	124.0303
73	1997	1	15	6	46.26087	124.1671
74	1997	3	17	20	46.22074	123.894
75	1998	7	2	10	46.26118	124.1715
76	1992	4	6	18	46.21751	123.8712
77	1995	11	12	2	46.26236	124.1886
78	1998	6	7	1	46.25689	124.0288
79	1998	11	11	2	46.21618	123.8618
80	2003	1	17	21	46.21976	123.887
81	1993	1	24	8	46.25565	124.0917
82	2003	12	18	10	46.25608	124.0481
83	1993	9	30	22	46.25697	124.0271
84	1996	7	21	11	46.26419	124.2151
85	1993	6	28	21	46.22986	123.9584
86	1995	5	17	19	46.25716	124.1136
87	2003	1	5	10	46.26	124.1545
88	1998	10	21	21	46.26072	124.1649
89	2000	7	11	18	46.26376	124.2088
90	1994	5	7	12	46.23235	123.9759
91	1994	3	2	21	46.26389	124.2106
92	1997	4	5	18	46.2643	124.2165
93	1998	11	4	5	46.2308	123.965
94	1993	12	24	18	46.25508	124.072
95	1999	6	11	18	46.23027	123.9613
96	1995	7	25	5	46.26187	124.1815
97	1999	2	13	4	46.26317	124.2003
98	1992	2	18	3	46.25831	124.1302
99	2003	10	13	3	46.2607	124.1647
100	1996	8	8	4	46.25504	124.0731

Table XVIII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	C1-HABS.HAB
Grid W edge	125° 24.1'W
Grid S edge	45° 26.4' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^o N
Cell size (m) west-east	140.19
Cell size (m) south-north	199.80
# cells west-east	1,122
# cells south-north	867
Water cell area (m^2)	28,010.09
Shore cell length (m)	167.36
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 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	10
February	10	8	10
March	10	8	10
April	11	8	10
May	12	8	10
June	14	8	10
July	14	7	5
August	14	7	5
September	14	7	5
October	13	7	10
November	12	7	10
December	10	7	10

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.

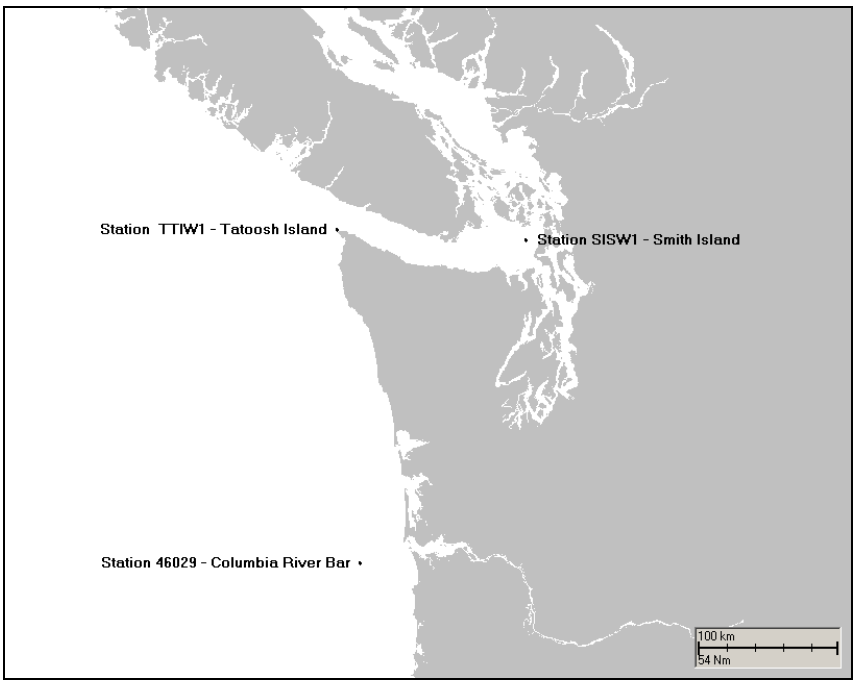


Figure XVIII.E-2. Wind Station Locations.

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 XIX: Model Results for Runs Assuming No Response for Lower Columbia River – Bunker C

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

XIX.A. Introduction 1
XIX.B. Maps of Exposure Probability and Time First Exposed 1
XIX.C. Statistics for All Model Runs 3
XIX.D. Shoreline Areas Exposed by Shore Type 6
XIX.E. Exposure for Representative Individual Model Runs. 8
XIX.F. Estimated Biological Impacts: Wildlife 10
XIX.G. Estimated Biological Impacts: Fish and Invertebrates 13
XIX.H. Estimated NRDA Costs: Habitat Restoration Costs 15
XIX.I. Estimated NRDA Costs: Washington Compensation schedule 18

List of Figures

Figure XIX.B-1. Lower Columbia River – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure XIX.B-2. Lower Columbia River – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. 2
Figure XIX.C-1. Lower Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 5
Figure XIX.C-2. Lower Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill. 5
Figure XIX.E-1. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 8
Figure XIX.E-2. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Baker Bay (estuary at entrance of river). 9
Figure XIX.E-3. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Columbia National Wildlife Refuge. 9

List of Tables

Table IV.C-1. Lower Columbia River – Bunker C, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 4
Table XIX.D-1. Lower Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 6
Table XIX.D-2. Lower Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 6
Table XIX.D-3. Lower Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 7
Table XIX.D-4. Lower Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 7
Table XIX.F-1. Lower Columbia River – Bunker C, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose. 11
Table XIX.F-2. Lower Columbia River – Bunker C, No mechanical removal: Wildlife injury (as numbers lost). 12
Table XIX.G-1. Lower Columbia River – Bunker C, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column. 14
Table XIX.G-2. Lower Columbia River – Bunker C, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 14
Table XIX.H-1. Lower Columbia River – Bunker C, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 16
Table XIX.H-2. Lower Columbia River – Bunker C, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 17
Table XIX.I-1. Lower Columbia River – Bunker C, No mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 18

XIX.A. INTRODUCTION

The results of the stochastic scenario for the Lower Columbia River – Bunker C 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).

XIX.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)

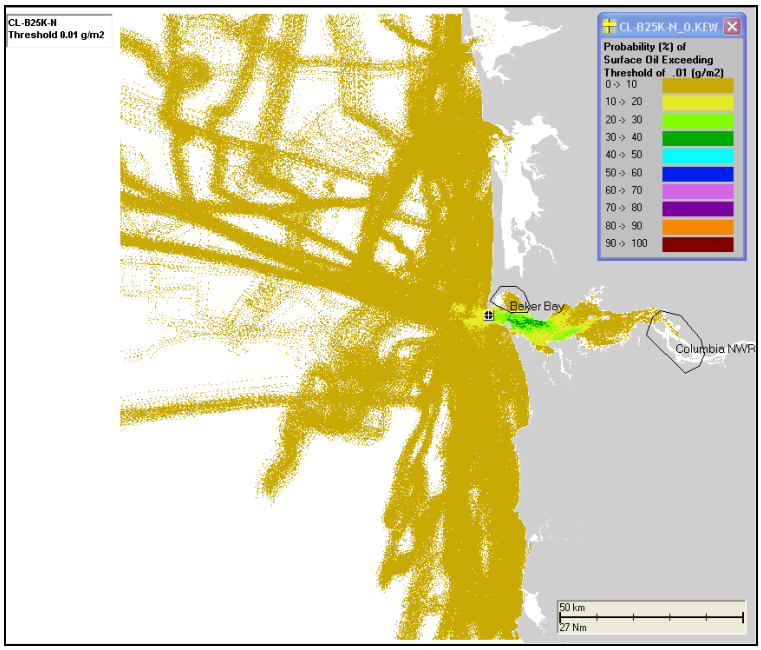


Figure XIX.B-1. Lower Columbia River – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

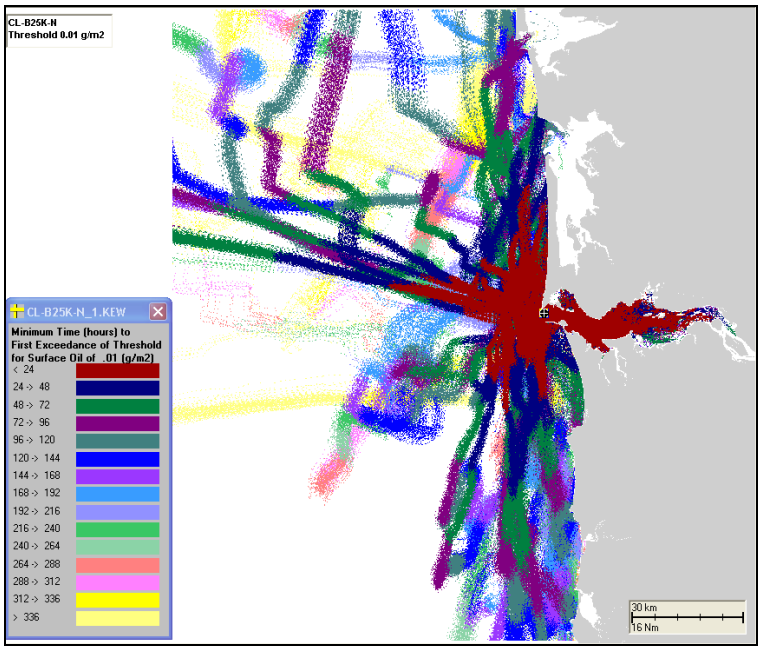


Figure XIX.B-2. Lower Columbia River – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed on the Lower Columbia River region, maximum water column exposure of dissolved aromatic concentration for this scenario never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

XIX.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 IV.C-1. Lower Columbia River – Bunker C, 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)	12	10	31	0	9	31	49
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	12	10	31	0	9	31	49
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	1,184	915	3,013	0	897	2,949	4,683
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	1,184	915	3,013	0	897	2,949	4,683
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	1,184	914	3,013	0	897	2,947	4,683
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	1,184	914	3,012	0	897	2,943	4,683
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	1,176	915	3,006	0	894	2,943	4,683
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	491	399	1,288	0	373	1,271	1,604
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 (%)	54.59	23.93	102.46	11	63.33	77.54	81.96
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	31.2448	20.4640	72.1728	0	33.9007	61.9695	63.9030
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	5.20	3.94	13.09	0	5.13	15.43	17.85

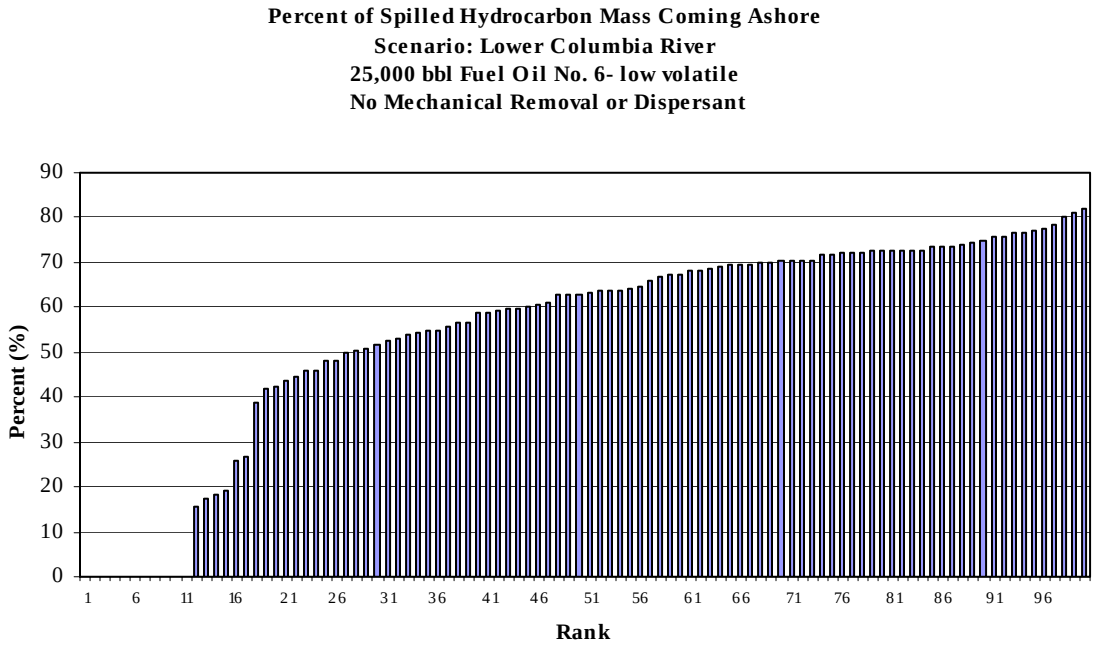


Figure XIX.C-1. Lower Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

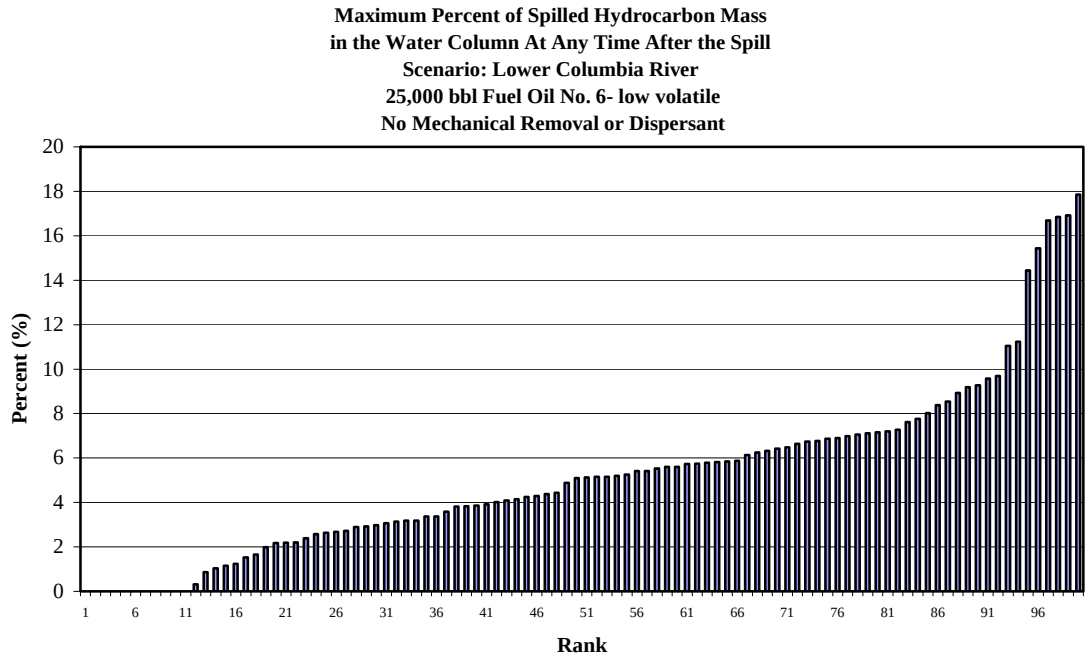


Figure XIX.C-2. Lower Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

XIX.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 XIX.D-1. Lower Columbia River – Bunker C, 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	615,056	2,510	0	85,355	0	527,191	0
95th	1,575,045	66,275	0	173,220	0	1,335,550	0
Maximum	1,737,721	100,919	91,380	346,440	281,168	1,511,280	0
Mean	632,378	36,743	5,483	127,279	2,812	460,062	0
Std. Dev.	491,138	30,275	14,771	79,477	28,117	465,411	0
Mean + 2 Std. Dev.	1,614,654	97,293	35,025	286,233	59,046	1,390,884	0

Table XIX.D-2. Lower Columbia River – Bunker C, 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	615,056	2,510	0	85,355	0	527,191	0
95th	1,567,514	51,213	0	110,459	0	1,405,842	0
Maximum	1,735,211	100,919	91,380	341,419	281,168	1,511,280	0
Mean	627,307	36,743	5,483	125,722	2,812	456,547	0
Std. Dev.	487,593	30,275	14,771	78,622	28,117	462,382	0
Mean + 2 Std. Dev.	1,602,493	97,293	35,025	282,966	59,046	1,381,311	0

Table XIX.D-3. Lower Columbia River – Bunker C, 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	525,685	45,690	28,117	100,417	0	351,461	0
95th	1,427,934	74,811	0	17,573	0	1,335,550	0
Maximum	1,596,635	100,919	90,208	228,449	281,168	1,476,134	0
Mean	549,863	36,692	5,436	89,145	2,812	415,778	0
Std. Dev.	440,264	30,244	14,663	55,600	28,117	423,290	0
Mean + 2 Std. Dev.	1,430,391	97,180	34,762	200,345	59,046	1,262,358	0

Table XIX.D-4. Lower Columbia River – Bunker C, 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	82,342	47,196	0	0	0	35,146	0
95th	353,971	2,510	0	0	0	351,461	0
Maximum	452,882	89,873	66,777	47,698	0	421,753	0
Mean	121,421	33,042	3,878	3,314	0	81,187	0
Std. Dev.	120,011	27,431	10,752	8,747	0	112,447	0
Mean + 2 Std. Dev.	361,443	87,904	25,382	20,808	0	306,081	0

XIX.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 Baker Bay (estuary at entrance of river); and
3. the worst case run for impacts at the Columbia National Wildlife Refuge.

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.

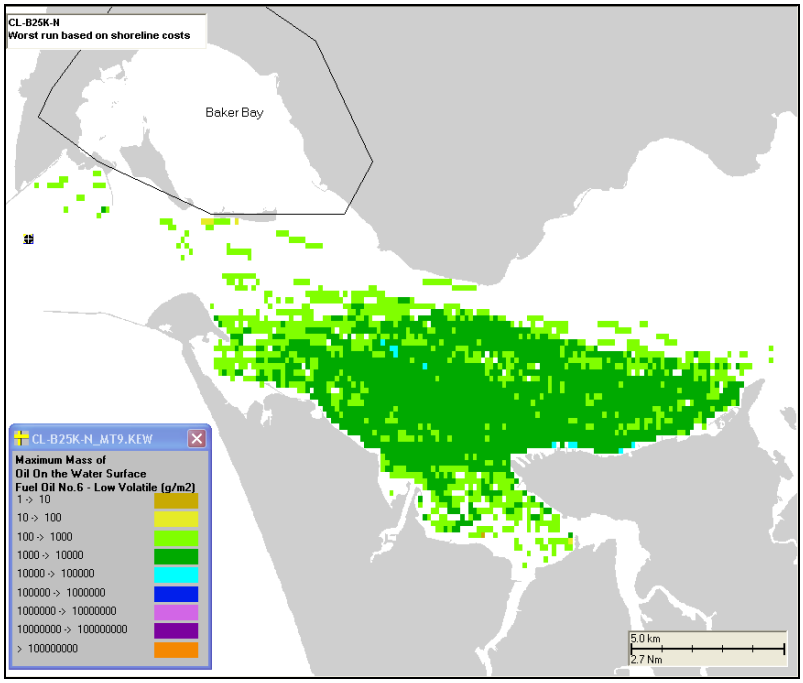


Figure XIX.E-1. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

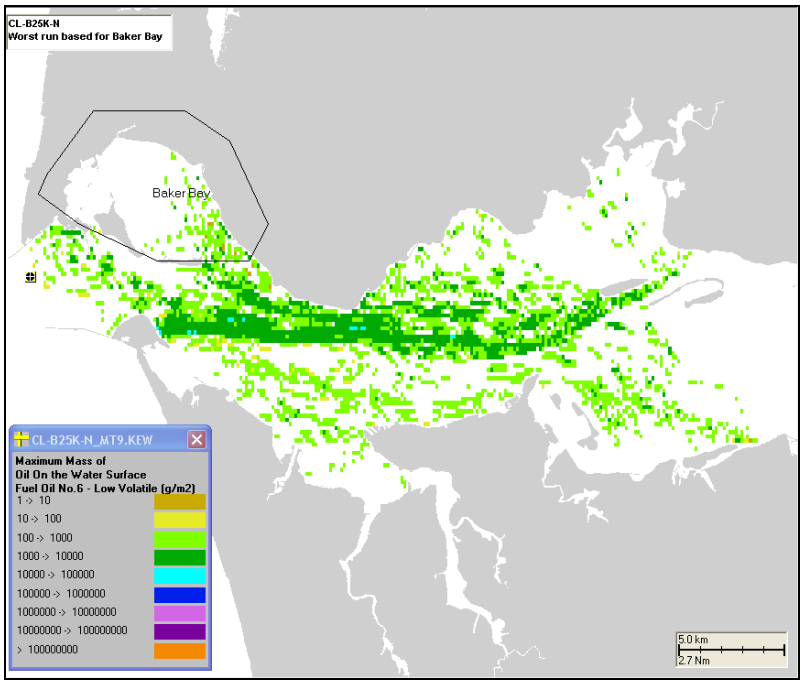


Figure XIX.E-2. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Baker Bay (estuary at entrance of river).

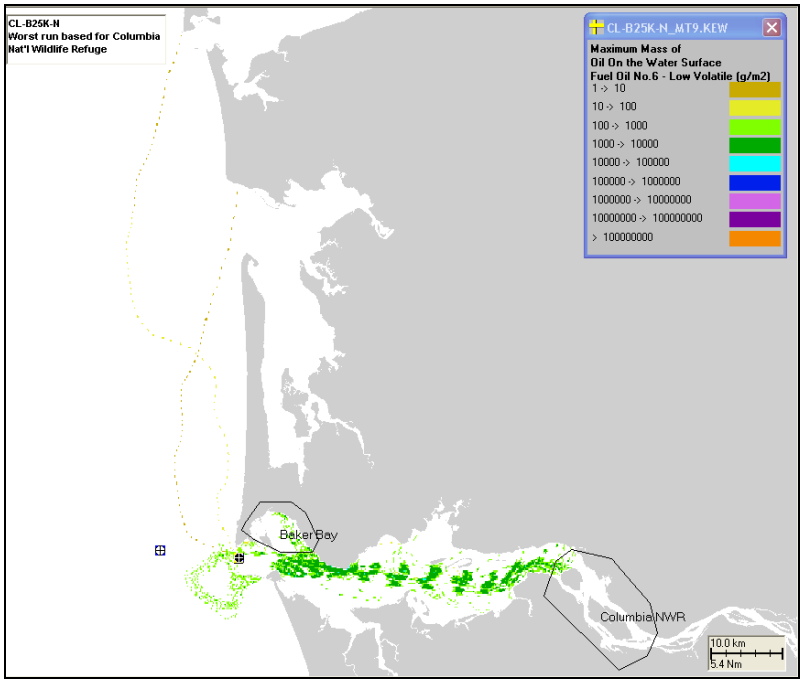


Figure XIX.E-3. Lower Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Columbia National Wildlife Refuge.

XIX.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table XIX.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 XIX.F-1. Lower Columbia River – Bunker C, 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	0.00	-7,791.51	9,360.75	0.9728	0.9863
Seabirds	0.00	-491.87	1,103.58	0.8950	0.9460
Wading birds	0.00	26.81	46.06	0.2789	0.5281
Shorebirds	0.00	85.97	166.37	0.2329	0.4826
Raptors[2]	0.00	0.00	0.00	0.0000	0.0000
Kingfishers	0.00	0.02	0.06	0.6437	0.8023
Cetaceans[2]	0.00	0.00	0.00	0.0000	0.0000
Pinnipeds (seals)	0.00	23.23	171.15	0.9682	0.9840
Other mammals[2]	0.00	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 XIX.F-2. Lower Columbia River – Bunker C, No 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	2,605	917	3	-	-	-	2	-	8,690	8,688	2.16
50th Percentile	28,111	2,755	29	3,259	-	-	6	-	39,607	39,600	6.42
95th Percentile	150,560	11,582	119	16,059	-	-	27	-	163,159	163,133	26.85
Mean	50,761	4,380	42	5,166	-	-	10	-	60,359	60,349	10.18
Std Dev (SD)	48,632	3,514	58	8,248	-	-	8	-	50,193	50,185	8.13
Mean - 2SD	-	-	-	-	-	-	-	-	-	-	-
Mean + 2SD	148,025	11,408	159	21,661	-	-	26	-	160,744	160,718	26.45

XIX.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XIX.G-1. Lower Columbia River – Bunker C, 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	2.64E+00	-9.75	9.87	0.4035	0.6352
Total large pelagic fish[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Total demersal fish	4.11E-02	0.26	0.17	0.3673	0.6060
Total demersal invertebrates[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Total mollusks[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 fishes and invertebrates (i.e., the regression's intercept) was used to estimate injuries for the additional 88 stochastic runs.
[2] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table XIX.G-2. Lower Columbia River – Bunker C, 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	-	-	0.26	-	-	-	0
50th Percentile	3.73	-	0.47	-	-	1,001	1,005
95th Percentile	28.46	-	0.85	-	-	2,686	2,716
Mean	5.96	-	0.47	-	-	1,086	1,092
Std Dev (SD)	8.54	-	0.16	-	-	860	868
Mean - 2SD	-	-	0.15	-	-	-	0
Mean + 2SD	23.04	-	0.79	-	-	2,805	2,829

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 injuries used to calculate habitat restoration costs are expressed as wet weights used to calculate habitat restoration costs 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.

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 XIX.H-1. Lower Columbia River – Bunker C, 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	-	3.7	28.5	6.0	-	23.0
Large pelagic fish	-	-	-	-	-	-
Demersal fish	0.3	0.5	0.9	0.5	0.1	0.8
Decapods	-	-	-	-	-	-
Molluscs	-	1,001	2,686	1,086	-	2,805
Birds:						
Waterfowl (# * kg each)	2,852	30,781	164,863	55,583	-	162,088
Seabirds (# * kg each)	612	1,839	7,731	2,924	-	7,615
Waders (# * kg each)	2	19	80	28	-	106
Shorebirds (# * kg each)	-	2,175	10,719	3,448	-	14,459
Raptors (# * kg each)	-	-	-	-	-	-
Other wildlife:						
Sea otters, other mammals	-	-	-	-	-	-
Pinnipeds	1.4	4.3	17.9	6.8	-	17.7
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	0	1,005	2,716	1,092	0	2,829
Subtotal birds	3,466	34,815	183,393	61,983	-	184,267
Subtotal other wildlife	1	4	18	7	-	18
Total all species	3,468	35,824	186,127	63,082	0	187,113

Table XIX.H-2. Lower Columbia River – Bunker C, 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)	7.2	51.3	260.3	89.5	85.7	0.0	260.9
Saltmarsh Area (acres)	17.9	126.9	643.2	221.3	211.7	0.0	644.7
Saltmarsh Cost (millions of 2004$)	3.3	23.8	120.5	41.4	39.7	0.000016	120.8
Eelgrass Area (m^2)	4.5	32.1	162.7	56.0	53.5	0.0	163.0
Eelgrass Area (acres)	11.2	79.3	401.9	138.3	132.3	0.0	402.9
Eelgrass Cost (millions of 2004$)	1.3	9.5	48.0	16.5	15.8	0.000006	48.1

XIX.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XIX.I-1. Lower Columbia River – Bunker C, 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.)	0.00*	25.82	28.14	18.95	0.00	42.43
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	0.0	27.1	29.5	19.9	0.0	44.6

* Some runs had trajectories completely outside WA jurisdiction, and so the vulnerability score was zero.

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 XX: Results of Alternative Response Scenarios for Lower Columbia River – Bunker C

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

XX.A. Introduction 1
XX.B. Oil Fate Over Time 3
XX.C. Estimated Biological Impacts: Wildlife 42
XX.D. Estimated Biological Impacts: Fish and Invertebrates 46
XX.E. Estimated NRDA Costs: Habitat Restoration Costs 48
XX.F. Estimated NRDA Costs: Washington Compensation schedule 57

List of Figures

Figure XX.A-1 Sensitive sites for location: Lower Columbia River..... 2
Figure XX.B-1 Lower Columbia River - Bunker C: 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 XX.B-2 Lower Columbia River - Bunker C: 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 XX.B-3 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). 6
Figure XX.B-4 Lower Columbia River - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Baker Bay..... 7
Figure XX.B-5 Lower Columbia River - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Baker Bay. 8
Figure XX.B-6 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Baker Bay. 9
Figure XX.B-7 Lower Columbia River - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Baker Bay.... 10
Figure XX.B-8 Lower Columbia River - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Columbia National Wildlife RefugeColumbia National Wildlife Refuge. 11
Figure XX.B-9 Lower Columbia River - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Columbia National Wildlife RefugeColumbia National Wildlife Refuge..... 12
Figure XX.B-10 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Columbia National Wildlife Refuge..... 13

List of Tables

Table XX.B-1 Lower Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 14
Table XX.B-2 Lower Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 16
Table XX.B-3 Lower Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 18
Table XX.B-4 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost)..... 20
Table XX.B-5 Lower Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker Bay. 22
Table XX.B-6 Lower Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker Bay. ... 24
Table XX.B-7 Lower Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker Bay. ... 26
Table XX.B-8 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker Bay. 28
Table XX.B-9 Lower Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge. 30
Table XX.B-10 Lower Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge. 32
Table XX.B-11 Lower Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge. 34
Table XX.B-12 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge. 36
Table XX.B-13 Lower Columbia River - Bunker C, 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. ... 38
Table XX.B-14 Lower Columbia River - Bunker C, 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. 39
Table XXB-15 Lower Columbia River - Bunker C, 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. 40

Table XX.B-16 Lower Columbia River - Bunker C, 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. 41
Table XX.C-1 Lower Columbia River - Bunker C, no removal: Wildlife injury (as numbers lost)..... 42
Table XX.C-2 Lower Columbia River - Bunker C, federal mechanical removal: Wildlife injury (as numbers lost). 43
Table XX.C-3 Lower Columbia River - Bunker C, WA state mechanical removal: Wildlife injury (as numbers lost). 44
Table XX.C-4 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 45
Table XX.D-1. Lower Columbia River - Bunker C, no removal: Fish and invertebrate injury (as biomass lost in kg). 46
Table XX.D-2. Lower Columbia River - Bunker C, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 46
Table XX.D-3. Lower Columbia River - Bunker C, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XX.D-4. Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XX.E-1. Lower Columbia River - Bunker C, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 49
Table XX.E-2. Lower Columbia River - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration..... 50
Table XX.E-3. Lower Columbia River - Bunker C, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 51
Table XX.E-4. Lower Columbia River - Bunker C, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 52
Table XX.E-5. Lower Columbia River - Bunker C, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 53
Table XX.E-6. Lower Columbia River - Bunker C, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 54
Table XX.E-7. Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 55
Table XX.E-8. Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 56
Table XX.F-1. Lower Columbia River - Bunker C, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 57
Table XX.F-2. Lower Columbia River - Bunker C, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 57

Table XX.F-3. Lower Columbia River - Bunker C, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 57
Table XX.F-4. Lower Columbia River - Bunker C, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 58

XX.A. INTRODUCTION

The results of the alternate response scenarios for the Lower Columbia River – Bunker C 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Baker Bay; and
3. the worst case run for impacts at the Columbia National Wildlife Refuge.

Locations of the sensitive sites are shown in Figure XX.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.

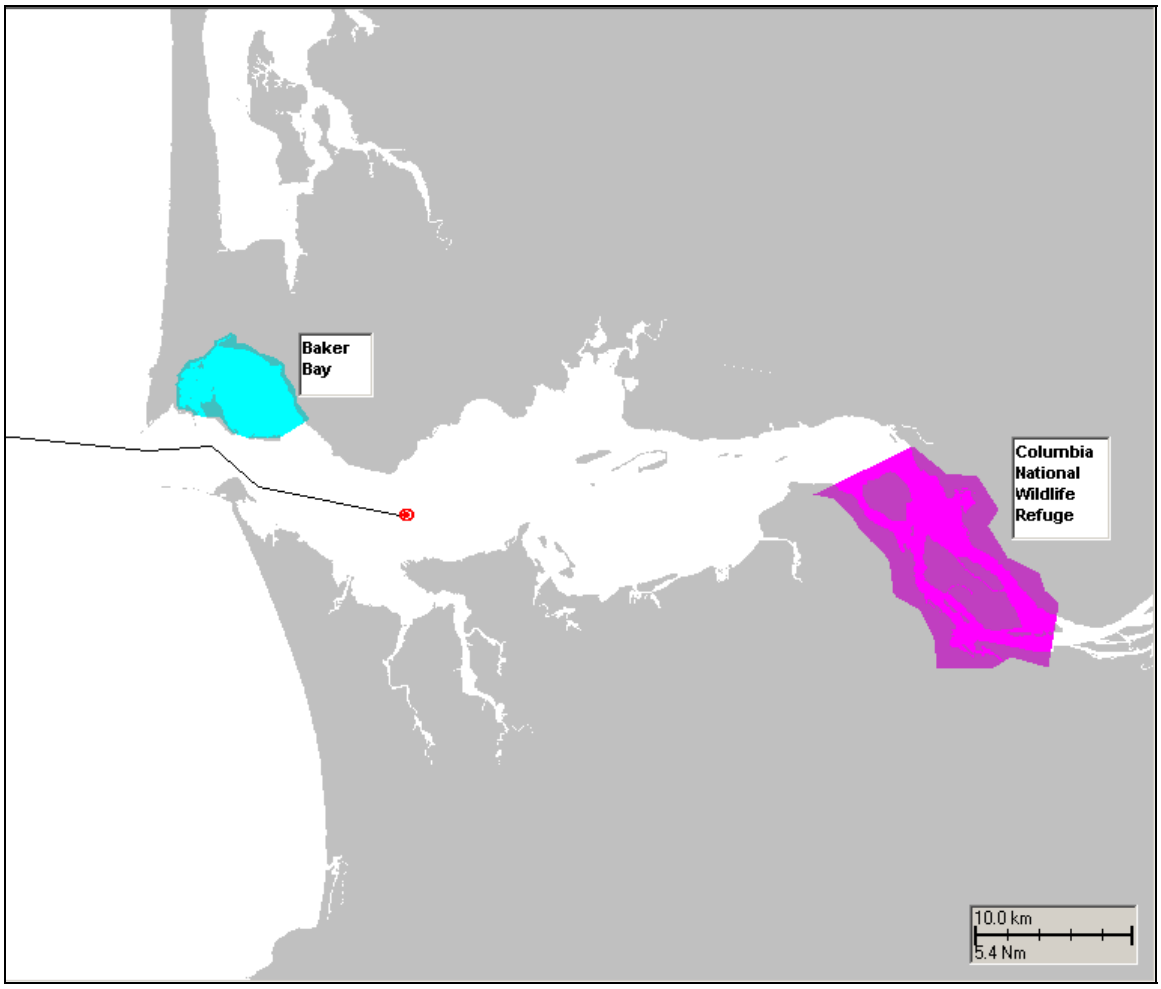


Figure XX.A-1 Sensitive sites for location: Lower Columbia River.

XX.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XX.B-1 to XX.B-12 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 XX.B-1 to XX.B-11 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 XX.B-13 to XX.B-16 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 Etkin 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.

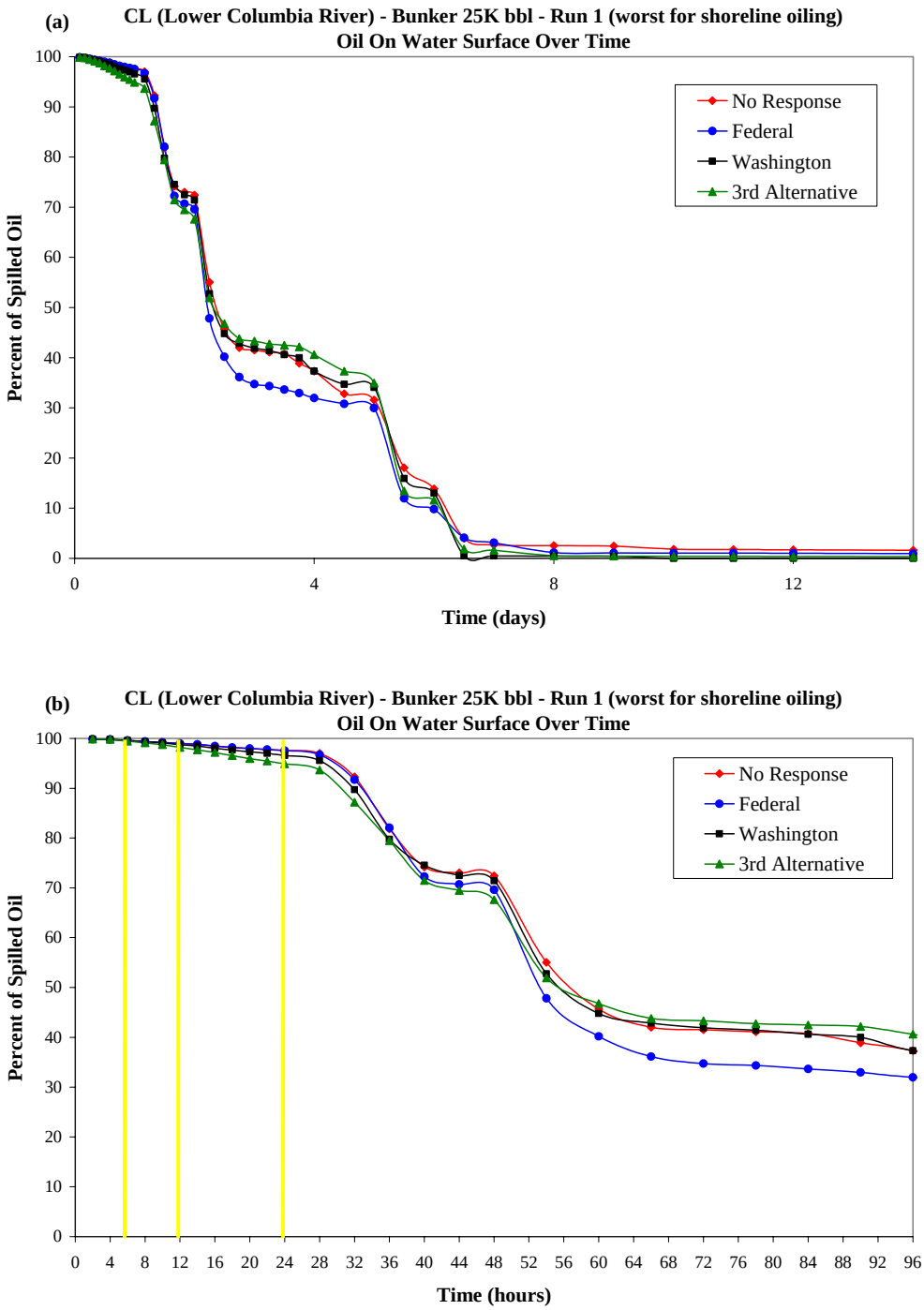
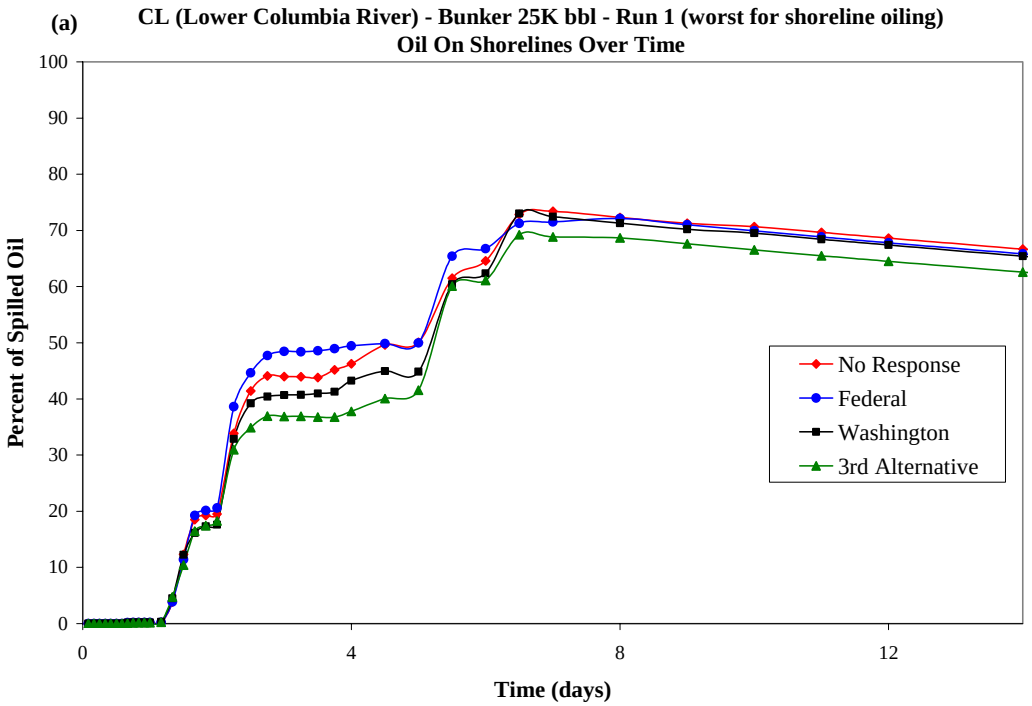


Figure XX.B-1 Lower Columbia River - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



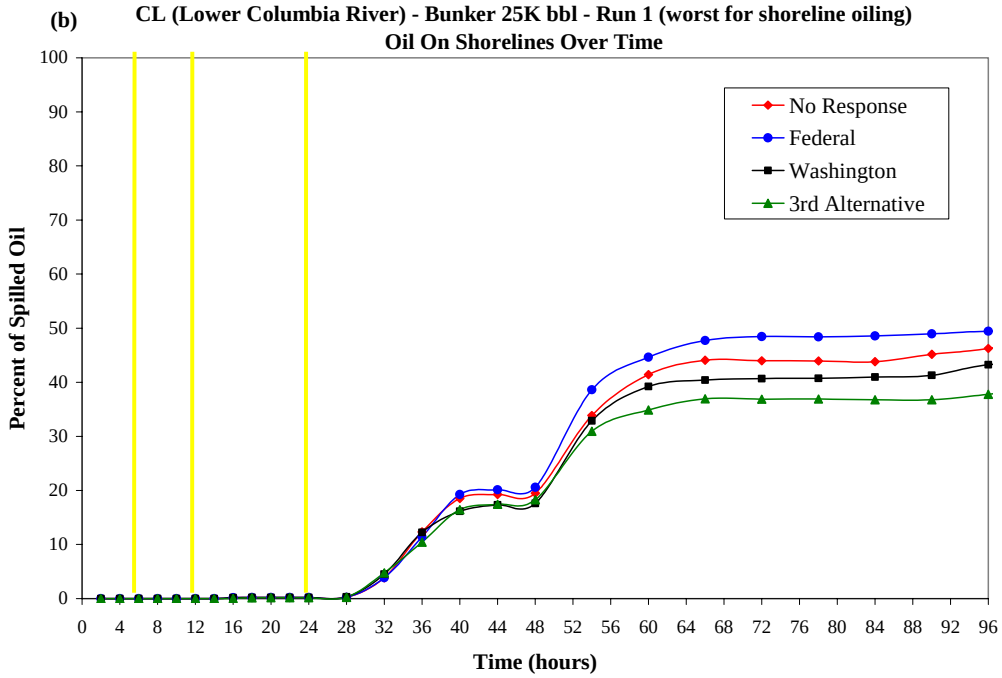
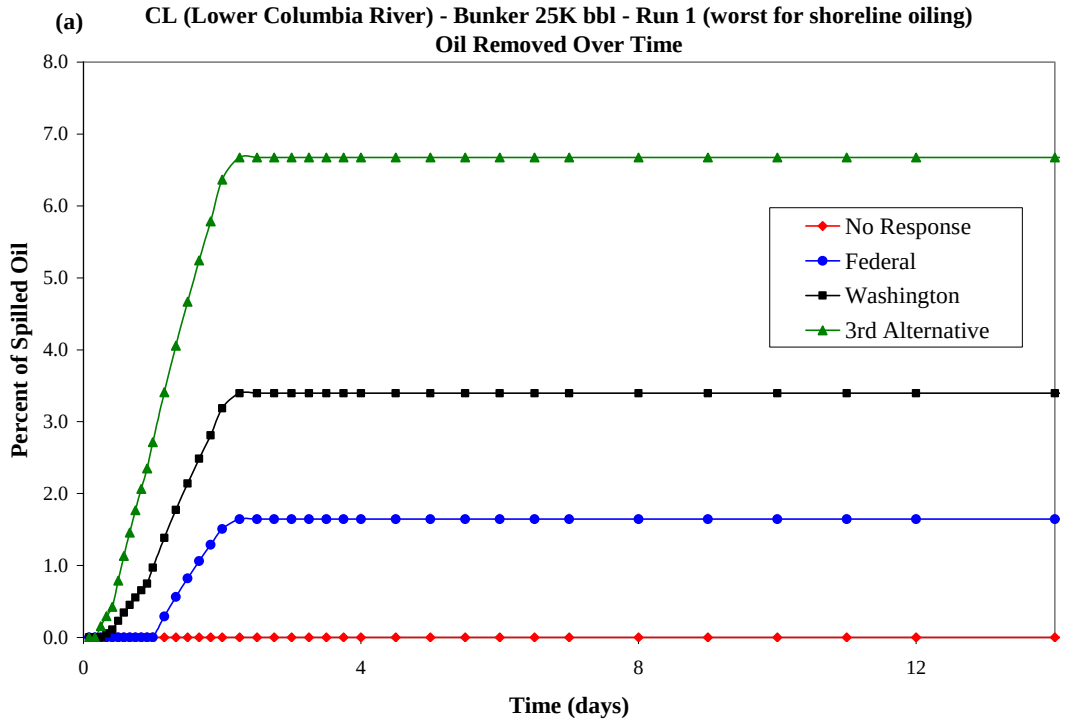


Figure XX.B-2 Lower Columbia River - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



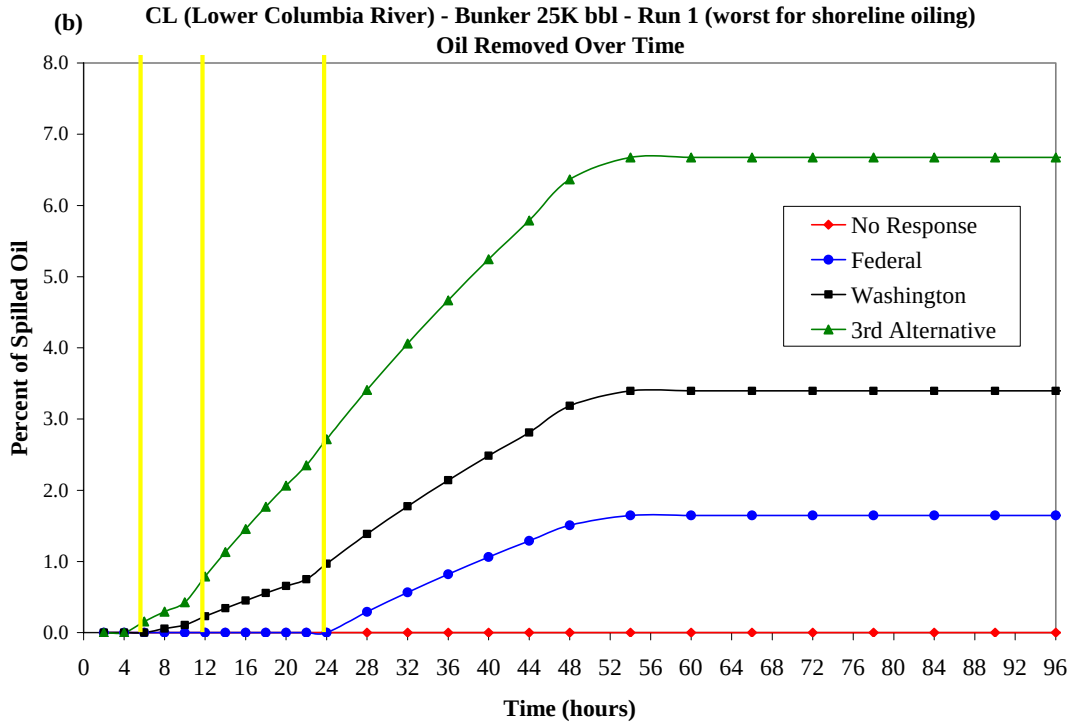
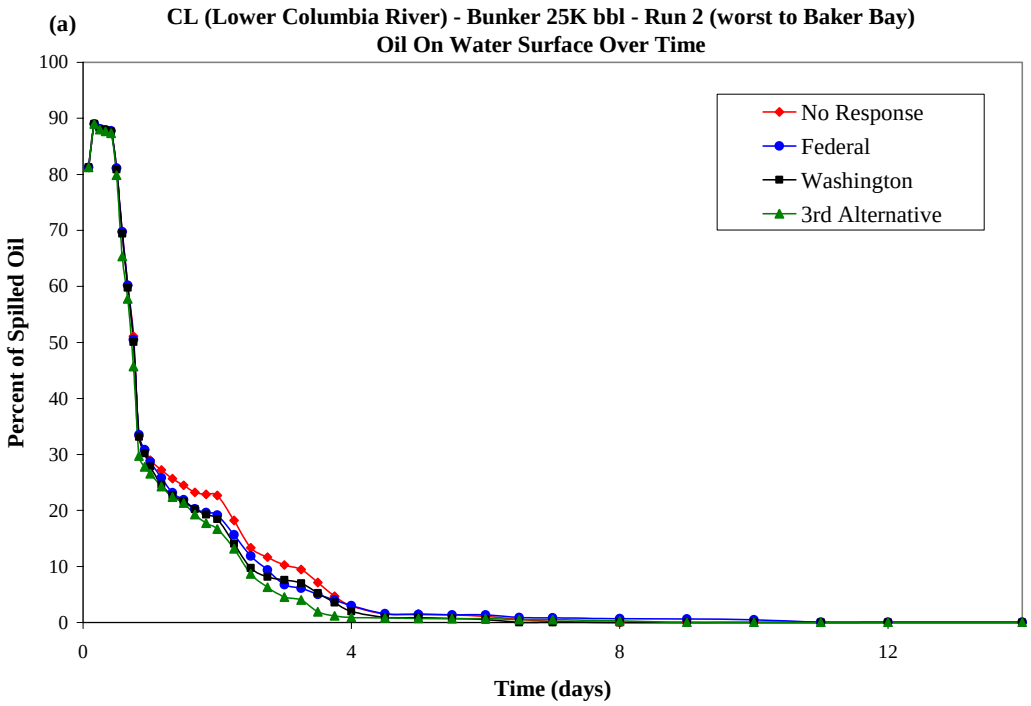


Figure XX.B-3 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



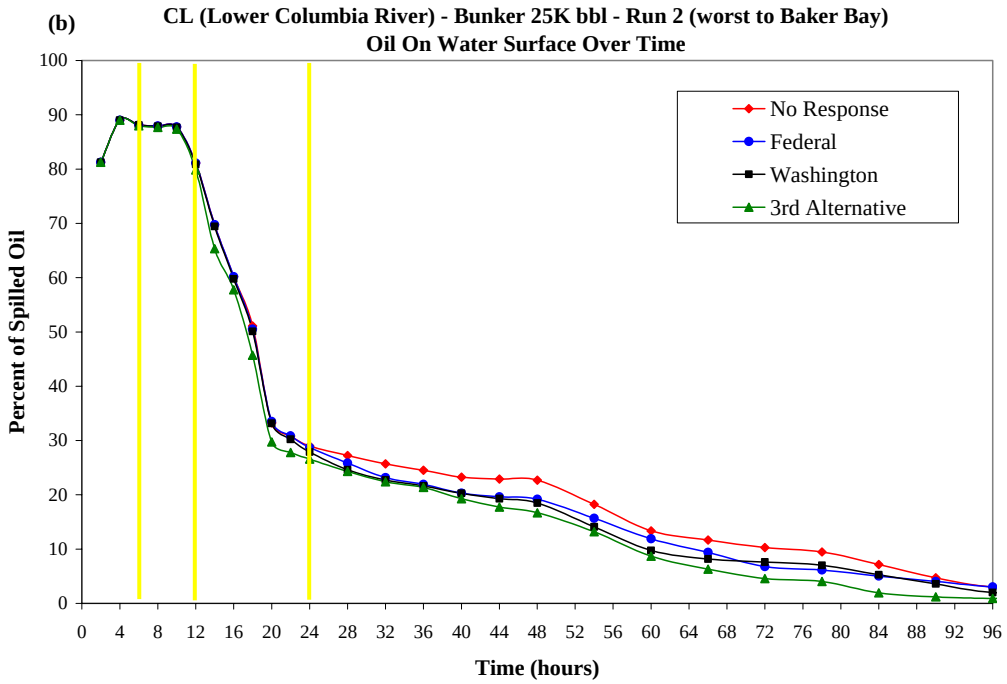


Figure XX.B-4 Lower Columbia River - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Baker Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

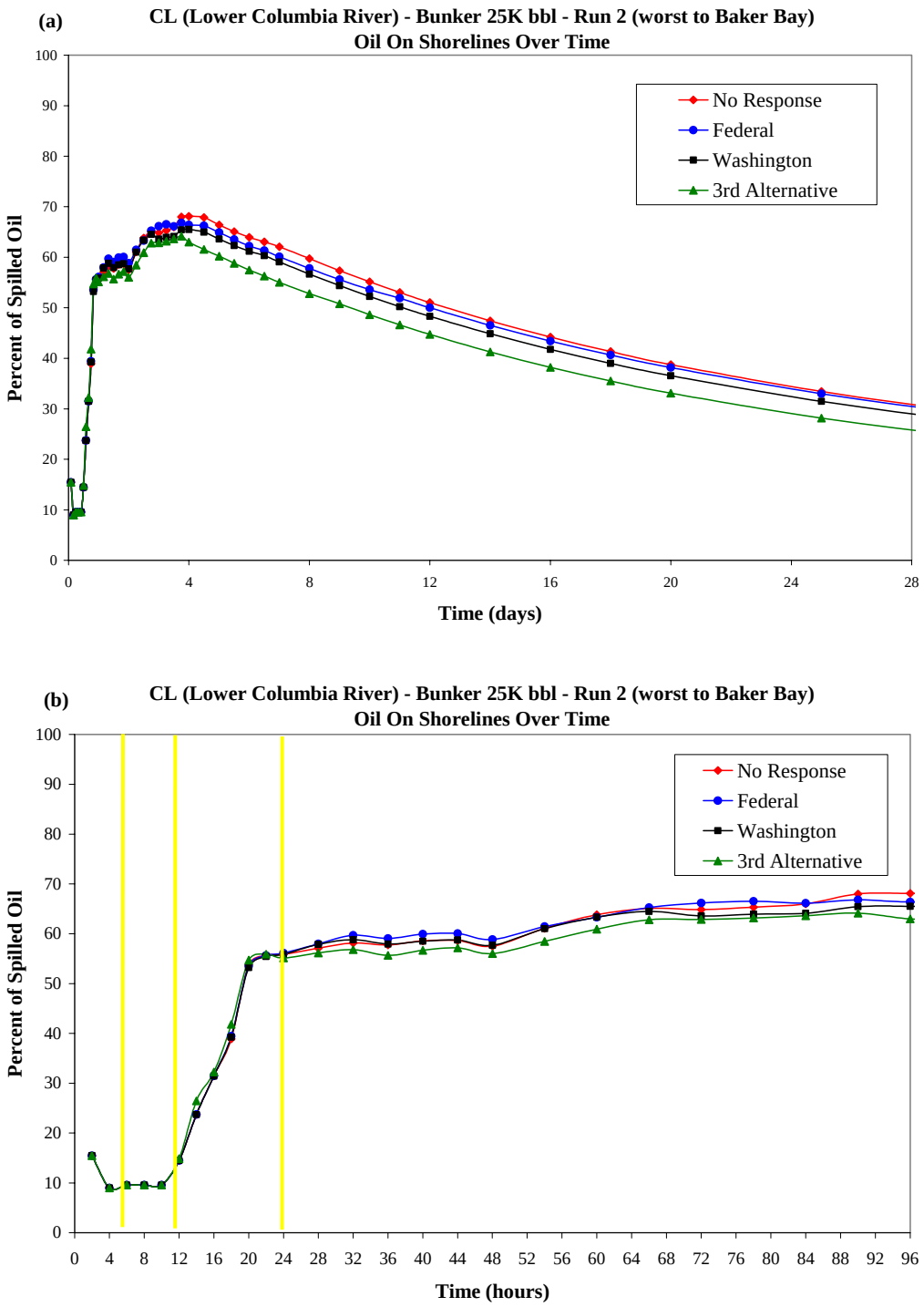
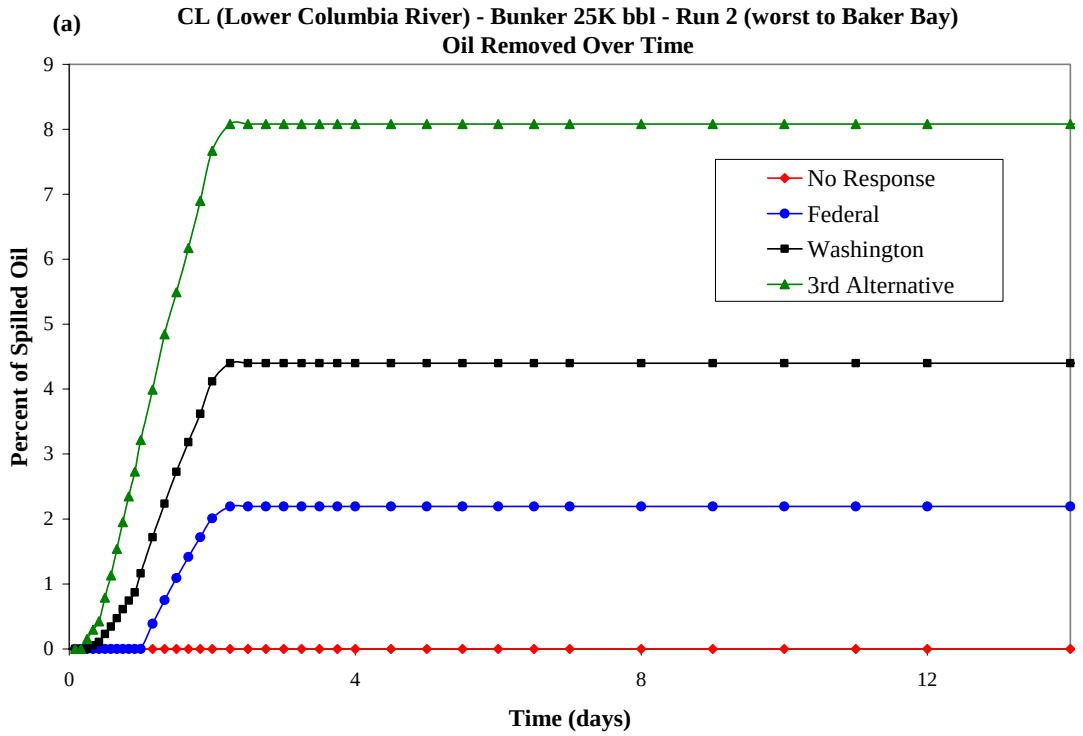


Figure XX.B-5 Lower Columbia River - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Baker Bay. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



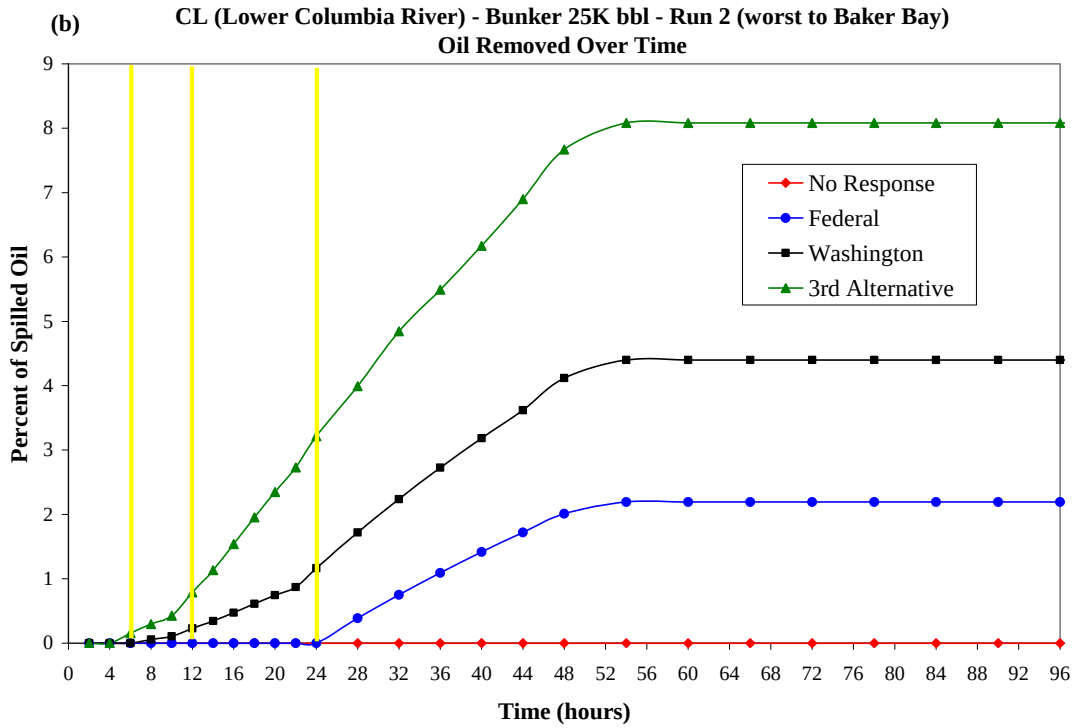
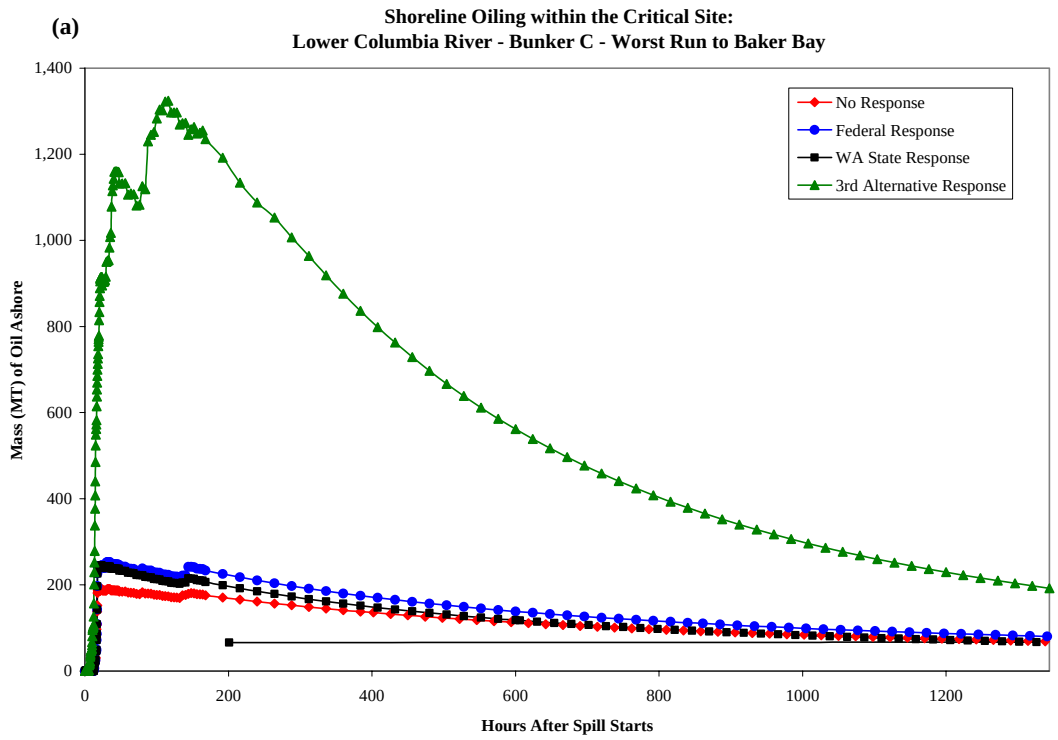


Figure XX.B-6 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Baker Bay. Part b of this figure is a subset of Part a.



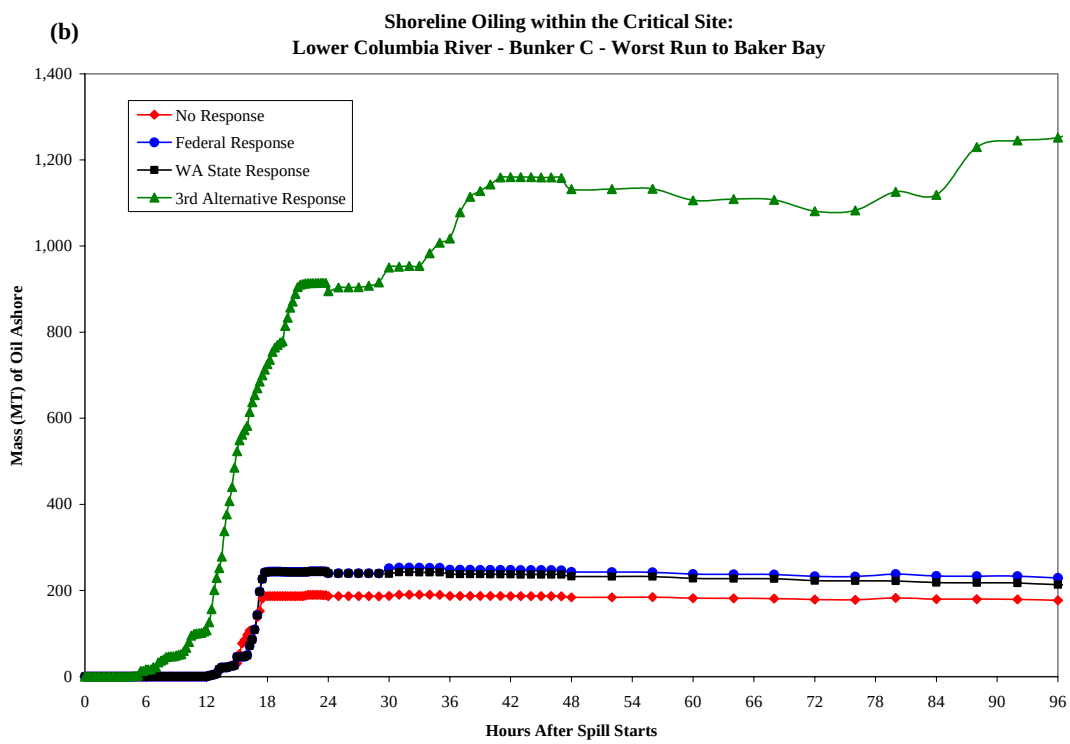


Figure XX.B-7 Lower Columbia River - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Baker Bay. Part b of this figure is a subset of Part a.

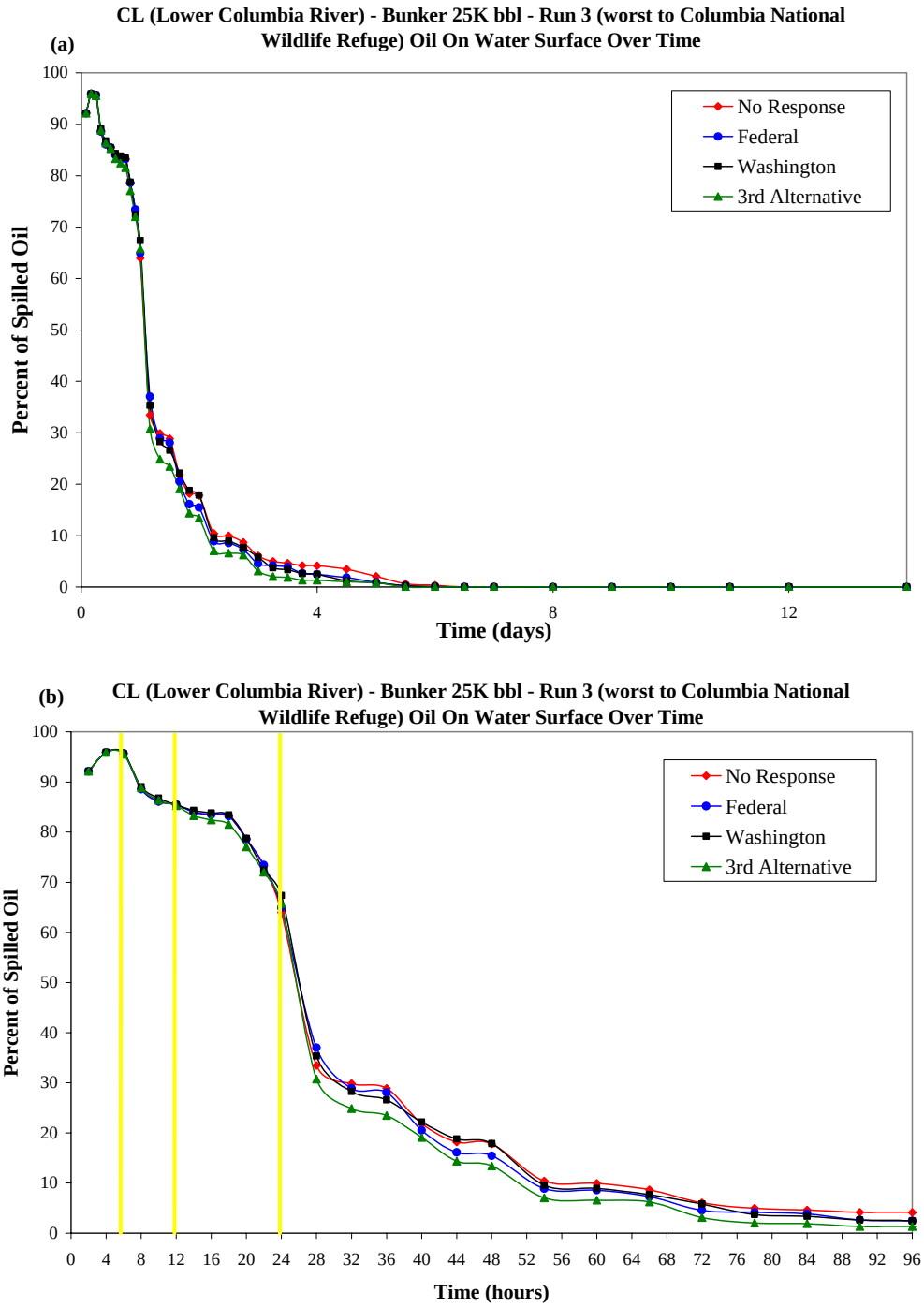
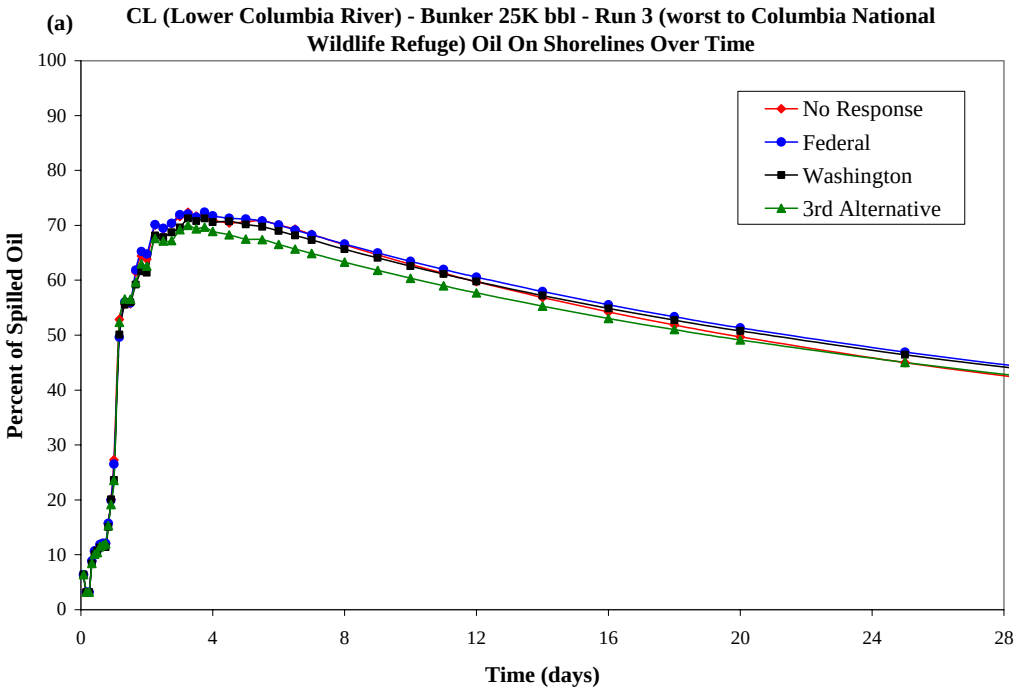


Figure XX.B-8 Lower Columbia River - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Columbia National Wildlife RefugeColumbia National Wildlife Refuge. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



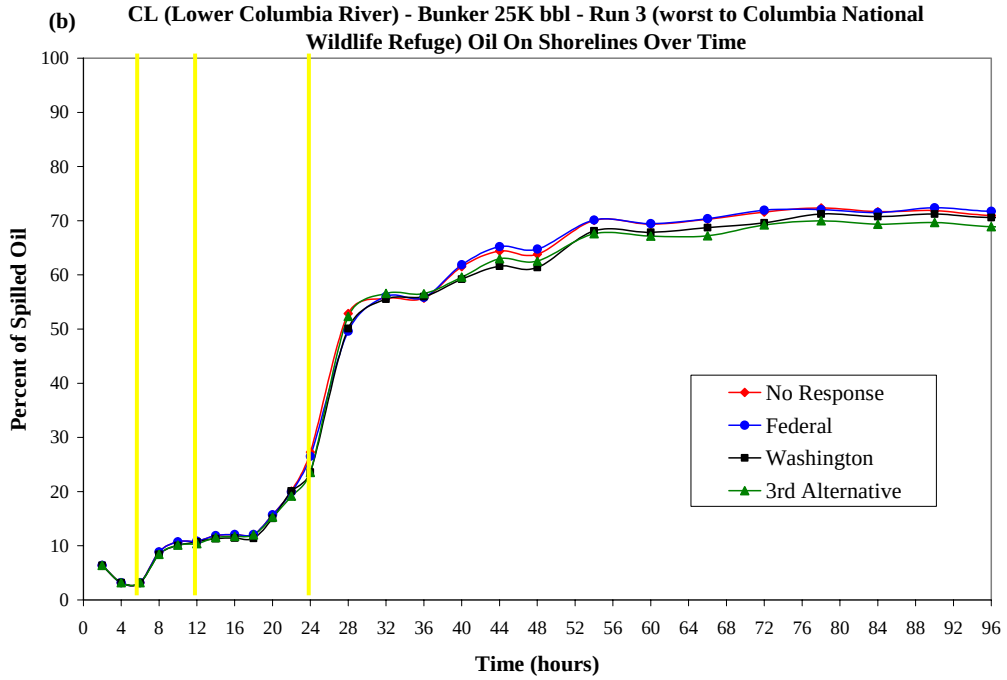


Figure XX.B-9 Lower Columbia River - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Columbia National Wildlife RefugeColumbia National Wildlife Refuge. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

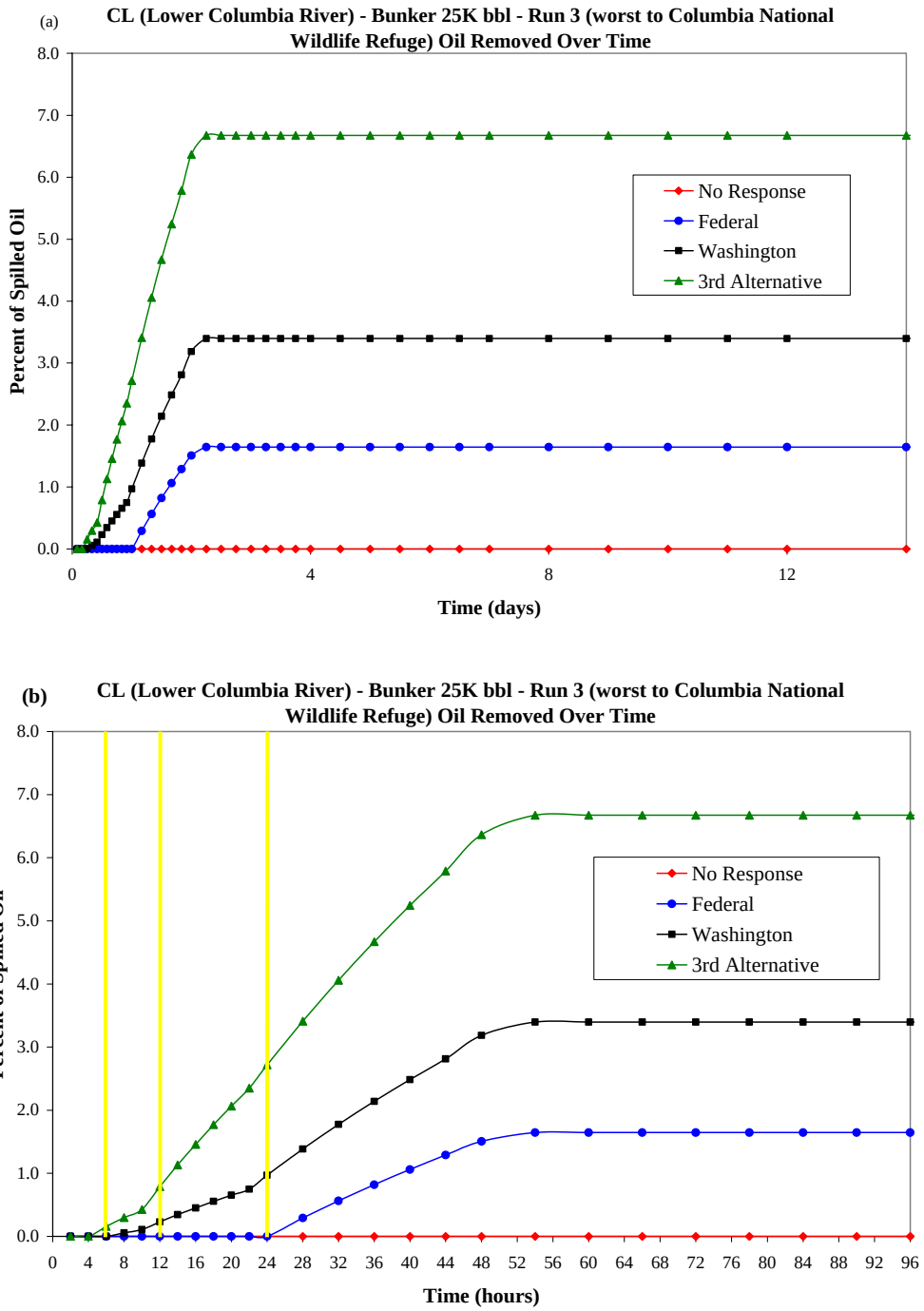


Figure XX.B-10 Lower Columbia River - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Columbia National Wildlife Refuge. Part b of this figure is a subset of Part a.

Since oil never traveled as far upstream as the Columbia National Wildlife Refuge, no shoreline oiling occurred at this critical site.

Table XX.B-1 Lower Columbia River - Bunker C, 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	99.86	0.09	0.00	0.00	0.00	0.05	0.00	0.00	99.86
4	0.17	99.78	0.13	0.00	0.00	0.00	0.09	0.00	0.00	99.78
6	0.25	99.58	0.25	0.00	0.00	0.00	0.17	0.00	0.00	99.58
8	0.33	99.37	0.37	0.00	0.00	0.00	0.25	0.00	0.00	99.37
10	0.42	99.18	0.48	0.00	0.00	0.00	0.34	0.00	0.00	99.18
12	0.50	98.98	0.60	0.00	0.00	0.00	0.42	0.00	0.00	98.98
14	0.58	98.81	0.68	0.00	0.00	0.00	0.50	0.00	0.00	98.81
16	0.67	98.45	0.80	0.00	0.00	0.17	0.58	0.00	0.00	98.45
18	0.75	98.20	0.93	0.00	0.00	0.21	0.67	0.00	0.00	98.20
20	0.83	97.97	1.08	0.00	0.00	0.21	0.75	0.00	0.00	97.97
22	0.92	97.75	1.21	0.00	0.00	0.21	0.83	0.00	0.00	97.75
24	1.00	97.54	1.34	0.00	0.00	0.21	0.91	0.00	0.00	97.54
28	1.17	97.00	1.67	0.00	0.00	0.25	1.07	0.00	0.00	97.00
32	1.33	92.27	2.64	0.00	0.00	3.85	1.24	0.00	0.00	92.27
36	1.50	81.82	4.44	0.02	0.00	12.33	1.39	0.00	0.00	81.82
40	1.67	74.19	5.72	0.02	0.00	18.51	1.55	0.00	0.00	74.19
44	1.83	73.01	6.02	0.02	0.00	19.25	1.71	0.00	0.00	73.01
48	2.00	72.39	6.20	0.05	0.00	19.51	1.86	0.00	0.00	72.39
54	2.25	55.05	8.96	0.04	0.00	33.86	2.09	0.00	0.00	55.05
60	2.50	45.64	10.53	0.11	0.00	41.41	2.31	0.00	0.00	45.64
66	2.75	42.02	11.27	0.09	0.00	44.07	2.54	0.00	0.00	42.02
72	3.00	41.54	11.54	0.16	0.00	43.99	2.77	0.00	0.00	41.54
78	3.25	41.11	11.82	0.14	0.01	43.93	2.99	0.00	0.00	41.11
84	3.50	40.77	11.99	0.20	0.01	43.81	3.22	0.00	0.00	40.77
90	3.75	38.90	12.28	0.19	0.01	45.18	3.44	0.00	0.00	38.90

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
96	4.00	37.32	12.51	0.26	0.01	46.24	3.66	0.00	0.00	37.32
108	4.50	32.82	13.14	0.32	0.02	49.60	4.10	0.00	0.00	32.82
120	5.00	31.57	13.41	0.36	0.04	50.08	4.53	0.00	0.00	31.57
132	5.50	18.06	14.91	0.54	0.06	61.47	4.97	0.00	0.00	18.06
144	6.00	13.86	15.38	0.69	0.10	64.58	5.40	0.00	0.00	13.86
156	6.50	4.00	16.37	0.79	0.19	72.82	5.82	0.00	0.00	4.00
168	7.00	2.69	16.50	0.89	0.28	73.39	6.24	0.00	0.00	2.69
192	8.00	2.54	16.53	1.00	0.54	72.31	7.08	0.00	0.00	2.54
216	9.00	2.44	16.55	1.00	0.87	71.24	7.90	0.00	0.00	2.44
240	10.00	1.83	16.60	1.04	1.15	70.67	8.70	0.00	0.00	1.83
264	11.00	1.77	16.61	0.92	1.58	69.64	9.50	0.00	0.00	1.77
288	12.00	1.72	16.61	0.77	2.01	68.61	10.28	0.00	0.00	1.72
336	14.00	1.62	16.62	0.70	2.59	66.68	11.80	0.00	0.00	1.62
384	16.00	1.53	16.62	0.60	3.15	64.83	13.27	0.00	0.00	1.53
432	18.00	1.30	16.63	0.59	3.56	63.21	14.70	0.00	0.00	1.30
480	20.00	1.00	16.65	0.64	3.88	61.74	16.09	0.00	0.00	1.00
600	25.00	0.00	16.73	0.63	4.70	58.57	19.38	0.00	0.00	0.00
720	30.00	0.00	16.73	0.42	5.52	54.89	22.44	0.00	0.00	0.00
840	35.00	0.00	16.73	0.48	5.94	51.57	25.29	0.00	0.00	0.00
1080	45.00	0.00	16.73	0.30	6.79	45.76	30.43	0.00	0.00	0.00
1200	50.00	0.00	16.73	0.29	7.04	43.19	32.75	0.00	0.00	0.00
1320	55.00	0.00	16.73	0.25	7.28	40.82	34.92	0.00	0.00	0.00
Maximum	56.00	99.90	16.73	1.04	7.34	73.39	35.34	0.00	0.00	99.90

Table XX.B-2 Lower Columbia River - Bunker C, 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	99.86	0.09	0.00	0.00	0.00	0.05	0.00	0.00	99.86
4	0.17	99.78	0.13	0.00	0.00	0.00	0.09	0.00	0.00	99.78
6	0.25	99.58	0.25	0.00	0.00	0.00	0.17	0.00	0.00	99.58
8	0.33	99.37	0.37	0.00	0.00	0.00	0.25	0.00	0.00	99.37
10	0.42	99.18	0.48	0.00	0.00	0.00	0.34	0.00	0.00	99.18
12	0.50	98.98	0.60	0.00	0.00	0.00	0.42	0.00	0.00	98.98
14	0.58	98.81	0.68	0.00	0.00	0.00	0.50	0.00	0.00	98.81
16	0.67	98.45	0.80	0.00	0.00	0.17	0.58	0.00	0.00	98.45
18	0.75	98.20	0.93	0.00	0.00	0.21	0.67	0.00	0.00	98.20
20	0.83	97.97	1.08	0.00	0.00	0.21	0.75	0.00	0.00	97.97
22	0.92	97.75	1.21	0.00	0.00	0.21	0.83	0.00	0.00	97.75
24	1.00	97.54	1.34	0.00	0.00	0.21	0.91	0.00	0.00	97.54
28	1.17	96.71	1.67	0.00	0.00	0.25	1.07	0.29	0.00	96.71
32	1.33	91.71	2.64	0.00	0.00	3.85	1.23	0.56	0.00	91.71
36	1.50	82.09	4.26	0.02	0.00	11.42	1.39	0.82	0.00	82.09
40	1.67	72.28	5.84	0.02	0.00	19.24	1.55	1.06	0.00	72.28
44	1.83	70.68	6.17	0.02	0.00	20.15	1.70	1.29	0.00	70.68
48	2.00	69.59	6.38	0.07	0.00	20.60	1.85	1.51	0.00	69.59
54	2.25	47.83	9.76	0.07	0.00	38.62	2.08	1.65	0.00	47.83
60	2.50	40.21	11.06	0.15	0.00	44.64	2.30	1.65	0.00	40.21
66	2.75	36.14	11.84	0.13	0.01	47.72	2.52	1.65	0.00	36.14
72	3.00	34.73	12.20	0.22	0.01	48.46	2.74	1.65	0.00	34.73
78	3.25	34.34	12.44	0.19	0.02	48.40	2.96	1.65	0.00	34.34
84	3.50	33.66	12.63	0.28	0.03	48.57	3.18	1.65	0.00	33.66
90	3.75	32.93	12.77	0.26	0.03	48.95	3.40	1.65	0.00	32.93
96	4.00	31.97	12.93	0.35	0.04	49.45	3.62	1.65	0.00	31.97

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	30.81	13.17	0.41	0.05	49.86	4.05	1.65	0.00	30.81
120	5.00	29.98	13.39	0.45	0.09	49.97	4.48	1.65	0.00	29.98
132	5.50	11.98	15.33	0.62	0.12	65.41	4.90	1.65	0.00	11.98
144	6.00	9.80	15.58	0.76	0.16	66.73	5.32	1.65	0.00	9.80
156	6.50	4.09	16.16	0.85	0.27	71.25	5.74	1.65	0.00	4.09
168	7.00	3.13	16.26	0.93	0.37	71.52	6.15	1.65	0.00	3.13
192	8.00	1.15	16.44	1.03	0.64	72.13	6.97	1.65	0.00	1.15
216	9.00	1.09	16.45	1.04	0.99	71.01	7.77	1.65	0.00	1.09
240	10.00	1.06	16.45	1.09	1.28	69.91	8.56	1.65	0.00	1.06
264	11.00	1.03	16.45	0.95	1.73	68.84	9.34	1.65	0.00	1.03
288	12.00	1.01	16.45	0.80	2.18	67.80	10.11	1.65	0.00	1.01
336	14.00	0.96	16.46	0.72	2.80	65.82	11.60	1.65	0.00	0.96
384	16.00	0.92	16.46	0.62	3.38	63.94	13.04	1.65	0.00	0.92
432	18.00	0.81	16.47	0.61	3.81	62.23	14.43	1.65	0.00	0.81
480	20.00	0.73	16.47	0.65	4.15	60.57	15.79	1.65	0.00	0.73
600	25.00	0.07	16.52	0.63	4.98	57.15	19.01	1.65	0.00	0.07
720	30.00	0.00	16.52	0.42	5.80	53.56	21.99	1.65	0.07	0.07
840	35.00	0.00	16.52	0.47	6.22	50.31	24.77	1.65	0.07	0.07
1080	45.00	0.00	16.52	0.28	7.04	44.66	29.78	1.65	0.07	0.07
1200	50.00	0.00	16.52	0.28	7.27	42.17	32.05	1.65	0.07	0.07
1320	55.00	0.00	16.52	0.24	7.50	39.87	34.17	1.65	0.07	0.07
Maximum	56.00	99.90	16.52	1.09	7.55	72.13	34.58	1.65	0.07	99.90

Table XX.B-3 Lower Columbia River - Bunker C, 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	99.86	0.09	0.00	0.00	0.00	0.05	0.00	0.00	99.86
4	0.17	99.78	0.13	0.00	0.00	0.00	0.09	0.00	0.00	99.78
6	0.25	99.58	0.25	0.00	0.00	0.00	0.17	0.00	0.00	99.58
8	0.33	99.32	0.37	0.00	0.00	0.00	0.25	0.06	0.00	99.32
10	0.42	99.07	0.48	0.00	0.00	0.00	0.34	0.11	0.00	99.07
12	0.50	98.75	0.60	0.00	0.00	0.00	0.42	0.23	0.00	98.75
14	0.58	98.47	0.68	0.00	0.00	0.00	0.50	0.34	0.00	98.47
16	0.67	98.00	0.80	0.00	0.00	0.17	0.58	0.45	0.00	98.00
18	0.75	97.64	0.93	0.00	0.00	0.21	0.67	0.56	0.00	97.64
20	0.83	97.32	1.07	0.00	0.00	0.21	0.75	0.65	0.00	97.32
22	0.92	97.00	1.21	0.00	0.00	0.21	0.83	0.75	0.00	97.00
24	1.00	96.58	1.34	0.00	0.00	0.21	0.91	0.97	0.00	96.58
28	1.17	95.55	1.67	0.00	0.00	0.32	1.07	1.39	0.00	95.55
32	1.33	89.71	2.75	0.00	0.00	4.53	1.23	1.77	0.00	89.71
36	1.50	79.77	4.41	0.04	0.00	12.26	1.38	2.14	0.00	79.77
40	1.67	74.53	5.27	0.03	0.00	16.15	1.54	2.49	0.00	74.53
44	1.83	72.47	5.65	0.03	0.00	17.35	1.69	2.81	0.00	72.47
48	2.00	71.41	5.84	0.11	0.00	17.62	1.84	3.19	0.00	71.41
54	2.25	52.78	8.77	0.10	0.00	32.89	2.06	3.40	0.00	52.78
60	2.50	44.78	10.14	0.19	0.00	39.20	2.28	3.40	0.00	44.78
66	2.75	42.86	10.65	0.17	0.02	40.41	2.50	3.40	0.00	42.86
72	3.00	41.93	10.98	0.25	0.03	40.70	2.72	3.40	0.00	41.93
78	3.25	41.42	11.27	0.22	0.05	40.71	2.94	3.40	0.00	41.42
84	3.50	40.62	11.50	0.30	0.06	40.98	3.15	3.40	0.00	40.62
90	3.75	39.99	11.64	0.28	0.07	41.27	3.37	3.40	0.00	39.99

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	37.34	12.00	0.38	0.07	43.24	3.58	3.40	0.00	37.34
108	4.50	34.71	12.41	0.44	0.09	44.94	4.01	3.40	0.00	34.71
120	5.00	34.08	12.63	0.49	0.13	44.85	4.43	3.40	0.00	34.08
132	5.50	15.92	14.62	0.65	0.17	60.39	4.84	3.40	0.00	15.92
144	6.00	12.97	14.97	0.81	0.22	62.37	5.26	3.40	0.00	12.97
156	6.50	0.50	16.20	0.89	0.34	73.02	5.66	3.40	0.00	0.50
168	7.00	0.47	16.20	0.97	0.45	72.44	6.07	3.40	0.00	0.47
192	8.00	0.45	16.21	1.05	0.73	71.29	6.87	3.40	0.00	0.45
216	9.00	0.42	16.21	1.04	1.08	70.19	7.66	3.40	0.00	0.42
240	10.00	0.00	16.24	1.06	1.37	69.49	8.44	3.40	0.00	0.00
264	11.00	0.00	16.24	0.93	1.81	68.42	9.20	3.40	0.00	0.00
288	12.00	0.00	16.24	0.77	2.25	67.39	9.95	3.40	0.00	0.00
336	14.00	0.00	16.24	0.69	2.83	65.42	11.41	3.40	0.00	0.00
384	16.00	0.00	16.24	0.59	3.39	63.55	12.82	3.40	0.00	0.00
432	18.00	0.00	16.24	0.58	3.80	61.78	14.19	3.40	0.00	0.00
480	20.00	0.00	16.24	0.62	4.11	60.10	15.52	3.40	0.00	0.00
600	25.00	0.00	16.24	0.58	4.88	56.22	18.68	3.40	0.00	0.00
720	30.00	0.00	16.24	0.38	5.61	52.75	21.62	3.40	0.00	0.00
840	35.00	0.00	16.24	0.43	5.98	49.60	24.35	3.40	0.00	0.00
1080	45.00	0.00	16.24	0.26	6.71	44.09	29.30	3.40	0.00	0.00
1200	50.00	0.00	16.24	0.26	6.91	41.66	31.53	3.40	0.00	0.00
1320	55.00	0.00	16.24	0.22	7.11	39.40	33.63	3.40	0.00	0.00
Maximum	56.00	99.90	16.24	1.06	7.16	73.02	34.03	3.40	0.00	99.90

Table XX.B-4 Lower Columbia River - Bunker C, 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	99.86	0.09	0.00	0.00	0.00	0.05	0.00	0.00	99.86
4	0.17	99.78	0.13	0.00	0.00	0.00	0.09	0.00	0.00	99.78
6	0.25	99.42	0.25	0.00	0.00	0.00	0.17	0.16	0.00	99.42
8	0.33	99.08	0.37	0.00	0.00	0.00	0.25	0.30	0.00	99.08
10	0.42	98.76	0.48	0.00	0.00	0.00	0.34	0.43	0.00	98.76
12	0.50	98.19	0.60	0.00	0.00	0.00	0.42	0.79	0.00	98.19
14	0.58	97.68	0.68	0.00	0.00	0.00	0.50	1.13	0.00	97.68
16	0.67	97.16	0.77	0.00	0.00	0.03	0.58	1.46	0.00	97.16
18	0.75	96.52	0.91	0.00	0.00	0.14	0.66	1.77	0.00	96.52
20	0.83	95.95	1.06	0.00	0.00	0.18	0.74	2.07	0.00	95.95
22	0.92	95.45	1.20	0.00	0.00	0.18	0.82	2.35	0.00	95.45
24	1.00	94.88	1.32	0.00	0.00	0.18	0.90	2.72	0.00	94.88
28	1.17	93.65	1.64	0.00	0.00	0.24	1.06	3.41	0.00	93.65
32	1.33	87.18	2.78	0.00	0.00	4.77	1.21	4.06	0.00	87.18
36	1.50	79.44	4.06	0.02	0.00	10.45	1.37	4.67	0.00	79.44
40	1.67	71.45	5.30	0.02	0.00	16.47	1.51	5.24	0.00	71.45
44	1.83	69.48	5.63	0.02	0.00	17.42	1.66	5.79	0.00	69.48
48	2.00	67.60	5.91	0.05	0.00	18.28	1.81	6.37	0.00	67.60
54	2.25	51.92	8.38	0.04	0.00	30.97	2.02	6.67	0.00	51.92
60	2.50	46.77	9.34	0.12	0.00	34.86	2.23	6.67	0.00	46.77
66	2.75	43.81	10.00	0.11	0.01	36.95	2.44	6.67	0.00	43.81
72	3.00	43.31	10.28	0.19	0.01	36.89	2.65	6.67	0.00	43.31
78	3.25	42.77	10.59	0.16	0.02	36.92	2.86	6.67	0.00	42.77
84	3.50	42.47	10.75	0.24	0.03	36.77	3.07	6.67	0.00	42.47
90	3.75	42.17	10.86	0.22	0.03	36.76	3.28	6.67	0.00	42.17

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
96	4.00	40.60	11.09	0.31	0.04	37.79	3.49	6.67	0.00	40.60
108	4.50	37.33	11.60	0.38	0.06	40.07	3.90	6.67	0.00	37.33
120	5.00	34.93	12.01	0.43	0.09	41.56	4.30	6.67	0.00	34.93
132	5.50	13.45	14.36	0.62	0.12	60.07	4.70	6.67	0.00	13.45
144	6.00	11.58	14.59	0.79	0.17	61.09	5.10	6.67	0.00	11.58
156	6.50	1.87	15.56	0.89	0.28	69.22	5.50	6.67	0.00	1.87
168	7.00	1.62	15.59	0.99	0.39	68.84	5.89	6.67	0.00	1.62
192	8.00	0.51	15.69	1.09	0.69	68.68	6.66	6.67	0.00	0.51
216	9.00	0.45	15.70	1.09	1.06	67.60	7.43	6.67	0.00	0.45
240	10.00	0.42	15.70	1.12	1.37	66.54	8.18	6.67	0.00	0.42
264	11.00	0.41	15.70	0.98	1.84	65.49	8.91	6.67	0.00	0.41
288	12.00	0.39	15.70	0.82	2.31	64.48	9.63	6.67	0.00	0.39
336	14.00	0.35	15.70	0.73	2.95	62.56	11.04	6.67	0.00	0.35
384	16.00	0.32	15.71	0.63	3.55	60.73	12.40	6.67	0.00	0.32
432	18.00	0.18	15.72	0.62	3.99	59.11	13.72	6.67	0.00	0.18
480	20.00	0.08	15.72	0.66	4.33	57.54	14.99	6.67	0.00	0.08
600	25.00	0.00	15.73	0.62	5.17	53.79	18.02	6.67	0.00	0.00
720	30.00	0.00	15.73	0.40	5.99	50.38	20.83	6.67	0.00	0.00
840	35.00	0.00	15.73	0.45	6.40	47.31	23.44	6.67	0.00	0.00
1080	45.00	0.00	15.73	0.27	7.19	41.98	28.16	6.67	0.00	0.00
1200	50.00	0.00	15.73	0.26	7.42	39.63	30.29	6.67	0.00	0.00
1320	55.00	0.00	15.73	0.22	7.63	37.46	32.28	6.67	0.00	0.00
Maximum	56.00	99.90	15.73	1.12	7.68	69.22	32.66	6.67	0.00	99.90

Table XX.B-5 Lower Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker 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	81.25	3.25	0.00	0.00	15.46	0.05	0.00	0.00	81.25
4	0.17	88.99	1.94	0.00	0.00	8.98	0.09	0.00	0.00	88.99
6	0.25	88.13	2.15	0.00	0.00	9.55	0.17	0.00	0.00	88.13
8	0.33	87.94	2.25	0.00	0.00	9.56	0.25	0.00	0.00	87.94
10	0.42	87.76	2.34	0.00	0.00	9.57	0.33	0.00	0.00	87.76
12	0.50	81.11	3.57	0.44	0.00	14.47	0.41	0.00	0.00	81.11
14	0.58	69.74	5.59	0.43	0.01	23.73	0.49	0.00	0.00	69.74
16	0.67	60.20	7.30	0.41	0.03	31.49	0.57	0.00	0.00	60.20
18	0.75	51.11	8.89	0.39	0.04	38.91	0.65	0.00	0.00	51.11
20	0.83	33.24	11.84	0.37	0.06	53.76	0.73	0.00	0.00	33.24
22	0.92	30.80	12.30	0.35	0.07	55.67	0.81	0.00	0.00	30.80
24	1.00	29.00	12.66	1.50	0.09	55.87	0.88	0.00	0.00	29.00
28	1.17	27.25	13.06	1.34	0.24	57.08	1.03	0.00	0.00	27.25
32	1.33	25.70	13.40	1.19	0.38	58.14	1.19	0.00	0.00	25.70
36	1.50	24.50	13.69	2.23	0.50	57.75	1.34	0.00	0.00	24.50
40	1.67	23.25	13.97	2.00	0.71	58.58	1.49	0.00	0.00	23.25
44	1.83	22.90	14.11	1.80	0.90	58.66	1.64	0.00	0.00	22.90
48	2.00	22.66	14.22	2.77	1.05	57.51	1.78	0.00	0.00	22.66
54	2.25	18.23	14.87	2.41	1.40	61.09	2.00	0.00	0.00	18.23
60	2.50	13.37	15.51	3.41	1.67	63.81	2.22	0.00	0.00	13.37
66	2.75	11.67	15.75	3.01	2.05	65.08	2.44	0.00	0.00	11.67
72	3.00	10.27	15.94	3.99	2.31	64.84	2.65	0.00	0.00	10.27
78	3.25	9.48	16.04	3.69	2.58	65.34	2.87	0.00	0.00	9.48
84	3.50	7.14	16.30	4.60	2.89	65.99	3.08	0.00	0.00	7.14
90	3.75	4.68	16.57	4.06	3.40	67.99	3.29	0.00	0.00	4.68
96	4.00	2.98	16.75	4.84	3.81	68.12	3.49	0.00	0.00	2.98

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
108	4.50	1.56	16.89	5.19	4.59	67.86	3.90	0.00	0.00	1.56
120	5.00	1.53	16.90	5.38	5.49	66.39	4.31	0.00	0.00	1.53
132	5.50	1.37	16.92	5.41	6.51	65.09	4.70	0.00	0.00	1.37
144	6.00	1.10	16.95	5.33	7.61	63.94	5.09	0.00	0.00	1.10
156	6.50	0.57	16.99	4.91	9.01	63.06	5.46	0.00	0.00	0.57
168	7.00	0.21	17.02	4.48	10.40	62.07	5.83	0.00	0.00	0.21
192	8.00	0.00	17.04	4.16	12.53	59.74	6.54	0.00	0.00	0.00
216	9.00	0.00	17.04	4.02	14.36	57.36	7.22	0.00	0.00	0.00
240	10.00	0.00	17.04	3.53	16.43	55.13	7.87	0.00	0.00	0.00
264	11.00	0.00	17.04	3.13	18.31	53.03	8.49	0.00	0.00	0.00
288	12.00	0.00	17.04	2.97	19.86	51.05	9.09	0.00	0.00	0.00
336	14.00	0.00	17.04	2.57	22.76	47.43	10.21	0.00	0.00	0.00
384	16.00	0.00	17.04	2.52	24.99	44.20	11.25	0.00	0.00	0.00
432	18.00	0.00	17.04	2.49	26.93	41.33	12.22	0.00	0.00	0.00
480	20.00	0.00	17.04	2.19	28.89	38.76	13.13	0.00	0.00	0.00
600	25.00	0.00	17.04	1.80	32.58	33.44	15.14	0.00	0.00	0.00
720	30.00	0.00	17.04	1.39	35.37	29.33	16.88	0.00	0.00	0.00
840	35.00	0.00	17.04	1.47	37.01	26.09	18.39	0.00	0.00	0.00
1080	45.00	0.00	17.04	0.78	39.91	21.37	20.91	0.00	0.00	0.00
1200	50.00	0.00	17.04	0.59	40.81	19.59	21.97	0.00	0.00	0.00
1320	55.00	0.00	17.04	0.39	41.56	18.09	22.93	0.00	0.00	0.00
Maximum	56.00	88.99	17.04	5.41	41.66	68.12	23.11	0.00	0.00	88.99

Table XX.B-6 Lower Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker 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	81.25	3.25	0.00	0.00	15.46	0.05	0.00	0.00	81.25
4	0.17	88.99	1.94	0.00	0.00	8.98	0.09	0.00	0.00	88.99
6	0.25	88.13	2.15	0.00	0.00	9.55	0.17	0.00	0.00	88.13
8	0.33	87.94	2.25	0.00	0.00	9.56	0.25	0.00	0.00	87.94
10	0.42	87.76	2.34	0.00	0.00	9.57	0.33	0.00	0.00	87.76
12	0.50	81.11	3.57	0.44	0.00	14.47	0.41	0.00	0.00	81.11
14	0.58	69.74	5.59	0.43	0.01	23.73	0.49	0.00	0.00	69.74
16	0.67	60.20	7.30	0.42	0.02	31.49	0.57	0.00	0.00	60.20
18	0.75	50.50	8.99	0.40	0.04	39.42	0.65	0.00	0.00	50.50
20	0.83	33.50	11.80	0.38	0.05	53.54	0.73	0.00	0.00	33.50
22	0.92	30.84	12.30	0.36	0.07	55.63	0.81	0.00	0.00	30.84
24	1.00	28.72	12.70	1.51	0.09	56.10	0.88	0.00	0.00	28.72
28	1.17	25.82	13.21	1.36	0.22	57.97	1.03	0.39	0.00	25.82
32	1.33	23.16	13.66	1.21	0.36	59.68	1.19	0.75	0.00	23.16
36	1.50	21.91	13.89	2.24	0.48	59.05	1.33	1.09	0.00	21.91
40	1.67	20.30	14.16	2.02	0.69	59.92	1.48	1.42	0.00	20.30
44	1.83	19.61	14.30	1.82	0.88	60.04	1.63	1.72	0.00	19.61
48	2.00	19.16	14.39	2.79	1.04	58.84	1.77	2.01	0.00	19.16
54	2.25	15.67	14.89	2.44	1.37	61.46	1.99	2.19	0.00	15.67
60	2.50	11.88	15.40	3.37	1.66	63.30	2.20	2.19	0.00	11.88
66	2.75	9.40	15.72	2.99	2.02	65.26	2.41	2.19	0.00	9.40
72	3.00	6.77	16.03	3.95	2.28	66.16	2.62	2.19	0.00	6.77
78	3.25	6.13	16.12	3.66	2.54	66.54	2.83	2.19	0.00	6.13
84	3.50	5.01	16.25	4.54	2.84	66.13	3.04	2.19	0.00	5.01
90	3.75	4.03	16.36	4.02	3.34	66.82	3.24	2.19	0.00	4.03
96	4.00	3.01	16.47	4.75	3.75	66.38	3.44	2.19	0.00	3.01

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	1.56	16.61	5.07	4.51	66.20	3.84	2.19	0.00	1.56
120	5.00	1.42	16.63	5.24	5.38	64.89	4.23	2.19	0.00	1.42
132	5.50	1.38	16.64	5.26	6.38	63.53	4.62	2.19	0.00	1.38
144	6.00	1.36	16.64	5.16	7.45	62.20	5.00	2.19	0.00	1.36
156	6.50	0.91	16.68	4.74	8.81	61.30	5.37	2.19	0.00	0.91
168	7.00	0.84	16.69	4.30	10.16	60.10	5.72	2.19	0.00	0.84
192	8.00	0.70	16.70	3.98	12.20	57.81	6.42	2.19	0.00	0.70
216	9.00	0.64	16.71	3.84	13.96	55.58	7.08	2.19	0.00	0.64
240	10.00	0.48	16.72	3.37	15.95	53.58	7.72	2.19	0.00	0.48
264	11.00	0.08	16.74	2.99	17.74	51.91	8.33	2.19	0.00	0.08
288	12.00	0.07	16.75	2.85	19.22	50.00	8.91	2.19	0.00	0.07
336	14.00	0.06	16.75	2.47	22.01	46.51	10.01	2.19	0.00	0.06
384	16.00	0.04	16.75	2.43	24.16	43.41	11.03	2.19	0.00	0.04
432	18.00	0.00	16.75	2.40	26.02	40.65	11.98	2.19	0.00	0.00
480	20.00	0.00	16.75	2.11	27.91	38.16	12.87	2.19	0.00	0.00
600	25.00	0.00	16.75	1.74	31.48	32.98	14.86	2.19	0.00	0.00
720	30.00	0.00	16.75	1.34	34.17	28.98	16.57	2.19	0.00	0.00
840	35.00	0.00	16.75	1.43	35.75	25.81	18.06	2.19	0.00	0.00
1080	45.00	0.00	16.75	0.76	38.56	21.18	20.56	2.19	0.00	0.00
1200	50.00	0.00	16.75	0.57	39.43	19.44	21.61	2.19	0.00	0.00
1320	55.00	0.00	16.75	0.38	40.16	17.96	22.56	2.19	0.00	0.00
Maximum	56.00	88.99	16.75	5.26	40.26	66.82	22.74	2.19	0.00	88.99

Table XX.B-7 Lower Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker 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	81.25	3.25	0.00	0.00	15.46	0.05	0.00	0.00	81.25
4	0.17	88.99	1.94	0.00	0.00	8.98	0.09	0.00	0.00	88.99
6	0.25	88.13	2.15	0.00	0.00	9.55	0.17	0.00	0.00	88.13
8	0.33	87.89	2.25	0.00	0.00	9.56	0.25	0.06	0.00	87.89
10	0.42	87.65	2.34	0.00	0.00	9.57	0.33	0.11	0.00	87.65
12	0.50	80.88	3.57	0.44	0.00	14.47	0.41	0.23	0.00	80.88
14	0.58	69.45	5.58	0.43	0.01	23.70	0.49	0.34	0.00	69.45
16	0.67	59.77	7.29	0.42	0.02	31.45	0.57	0.47	0.00	59.77
18	0.75	50.08	8.96	0.40	0.04	39.27	0.65	0.61	0.00	50.08
20	0.83	33.15	11.74	0.38	0.05	53.21	0.73	0.74	0.00	33.15
22	0.92	30.20	12.26	0.36	0.07	55.44	0.80	0.87	0.00	30.20
24	1.00	27.86	12.65	1.51	0.09	55.86	0.88	1.16	0.00	27.86
28	1.17	24.61	13.18	1.36	0.22	57.88	1.03	1.72	0.00	24.61
32	1.33	22.72	13.49	1.21	0.36	58.81	1.18	2.24	0.00	22.72
36	1.50	21.62	13.68	2.23	0.48	57.94	1.32	2.73	0.00	21.62
40	1.67	20.26	13.90	2.01	0.69	58.49	1.47	3.19	0.00	20.26
44	1.83	19.29	14.05	1.81	0.88	58.74	1.61	3.62	0.00	19.29
48	2.00	18.47	14.16	2.76	1.04	57.70	1.76	4.12	0.00	18.47
54	2.25	14.08	14.76	2.41	1.37	61.02	1.97	4.40	0.00	14.08
60	2.50	9.74	15.33	3.37	1.65	63.35	2.17	4.40	0.00	9.74
66	2.75	8.18	15.54	2.99	2.01	64.51	2.38	4.40	0.00	8.18
72	3.00	7.60	15.63	3.93	2.27	63.59	2.58	4.40	0.00	7.60
78	3.25	7.00	15.71	3.64	2.53	63.94	2.79	4.40	0.00	7.00
84	3.50	5.26	15.90	4.51	2.83	64.11	2.99	4.40	0.00	5.26
90	3.75	3.58	16.08	3.99	3.33	65.43	3.19	4.40	0.00	3.58

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	2.00	16.25	4.73	3.74	65.50	3.38	4.40	0.00	2.00
108	4.50	0.93	16.35	5.07	4.49	64.99	3.77	4.40	0.00	0.93
120	5.00	0.88	16.36	5.24	5.36	63.60	4.16	4.40	0.00	0.88
132	5.50	0.74	16.37	5.26	6.36	62.33	4.53	4.40	0.00	0.74
144	6.00	0.53	16.39	5.17	7.43	61.18	4.90	4.40	0.00	0.53
156	6.50	0.03	16.43	4.76	8.80	60.32	5.26	4.40	0.00	0.03
168	7.00	0.02	16.43	4.32	10.15	59.06	5.61	4.40	0.00	0.02
192	8.00	0.00	16.43	4.01	12.21	56.66	6.28	4.40	0.00	0.00
216	9.00	0.00	16.43	3.87	13.99	54.38	6.93	4.40	0.00	0.00
240	10.00	0.00	16.43	3.40	15.99	52.24	7.54	4.40	0.00	0.00
264	11.00	0.00	16.43	3.01	17.81	50.22	8.13	4.40	0.00	0.00
288	12.00	0.00	16.43	2.86	19.30	48.32	8.70	4.40	0.00	0.00
336	14.00	0.00	16.43	2.47	22.09	44.85	9.76	4.40	0.00	0.00
384	16.00	0.00	16.43	2.42	24.24	41.76	10.74	4.40	0.00	0.00
432	18.00	0.00	16.43	2.39	26.11	39.01	11.66	4.40	0.00	0.00
480	20.00	0.00	16.43	2.10	28.00	36.55	12.51	4.40	0.00	0.00
600	25.00	0.00	16.43	1.73	31.56	31.47	14.41	4.40	0.00	0.00
720	30.00	0.00	16.43	1.33	34.24	27.55	16.04	4.40	0.00	0.00
840	35.00	0.00	16.43	1.41	35.81	24.47	17.47	4.40	0.00	0.00
1080	45.00	0.00	16.43	0.74	38.59	20.00	19.83	4.40	0.00	0.00
1200	50.00	0.00	16.43	0.56	39.45	18.33	20.82	4.40	0.00	0.00
1320	55.00	0.00	16.43	0.37	40.17	16.92	21.71	4.40	0.00	0.00
Maximum	56.00	88.99	16.43	5.26	40.26	65.50	21.88	4.40	0.00	88.99

Table XX.B-8 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Baker 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	81.25	3.25	0.00	0.00	15.46	0.05	0.00	0.00	81.25
4	0.17	88.99	1.94	0.00	0.00	8.98	0.09	0.00	0.00	88.99
6	0.25	87.98	2.15	0.00	0.00	9.55	0.17	0.16	0.00	87.98
8	0.33	87.64	2.25	0.00	0.00	9.56	0.25	0.30	0.00	87.64
10	0.42	87.35	2.34	0.00	0.00	9.56	0.33	0.43	0.00	87.35
12	0.50	79.85	3.65	0.45	0.00	14.85	0.41	0.79	0.00	79.85
14	0.58	65.33	6.13	0.45	0.01	26.46	0.49	1.13	0.00	65.33
16	0.67	57.76	7.44	0.43	0.02	32.24	0.57	1.54	0.00	57.76
18	0.75	45.69	9.44	0.41	0.04	41.82	0.65	1.95	0.00	45.69
20	0.83	29.74	12.02	0.39	0.05	54.73	0.72	2.35	0.00	29.74
22	0.92	27.79	12.34	0.36	0.07	55.91	0.80	2.73	0.00	27.79
24	1.00	26.59	12.52	1.60	0.09	55.12	0.87	3.22	0.00	26.59
28	1.17	24.31	12.87	1.44	0.23	56.14	1.02	3.99	0.00	24.31
32	1.33	22.39	13.13	1.28	0.38	56.80	1.16	4.84	0.00	22.39
36	1.50	21.36	13.29	2.36	0.51	55.68	1.31	5.49	0.00	21.36
40	1.67	19.27	13.58	2.13	0.73	56.67	1.45	6.17	0.00	19.27
44	1.83	17.74	13.76	1.92	0.93	57.16	1.58	6.90	0.00	17.74
48	2.00	16.68	13.87	2.94	1.10	56.02	1.72	7.67	0.00	16.68
54	2.25	13.19	14.32	2.57	1.45	58.46	1.92	8.08	0.00	13.19
60	2.50	8.68	14.91	3.55	1.76	60.90	2.12	8.08	0.00	8.68
66	2.75	6.31	15.21	3.15	2.14	62.80	2.32	8.08	0.00	6.31
72	3.00	4.57	15.41	4.14	2.41	62.87	2.51	8.08	0.00	4.57
78	3.25	4.04	15.48	3.84	2.69	63.17	2.71	8.08	0.00	4.04
84	3.50	1.94	15.70	4.75	3.01	63.62	2.90	8.08	0.00	1.94
90	3.75	1.17	15.78	4.20	3.53	64.14	3.09	8.08	0.00	1.17

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
96	4.00	0.91	15.81	4.96	3.96	62.99	3.28	8.08	0.00	0.91
108	4.50	0.85	15.82	5.30	4.76	61.54	3.65	8.08	0.00	0.85
120	5.00	0.73	15.83	5.47	5.68	60.20	4.01	8.08	0.00	0.73
132	5.50	0.70	15.84	5.48	6.72	58.81	4.37	8.08	0.00	0.70
144	6.00	0.68	15.84	5.37	7.84	57.47	4.72	8.08	0.00	0.68
156	6.50	0.52	15.85	4.93	9.26	56.30	5.06	8.08	0.00	0.52
168	7.00	0.52	15.85	4.47	10.67	55.02	5.39	8.08	0.00	0.52
192	8.00	0.28	15.87	4.14	12.80	52.80	6.03	8.08	0.00	0.28
216	9.00	0.00	15.89	3.98	14.64	50.78	6.63	8.08	0.00	0.00
240	10.00	0.00	15.89	3.49	16.70	48.63	7.21	8.08	0.00	0.00
264	11.00	0.00	15.89	3.09	18.56	46.62	7.76	8.08	0.00	0.00
288	12.00	0.00	15.89	2.92	20.09	44.72	8.29	8.08	0.00	0.00
336	14.00	0.00	15.89	2.52	22.96	41.27	9.27	8.08	0.00	0.00
384	16.00	0.00	15.89	2.47	25.17	38.21	10.18	8.08	0.00	0.00
432	18.00	0.00	15.89	2.43	27.07	35.50	11.02	8.08	0.00	0.00
480	20.00	0.00	15.89	2.13	29.00	33.09	11.80	8.08	0.00	0.00
600	25.00	0.00	15.89	1.74	32.62	28.15	13.52	8.08	0.00	0.00
720	30.00	0.00	15.89	1.33	35.33	24.39	14.98	8.08	0.00	0.00
840	35.00	0.00	15.89	1.40	36.91	21.49	16.23	8.08	0.00	0.00
1080	45.00	0.00	15.89	0.71	39.65	17.36	18.30	8.08	0.00	0.00
1200	50.00	0.00	15.89	0.53	40.48	15.86	19.15	8.08	0.00	0.00
1320	55.00	0.00	15.89	0.34	41.16	14.60	19.92	8.08	0.00	0.00
Maximum	56.00	88.99	15.89	5.48	41.25	64.14	20.07	8.08	0.00	88.99

Table XX.B-9 Lower Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge.

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	92.14	1.43	0.00	0.00	6.38	0.05	0.00	0.00	92.14
4	0.17	95.90	0.83	0.00	0.00	3.19	0.09	0.00	0.00	95.90
6	0.25	95.68	0.96	0.00	0.00	3.19	0.17	0.00	0.00	95.68
8	0.33	88.59	2.30	0.00	0.00	8.86	0.25	0.00	0.00	88.59
10	0.42	86.09	2.86	0.00	0.00	10.72	0.33	0.00	0.00	86.09
12	0.50	85.49	3.11	0.15	0.00	10.84	0.41	0.00	0.00	85.49
14	0.58	84.00	3.49	0.14	0.00	11.87	0.49	0.00	0.00	84.00
16	0.67	83.49	3.73	0.13	0.01	12.07	0.58	0.00	0.00	83.49
18	0.75	83.21	3.92	0.13	0.02	12.07	0.66	0.00	0.00	83.21
20	0.83	78.60	4.80	0.12	0.02	15.72	0.74	0.00	0.00	78.60
22	0.92	73.21	5.74	0.12	0.02	20.10	0.82	0.00	0.00	73.21
24	1.00	63.95	7.29	0.55	0.03	27.28	0.89	0.00	0.00	63.95
28	1.17	33.44	12.08	0.51	0.06	52.86	1.05	0.00	0.00	33.44
32	1.33	29.84	12.72	0.46	0.10	55.67	1.20	0.00	0.00	29.84
36	1.50	28.88	12.96	0.96	0.13	55.72	1.35	0.00	0.00	28.88
40	1.67	21.84	14.07	0.86	0.22	61.51	1.51	0.00	0.00	21.84
44	1.83	18.19	14.68	0.75	0.31	64.41	1.66	0.00	0.00	18.19
48	2.00	17.80	14.78	1.42	0.36	63.84	1.80	0.00	0.00	17.80
54	2.25	10.39	15.78	1.23	0.52	70.05	2.03	0.00	0.00	10.39
60	2.50	9.96	15.90	1.84	0.69	69.37	2.25	0.00	0.00	9.96
66	2.75	8.65	16.09	1.58	0.93	70.28	2.47	0.00	0.00	8.65
72	3.00	6.05	16.40	2.13	1.13	71.59	2.69	0.00	0.00	6.05
78	3.25	4.96	16.54	1.81	1.43	72.36	2.90	0.00	0.00	4.96
84	3.50	4.63	16.59	2.37	1.63	71.67	3.12	0.00	0.00	4.63
90	3.75	4.16	16.64	2.09	1.89	71.89	3.33	0.00	0.00	4.16
96	4.00	4.13	16.65	2.60	2.12	70.96	3.54	0.00	0.00	4.13

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	3.46	16.73	2.72	2.69	70.44	3.96	0.00	0.00	3.46
120	5.00	2.06	16.85	2.99	3.11	70.62	4.38	0.00	0.00	2.06
132	5.50	0.63	16.96	2.98	3.79	70.85	4.79	0.00	0.00	0.63
144	6.00	0.35	16.99	2.79	4.62	70.06	5.19	0.00	0.00	0.35
156	6.50	0.02	17.01	2.62	5.42	69.35	5.58	0.00	0.00	0.02
168	7.00	0.01	17.01	2.60	6.05	68.35	5.97	0.00	0.00	0.01
192	8.00	0.01	17.01	2.52	7.28	66.44	6.74	0.00	0.00	0.01
216	9.00	0.00	17.01	2.08	8.80	64.64	7.47	0.00	0.00	0.00
240	10.00	0.00	17.01	1.86	10.02	62.92	8.19	0.00	0.00	0.00
264	11.00	0.00	17.01	1.65	11.17	61.28	8.88	0.00	0.00	0.00
288	12.00	0.00	17.01	1.60	12.10	59.73	9.56	0.00	0.00	0.00
336	14.00	0.00	17.01	1.94	13.34	56.85	10.86	0.00	0.00	0.00
384	16.00	0.00	17.01	1.53	15.13	54.23	12.09	0.00	0.00	0.00
432	18.00	0.00	17.01	1.16	16.71	51.85	13.26	0.00	0.00	0.00
480	20.00	0.00	17.01	0.92	18.01	49.67	14.38	0.00	0.00	0.00
600	25.00	0.00	17.01	0.77	20.28	44.99	16.95	0.00	0.00	0.00
720	30.00	0.00	17.01	0.61	21.96	41.15	19.27	0.00	0.00	0.00
840	35.00	0.00	17.01	1.27	22.39	37.93	21.39	0.00	0.00	0.00
1080	45.00	0.00	17.01	2.17	22.77	32.81	25.23	0.00	0.00	0.00
1200	50.00	0.00	17.01	2.24	23.06	30.72	26.97	0.00	0.00	0.00
1320	55.00	0.00	17.01	2.18	23.36	28.85	28.59	0.00	0.00	0.00
Maximum	56.00	95.90	17.01	2.99	23.42	72.36	28.90	0.00	0.00	95.90

Table XX.B-10 Lower Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge.

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	92.14	1.43	0.00	0.00	6.38	0.05	0.00	0.00	92.14
4	0.17	95.90	0.83	0.00	0.00	3.19	0.09	0.00	0.00	95.90
6	0.25	95.68	0.96	0.00	0.00	3.19	0.17	0.00	0.00	95.68
8	0.33	88.59	2.30	0.00	0.00	8.86	0.25	0.00	0.00	88.59
10	0.42	86.09	2.86	0.00	0.00	10.72	0.33	0.00	0.00	86.09
12	0.50	85.49	3.11	0.15	0.00	10.84	0.41	0.00	0.00	85.49
14	0.58	84.00	3.49	0.14	0.00	11.87	0.49	0.00	0.00	84.00
16	0.67	83.49	3.73	0.14	0.01	12.07	0.58	0.00	0.00	83.49
18	0.75	83.21	3.92	0.13	0.01	12.07	0.66	0.00	0.00	83.21
20	0.83	78.60	4.80	0.12	0.02	15.72	0.74	0.00	0.00	78.60
22	0.92	73.43	5.71	0.12	0.02	19.91	0.82	0.00	0.00	73.43
24	1.00	64.91	7.14	0.52	0.03	26.51	0.89	0.00	0.00	64.91
28	1.17	37.01	11.49	0.48	0.06	49.61	1.05	0.29	0.00	37.01
32	1.33	28.89	12.78	0.44	0.09	56.04	1.20	0.56	0.00	28.89
36	1.50	28.05	12.96	0.87	0.12	55.83	1.35	0.82	0.00	28.05
40	1.67	20.51	14.10	0.78	0.20	61.86	1.50	1.06	0.00	20.51
44	1.83	16.10	14.77	0.69	0.28	65.22	1.65	1.29	0.00	16.10
48	2.00	15.46	14.87	1.28	0.32	64.77	1.80	1.51	0.00	15.46
54	2.25	8.90	15.74	1.12	0.46	70.12	2.02	1.65	0.00	8.90
60	2.50	8.58	15.84	1.62	0.61	69.47	2.23	1.65	0.00	8.58
66	2.75	7.28	16.03	1.41	0.81	70.38	2.45	1.65	0.00	7.28
72	3.00	4.55	16.35	1.86	1.00	71.94	2.66	1.65	0.00	4.55
78	3.25	4.17	16.41	1.59	1.25	72.06	2.88	1.65	0.00	4.17
84	3.50	3.84	16.45	2.03	1.43	71.51	3.09	1.65	0.00	3.84
90	3.75	2.62	16.57	1.80	1.64	72.42	3.30	1.65	0.00	2.62
96	4.00	2.44	16.60	2.23	1.84	71.74	3.51	1.65	0.00	2.44

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	1.82	16.66	2.34	2.32	71.30	3.92	1.65	0.00	1.82
120	5.00	0.93	16.73	2.55	2.67	71.13	4.33	1.65	0.00	0.93
132	5.50	0.25	16.79	2.53	3.25	70.80	4.74	1.65	0.00	0.25
144	6.00	0.03	16.81	2.36	3.95	70.07	5.13	1.65	0.00	0.03
156	6.50	0.02	16.81	2.20	4.63	69.17	5.53	1.65	0.00	0.02
168	7.00	0.02	16.81	2.18	5.15	68.29	5.91	1.65	0.00	0.02
192	8.00	0.00	16.81	2.10	6.17	66.60	6.67	1.65	0.00	0.00
216	9.00	0.00	16.81	1.73	7.43	64.98	7.41	1.65	0.00	0.00
240	10.00	0.00	16.81	1.55	8.44	63.43	8.13	1.65	0.00	0.00
264	11.00	0.00	16.81	1.37	9.39	61.96	8.82	1.65	0.00	0.00
288	12.00	0.00	16.81	1.34	10.15	60.56	9.50	1.65	0.00	0.00
336	14.00	0.00	16.81	1.63	11.17	57.94	10.82	1.65	0.00	0.00
384	16.00	0.00	16.81	1.28	12.65	55.55	12.08	1.65	0.00	0.00
432	18.00	0.00	16.81	0.97	13.95	53.35	13.27	1.65	0.00	0.00
480	20.00	0.00	16.81	0.77	15.03	51.33	14.42	1.65	0.00	0.00
600	25.00	0.00	16.81	0.65	16.89	46.92	17.08	1.65	0.00	0.00
720	30.00	0.00	16.81	0.52	18.28	43.24	19.50	1.65	0.00	0.00
840	35.00	0.00	16.81	1.10	18.61	40.10	21.73	1.65	0.00	0.00
1080	45.00	0.00	16.81	1.91	18.86	34.99	25.79	1.65	0.00	0.00
1200	50.00	0.00	16.81	1.98	19.08	32.86	27.63	1.65	0.00	0.00
1320	55.00	0.00	16.81	1.94	19.32	30.94	29.35	1.65	0.00	0.00
Maximum	56.00	95.90	16.81	2.55	19.37	72.42	29.68	1.65	0.00	95.90

Table XX.B-11 Lower Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge.

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	92.14	1.43	0.00	0.00	6.38	0.05	0.00	0.00	92.14
4	0.17	95.90	0.83	0.00	0.00	3.19	0.09	0.00	0.00	95.90
6	0.25	95.68	0.96	0.00	0.00	3.19	0.17	0.00	0.00	95.68
8	0.33	89.06	2.22	0.00	0.00	8.42	0.25	0.06	0.00	89.06
10	0.42	86.77	2.74	0.00	0.00	10.06	0.33	0.11	0.00	86.77
12	0.50	85.43	3.09	0.15	0.00	10.70	0.41	0.23	0.00	85.43
14	0.58	84.31	3.39	0.14	0.00	11.32	0.49	0.34	0.00	84.31
16	0.67	83.82	3.61	0.14	0.01	11.40	0.57	0.45	0.00	83.82
18	0.75	83.45	3.80	0.13	0.01	11.40	0.65	0.56	0.00	83.45
20	0.83	78.75	4.68	0.12	0.02	15.04	0.73	0.65	0.00	78.75
22	0.92	72.43	5.75	0.12	0.02	20.12	0.81	0.75	0.00	72.43
24	1.00	67.37	6.61	0.52	0.03	23.61	0.89	0.97	0.00	67.37
28	1.17	35.34	11.58	0.49	0.06	50.11	1.05	1.39	0.00	35.34
32	1.33	28.26	12.68	0.44	0.09	55.55	1.20	1.77	0.00	28.26
36	1.50	26.58	12.97	0.87	0.12	55.97	1.34	2.14	0.00	26.58
40	1.67	22.18	13.65	0.78	0.20	59.21	1.49	2.49	0.00	22.18
44	1.83	18.79	14.18	0.69	0.28	61.61	1.64	2.81	0.00	18.79
48	2.00	17.85	14.31	1.18	0.33	61.37	1.78	3.19	0.00	17.85
54	2.25	9.57	15.40	1.03	0.45	68.15	2.00	3.40	0.00	9.57
60	2.50	8.94	15.54	1.47	0.60	67.85	2.21	3.40	0.00	8.94
66	2.75	7.68	15.73	1.27	0.77	68.73	2.42	3.40	0.00	7.68
72	3.00	5.80	15.97	1.67	0.94	69.59	2.63	3.40	0.00	5.80
78	3.25	3.72	16.20	1.43	1.16	71.25	2.84	3.40	0.00	3.72
84	3.50	3.36	16.25	1.86	1.32	70.76	3.05	3.40	0.00	3.36
90	3.75	2.62	16.32	1.65	1.52	71.24	3.26	3.40	0.00	2.62

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	2.47	16.34	2.06	1.69	70.57	3.46	3.40	0.00	2.47
108	4.50	1.22	16.46	2.19	2.14	70.73	3.87	3.40	0.00	1.22
120	5.00	0.81	16.49	2.41	2.47	70.15	4.27	3.40	0.00	0.81
132	5.50	0.24	16.54	2.40	3.01	69.74	4.67	3.40	0.00	0.24
144	6.00	0.11	16.55	2.24	3.68	68.96	5.06	3.40	0.00	0.11
156	6.50	0.00	16.56	2.10	4.32	68.18	5.45	3.40	0.00	0.00
168	7.00	0.00	16.56	2.09	4.81	67.32	5.83	3.40	0.00	0.00
192	8.00	0.00	16.56	2.02	5.79	65.66	6.58	3.40	0.00	0.00
216	9.00	0.00	16.56	1.66	7.00	64.08	7.30	3.40	0.00	0.00
240	10.00	0.00	16.56	1.49	7.97	62.57	8.01	3.40	0.00	0.00
264	11.00	0.00	16.56	1.32	8.89	61.14	8.70	3.40	0.00	0.00
288	12.00	0.00	16.56	1.29	9.62	59.77	9.37	3.40	0.00	0.00
336	14.00	0.00	16.56	1.57	10.60	57.21	10.66	3.40	0.00	0.00
384	16.00	0.00	16.56	1.23	12.03	54.88	11.91	3.40	0.00	0.00
432	18.00	0.00	16.56	0.94	13.28	52.73	13.09	3.40	0.00	0.00
480	20.00	0.00	16.56	0.75	14.32	50.75	14.22	3.40	0.00	0.00
600	25.00	0.00	16.56	0.63	16.13	46.43	16.85	3.40	0.00	0.00
720	30.00	0.00	16.56	0.51	17.47	42.82	19.25	3.40	0.00	0.00
840	35.00	0.00	16.56	1.07	17.78	39.73	21.46	3.40	0.00	0.00
1080	45.00	0.00	16.56	1.86	18.02	34.69	25.48	3.40	0.00	0.00
1200	50.00	0.00	16.56	1.93	18.23	32.58	27.30	3.40	0.00	0.00
1320	55.00	0.00	16.56	1.89	18.47	30.68	29.00	3.40	0.00	0.00
Maximum	56.00	95.90	16.56	2.41	18.51	71.25	29.33	3.40	0.00	95.90

Table XX.B-12 Lower Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Columbia National Wildlife Refuge.

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	92.14	1.43	0.00	0.00	6.38	0.05	0.00	0.00	92.14
4	0.17	95.90	0.83	0.00	0.00	3.19	0.09	0.00	0.00	95.90
6	0.25	95.52	0.96	0.00	0.00	3.19	0.17	0.16	0.00	95.52
8	0.33	88.82	2.22	0.00	0.00	8.42	0.25	0.30	0.00	88.82
10	0.42	86.38	2.75	0.00	0.00	10.12	0.33	0.43	0.00	86.38
12	0.50	85.25	3.02	0.14	0.00	10.39	0.41	0.79	0.00	85.25
14	0.58	83.27	3.43	0.13	0.00	11.54	0.49	1.13	0.00	83.27
16	0.67	82.42	3.67	0.13	0.01	11.75	0.57	1.46	0.00	82.42
18	0.75	81.54	3.91	0.12	0.01	12.00	0.65	1.77	0.00	81.54
20	0.83	77.05	4.71	0.11	0.02	15.31	0.73	2.07	0.00	77.05
22	0.92	72.00	5.55	0.11	0.02	19.15	0.81	2.35	0.00	72.00
24	1.00	65.79	6.57	0.49	0.02	23.52	0.89	2.72	0.00	65.79
28	1.17	30.76	11.95	0.46	0.05	52.34	1.04	3.41	0.00	30.76
32	1.33	24.84	12.83	0.42	0.08	56.59	1.18	4.06	0.00	24.84
36	1.50	23.46	13.02	0.85	0.11	56.56	1.33	4.67	0.00	23.46
40	1.67	19.08	13.66	0.76	0.18	59.60	1.47	5.24	0.00	19.08
44	1.83	14.36	14.32	0.67	0.27	62.98	1.61	5.79	0.00	14.36
48	2.00	13.40	14.41	1.21	0.31	62.56	1.75	6.37	0.00	13.40
54	2.25	7.03	15.23	1.06	0.44	67.61	1.96	6.67	0.00	7.03
60	2.50	6.59	15.33	1.51	0.58	67.15	2.16	6.67	0.00	6.59
66	2.75	6.24	15.41	1.30	0.77	67.24	2.37	6.67	0.00	6.24
72	3.00	3.10	15.76	1.71	0.94	69.24	2.57	6.67	0.00	3.10
78	3.25	2.05	15.88	1.46	1.17	70.00	2.77	6.67	0.00	2.05
84	3.50	1.88	15.91	1.88	1.33	69.36	2.97	6.67	0.00	1.88
90	3.75	1.33	15.96	1.66	1.53	69.68	3.17	6.67	0.00	1.33

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	1.32	15.96	2.06	1.71	68.91	3.37	6.67	0.00	1.32
108	4.50	1.01	15.99	2.15	2.15	68.26	3.76	6.67	0.00	1.01
120	5.00	0.84	16.01	2.34	2.48	67.50	4.15	6.67	0.00	0.84
132	5.50	0.00	16.08	2.32	3.00	67.40	4.53	6.67	0.00	0.00
144	6.00	0.00	16.08	2.15	3.65	66.54	4.91	6.67	0.00	0.00
156	6.50	0.00	16.08	2.01	4.26	65.70	5.28	6.67	0.00	0.00
168	7.00	0.00	16.08	1.99	4.74	64.88	5.65	6.67	0.00	0.00
192	8.00	0.00	16.08	1.91	5.66	63.30	6.37	6.67	0.00	0.00
216	9.00	0.00	16.08	1.57	6.81	61.80	7.07	6.67	0.00	0.00
240	10.00	0.00	16.08	1.41	7.72	60.37	7.75	6.67	0.00	0.00
264	11.00	0.00	16.08	1.25	8.58	59.01	8.41	6.67	0.00	0.00
288	12.00	0.00	16.08	1.21	9.27	57.71	9.06	6.67	0.00	0.00
336	14.00	0.00	16.08	1.47	10.19	55.28	10.31	6.67	0.00	0.00
384	16.00	0.00	16.08	1.16	11.53	53.05	11.51	6.67	0.00	0.00
432	18.00	0.00	16.08	0.88	12.70	51.01	12.66	6.67	0.00	0.00
480	20.00	0.00	16.08	0.70	13.67	49.13	13.75	6.67	0.00	0.00
600	25.00	0.00	16.08	0.59	15.35	45.01	16.30	6.67	0.00	0.00
720	30.00	0.00	16.08	0.47	16.59	41.56	18.62	6.67	0.00	0.00
840	35.00	0.00	16.08	0.99	16.88	38.61	20.77	6.67	0.00	0.00
1080	45.00	0.00	16.08	1.72	17.08	33.79	24.67	6.67	0.00	0.00
1200	50.00	0.00	16.08	1.78	17.27	31.77	26.44	6.67	0.00	0.00
1320	55.00	0.00	16.08	1.74	17.47	29.94	28.10	6.67	0.00	0.00
Maximum	56.00	95.90	16.08	2.34	17.52	70.00	28.42	6.67	0.00	95.90

Table XX.B-13 Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for Columbia National Wildlife Refuge
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	74	96	105
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	74	95	101
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,506	1,284	1,738
Shoreline length (km) oiled by > 100 g/m^2	1,471	1,176	1,665
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	671,790	929,360	1,211,500
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	833,970	354,980	526,190
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	188	111	167

Table XX.B-14 Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for Columbia National Wildlife Refuge
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	79	90	95
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	79	89	95
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,469	1,199	1,498
Shoreline length (km) oiled by > 100 g/m^2	1,469	1,162	1,463
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	812,380	892,210	889,700
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	656,230	307,280	608,530
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	169	101	160

Table XXB-15 Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for Columbia National Wildlife Refuge
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	69	83	90
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	69	83	90
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,640	1,231	1,840
Shoreline length (km) oiled by > 100 g/m^2	1,640	1,052	1,770
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	1,023,300	888,690	1,202,500
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	616,560	341,920	637,650
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	179	107	189

Table XX.B-16 Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for Columbia National Wildlife Refuge
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	71	76	86
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	71	76	85
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,502	1,037	1,607
Shoreline length (km) oiled by > 100 g/m^2	1,466	967	1,607
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	787,270	751,620	1,066,400
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	714,470	285,190	540,750
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	177	88	164

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 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 XX.C-1 Lower Columbia River - Bunker C, 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)	15,000	1,810	58	7,362	-	-	4	-	24,234	24,229	4
Worst run for Baker Bay	21,183	2,256	96	12,715	-	-	5	-	36,255	36,249	5
Worst run for the Columbia National Wildlife Refuge	23,094	2,393	432	60,484	-	-	6	-	86,410	86,404	6

Table XX.C-2 Lower Columbia River - Bunker C, 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)	16,394	1,910	61	7,759	-	-	4	-	26,128	26,123	4
Worst run for Baker Bay	19,405	2,128	67	8,578	-	-	5	-	30,183	30,178	5
Worst run for the Columbia National Wildlife Refuge	21,144	2,253	458	64,249	-	-	5	-	88,110	88,105	5

Table XX.C-3 Lower Columbia River - Bunker C, 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)	13,433	1,697	68	8,723	-	-	4	-	23,924	23,920	4
Worst run for Baker Bay	17,599	1,997	72	9,401	-	-	5	-	29,075	29,070	5
Worst run for the Columbia National Wildlife Refuge	19,816	2,157	430	60,180	-	-	5	-	82,587	82,582	5

Table XX.C-4 Lower Columbia River - Bunker C, 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)	14,140	1,748	60	7,611	-	-	4	-	23,563	23,559	4
Worst run for Baker Bay	15,388	1,838	67	8,582	-	-	4	-	25,878	25,874	4
Worst run for the Columbia National Wildlife Refuge	18,241	2,044	451	63,185	-	-	5	-	83,925	83,921	5

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 (i.e., the data were not corrected to be seasonal means).

Table XX.D-1. Lower Columbia River - Bunker C, 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)	-	-	0.3	-	-	2,681	2,682
Worst run for Baker Bay	4.5	-	0.5	-	-	2,074	2,079
Worst run for the Columbia National Wildlife Refuge	-	-	0.4	-	-	3,057	3,058

Table XX.D-2. Lower Columbia River - Bunker C, 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)	-	-	0.3	-	-	2,691	2,691
Worst run for Baker Bay	4.1	-	0.5	-	-	2,050	2,054
Worst run for the Columbia National Wildlife Refuge	-	-	0.4	-	-	2,681	2,682

Table XX.D-3. Lower Columbia River - Bunker C, 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)	-	-	0.3	-	-	3,024	3,024
Worst run for Baker Bay	4.1	-	0.5	-	-	1,852	1,856
Worst run for the Columbia National Wildlife Refuge	-	-	0.4	-	-	3,270	3,270

Table XX.D-4. Lower Columbia River - Bunker C, 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)	-	-	0.3	-	-	2,696	2,696
Worst run for Baker Bay	4.7	-	0.5	-	-	1,726	1,732
Worst run for the Columbia National Wildlife Refuge	-	-	0.4	-	-	2,975	2,976

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 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 XX.E-1. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Fish and Invertebrates:			
Small pelagic fish	-	4.5	-
Large pelagic fish	-	-	-
Demersal fish	0.3	0.5	0.4
Decapods	-	-	-
Molluscs	2,681	2,074	3,057
Birds:			
Waterfowl (# * kg each)	16,425	23,196	25,288
Seabirds (# * kg each)	1,208	1,506	1,598
Waders (# * kg each)	39	64	288
Shorebirds (# * kg each)	4,914	8,487	40,373
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.8	3.5	3.7
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	2,682	2,079	3,058
Subtotal birds	22,586	33,252	67,548
Subtotal other wildlife	3	4	4
Total all species	25,270	35,334	70,609

Table XX.E-2. Lower Columbia River - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Baker Bay	Worst run for the Columbia National Wildlife Refuge
Saltmarsh Area (ha)	34	48	91
Saltmarsh Area (acres)	83	119	225
Saltmarsh Cost (millions of 2004$)	15.6	22.3	42.2
Eelgrass Area (m2)	21	30	57
Eelgrass Area (acres)	52	74	141
Eelgrass Cost (millions of 2004$)	6.2	8.9	16.8

Table XX.E-3. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Fish and Invertebrates:			
Small pelagic fish	-	4.1	-
Large pelagic fish	-	-	-
Demersal fish	0.3	0.5	0.4
Decapods	-	-	-
Molluscs	2,691	2,050	2,681
Birds:			
Waterfowl (# * kg each)	17,951	21,249	23,153
Seabirds (# * kg each)	1,275	1,420	1,504
Waders (# * kg each)	41	44	306
Shorebirds (# * kg each)	5,179	5,726	42,886
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	3.0	3.3	3.5
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	2,691	2,054	2,682
Subtotal birds	24,446	28,439	67,849
Subtotal other wildlife	3	3	4
Total all species	27,140	30,497	70,535

Table XX.E-4. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Saltmarsh Area (ha)	36	42	91
Saltmarsh Area (acres)	90	103	225
Saltmarsh Cost (millions of 2004$)	16.8	19.4	42.2
Eelgrass Area (m2)	23	26	57
Eelgrass Area (acres)	56	65	141
Eelgrass Cost (millions of 2004$)	6.7	7.7	16.8

Table XX.E-5. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Fish and Invertebrates:			
Small pelagic fish	-	4.1	-
Large pelagic fish	-	-	-
Demersal fish	0.3	0.5	0.4
Decapods	-	-	-
Molluscs	3,024	1,852	3,270
Birds:			
Waterfowl (# * kg each)	14,709	19,271	21,698
Seabirds (# * kg each)	1,133	1,333	1,440
Waders (# * kg each)	45	48	287
Shorebirds (# * kg each)	5,822	6,275	40,170
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.7	3.1	3.4
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	3,024	1,856	3,270
Subtotal birds	21,709	26,928	63,595
Subtotal other wildlife	3	3	3
Total all species	24,735	28,787	66,868

Table XX.E-6. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Saltmarsh Area (ha)	32	40	86
Saltmarsh Area (acres)	80	98	212
Saltmarsh Cost (millions of 2004$)	15.0	18.3	39.6
Eelgrass Area (m2)	20	25	54
Eelgrass Area (acres)	50	61	132
Eelgrass Cost (millions of 2004$)	6.0	7.3	15.8

Table XX.E-7. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Fish and Invertebrates:			
Small pelagic fish	-	4.7	-
Large pelagic fish	-	-	-
Demersal fish	0.3	0.5	0.4
Decapods	-	-	-
Molluscs	2,696	1,726	2,975
Birds:			
Waterfowl (# * kg each)	15,484	16,849	19,974
Seabirds (# * kg each)	1,167	1,227	1,364
Waders (# * kg each)	40	44	301
Shorebirds (# * kg each)	5,080	5,728	42,176
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	-	-	-
Pinnipeds	2.7	2.9	3.2
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	2,696	1,732	2,976
Subtotal birds	21,771	23,849	63,815
Subtotal other wildlife	3	3	3
Total all species	24,470	25,584	66,794

Table XX.E-8. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Saltmarsh Area (ha)	33	35	86
Saltmarsh Area (acres)	81	87	211
Saltmarsh Cost (millions of 2004$)	15.1	16.3	39.6
Eelgrass Area (m2)	20	22	54
Eelgrass Area (acres)	50	55	132
Eelgrass Cost (millions of 2004$)	6.0	6.5	15.8

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. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Vulnerability Score ($/gal.)	28.81	26.83	26.40
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	30.3	28.2	27.7

Table XX.F-2. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Vulnerability Score ($/gal.)	25.75	26.87	26.35
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	27.0	28.2	27.7

Table XX.F-3. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Vulnerability Score ($/gal.)	27.06	26.92	26.41
% Removed by 24 hours	0.97	1.16	0.97
Compensation (millions $)	28.1	27.9	27.5

Table XX.F-4. Lower Columbia River - Bunker C, 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 Baker Bay	Worst run for the Columbia National Wildlife Refuge
Vulnerability Score ($/gal.)	28.37	26.47	26.74
% Removed by 24 hours	2.72	3.22	2.72
Compensation (millions $)	29.0	26.9	27.3

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 XXI: Model Inputs for Upper Columbia River – Bunker C

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

XXI.A. Introduction 1
XXI.B. Geographical Data 2
XXI.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XXI.B.2. Gridded Habitat Mapping 3
XXI.B-3. Gridded Depth Data 4
XXI.B-4. Areas Where Response Actions Assumed 5
XXI.C. Current Data 7
XXI.C.1. Basis of Current Data 7
XXI.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 8
XXI.D: Oil Properties 10
XXI.E: Inputs to the SIMAP Physical Fates Model 13

List of Figures

Figure XXI.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XXI.B.2-1 Habitat grid used for modeling the potential spills. 3
Figure XXI.B.2-2 Habitat grid used for modeling the potential spills (closer view). 3
Figure XXI.B.3-1 Depth grid used for modeling the potential spills. 4
Figure XXI.B.3-2 Depth grid used for modeling the potential spills (closer view). 4
Figure XXI.B.4-1 Jurisdictions in the area of the potential spills. 5
Figure XXI.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XXI.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XXI.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XXI.C.1-1 Grid used for the hydrodynamic model-generated current data. 7
Figure XXI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Stella, WA). 8
Figure XXI.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the dominant tidal component (M2) at Stella, WA. 9
Figure XXI.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the dominant tidal component (M2) at Stella, WA. 9
Figure XXI.E-1 Varied range of spill site from Portland to Longview. 16
Figure XXI.E-2. Wind Station Locations. 20

List of Tables

Table XXI.D-1. Oil properties for Bunker C assumed in the modeling. 10
Table XXI.D-2. Aromatic concentrations (mg/kg) for Bunker C. 11
Aromatic 11
Table XXI.E-1. Inputs to the Fates Model for Stochastic Scenarios 13
Table XXI.E-2. Time, date and location inputs for each of the 100 stochastic runs. 17
Table XXI.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs. 19
Table XXI.E-4. Water temperature by month of the year (from French et al., 1996b). .. 19
Table XXI.E-5. Wind data sources and records used. 20

XXI.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.

XXI.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.

XXI.B.1. Maps of the Vicinity of the Modeled Spill Locations

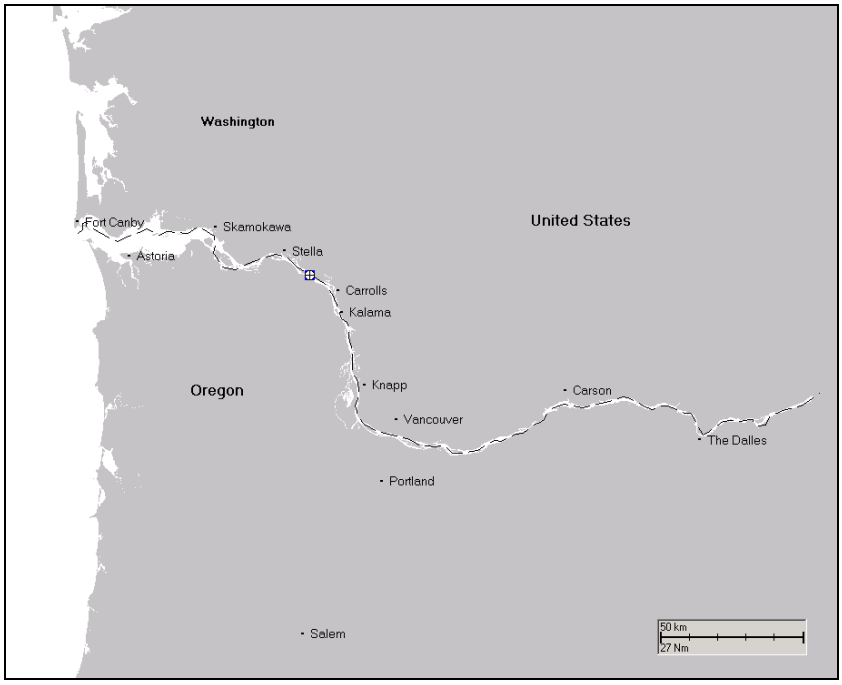


Figure XXI.B.1-1 Map of the vicinity of the potential spill locations.

XXI.B.2. Gridded Habitat Mapping

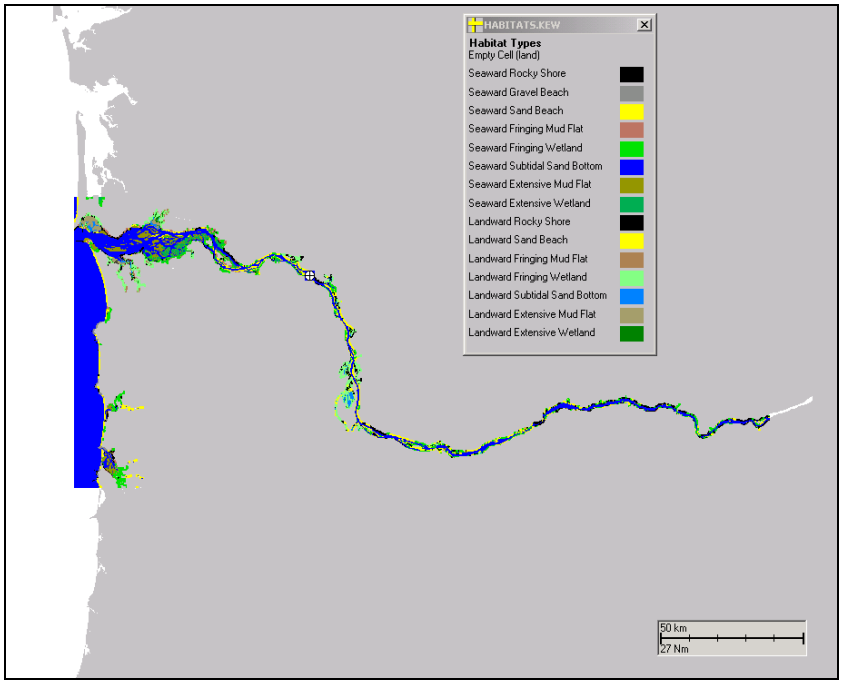


Figure XXI.B.2-1 Habitat grid used for modeling the potential spills.

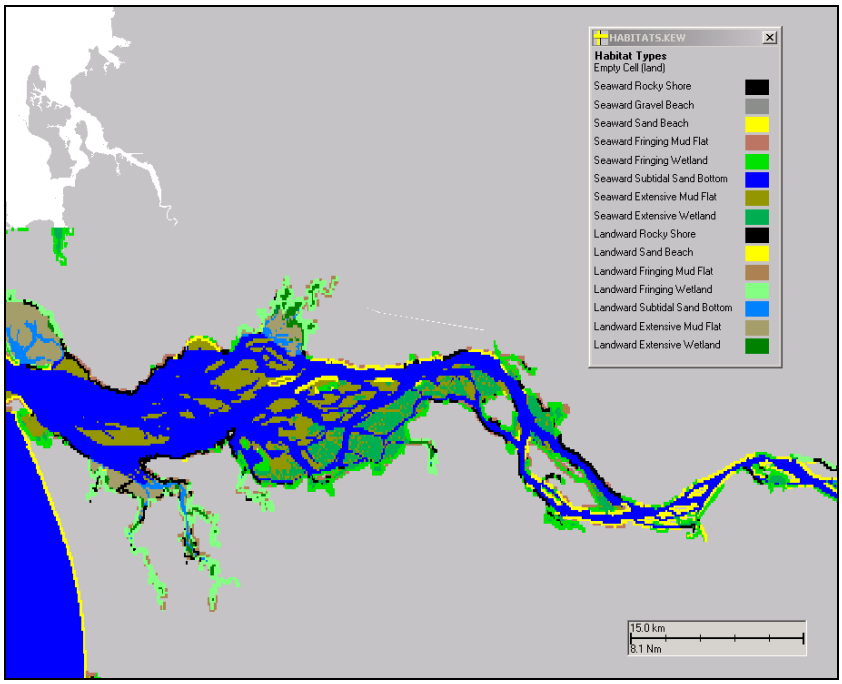


Figure XXI.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XXI.B-3. Gridded Depth Data

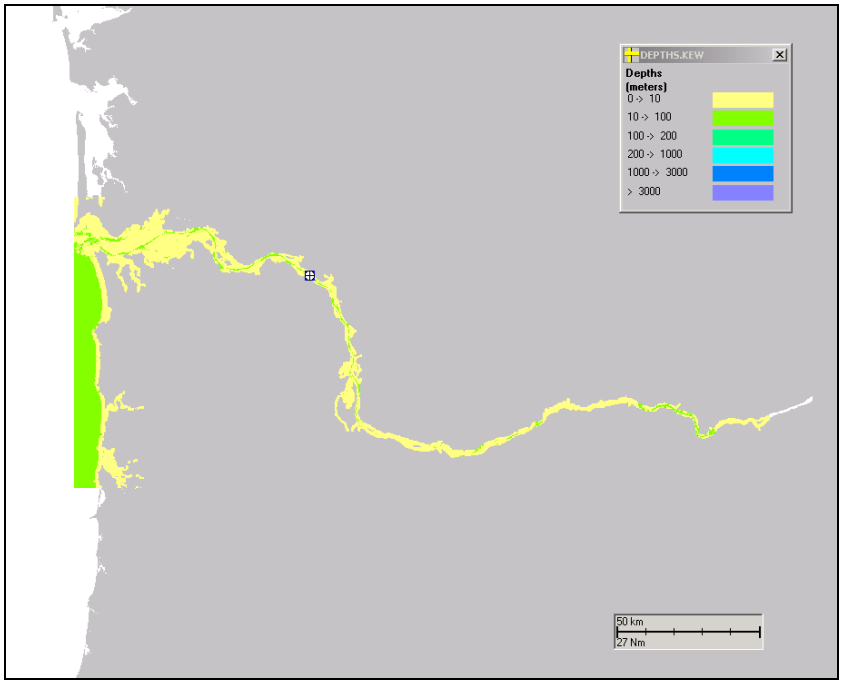


Figure XXI.B.3-1 Depth grid used for modeling the potential spills.

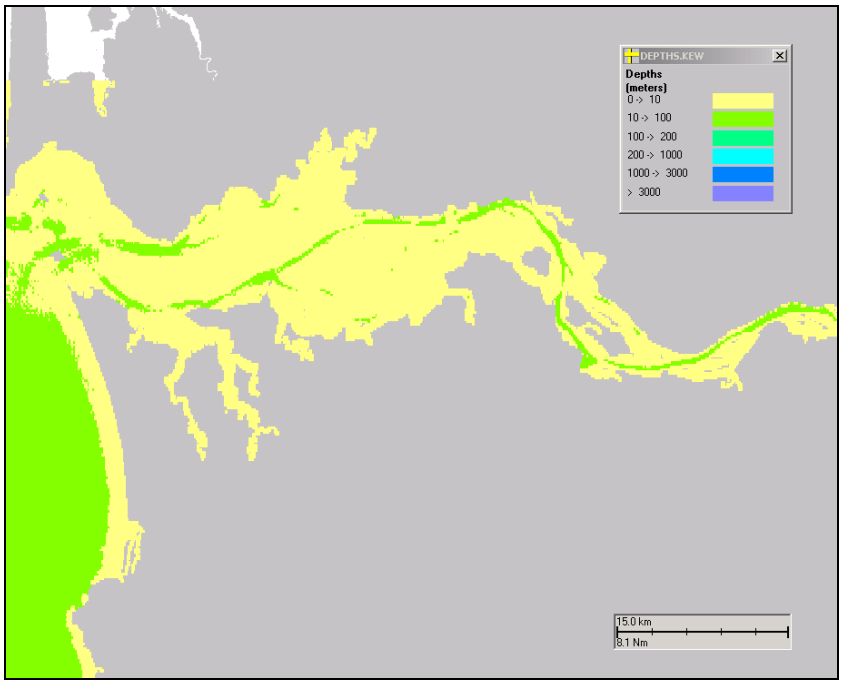


Figure XXI.B.3-2 Depth grid used for modeling the potential spills (closer view).

XXI.B-4. Areas Where Response Actions Assumed

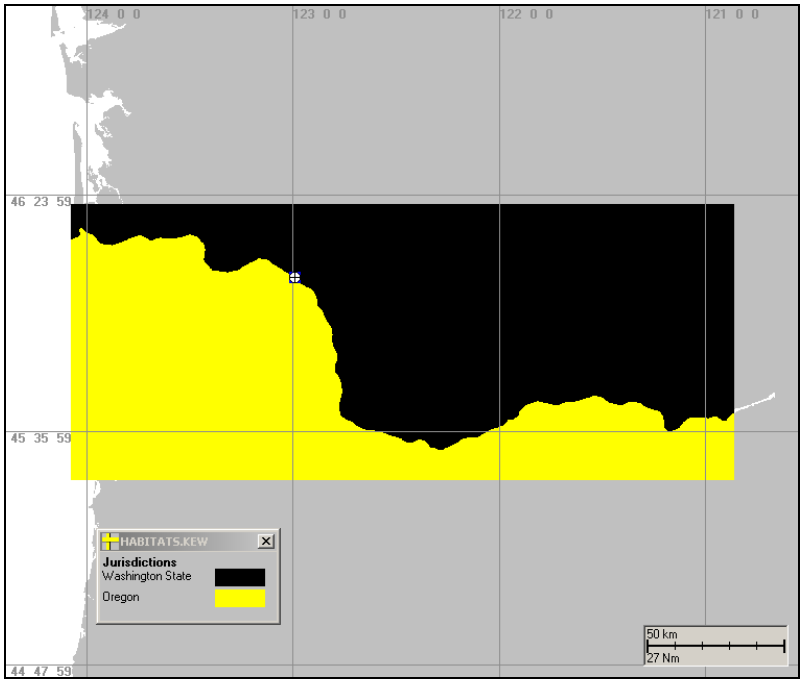


Figure XXI.B.4-1 Jurisdictions in the area of the potential spills.

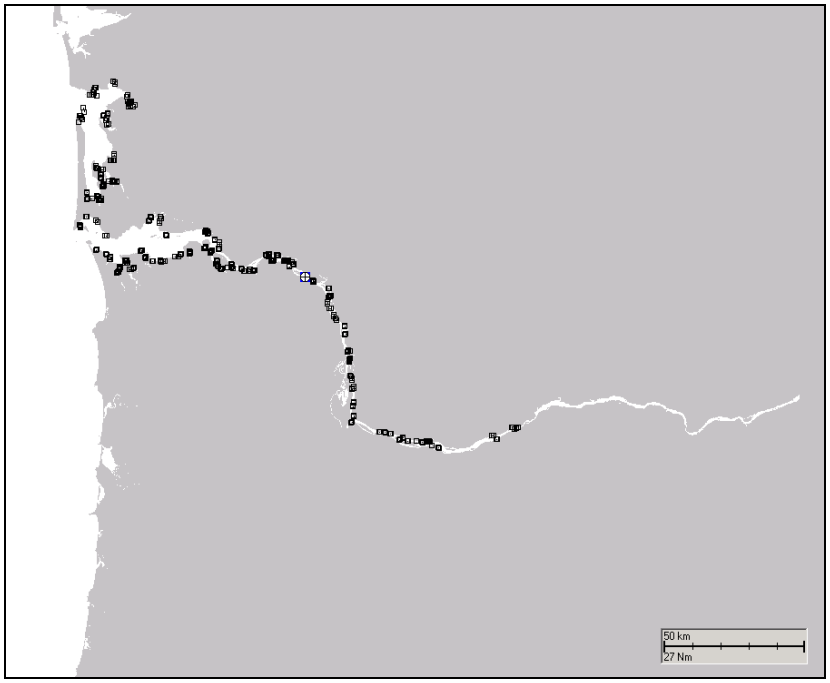


Figure XXI.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

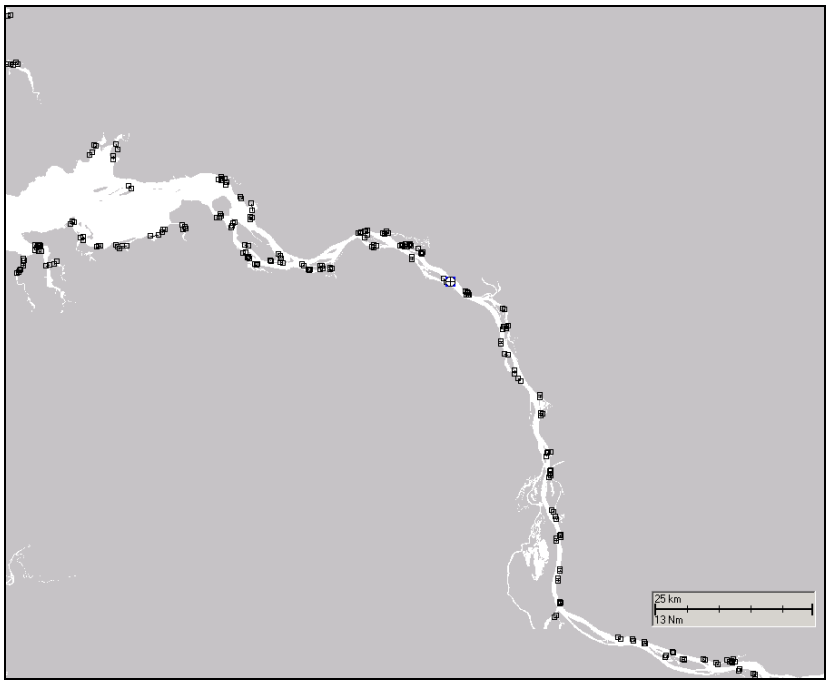


Figure XXI.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

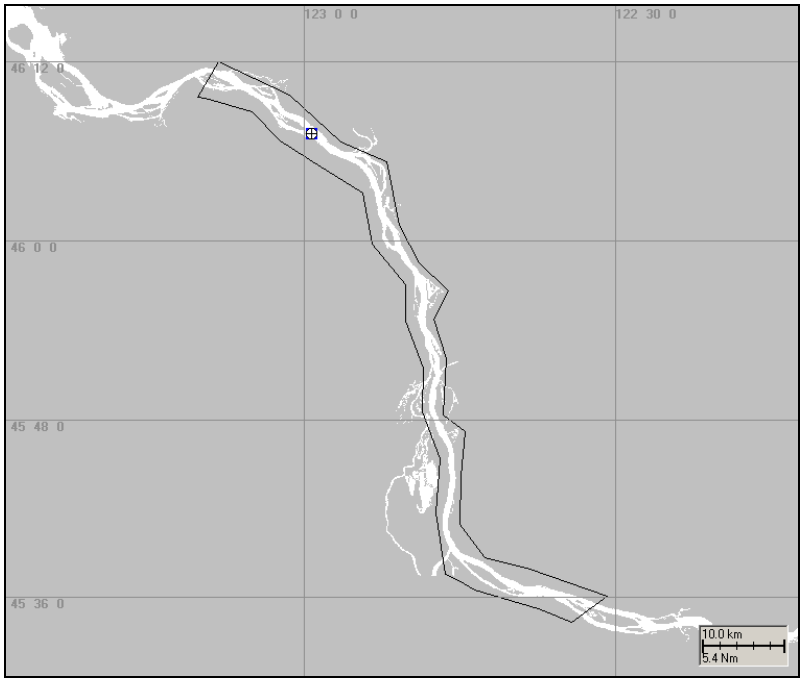


Figure XXI.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

XXI.C. CURRENT DATA

XXI.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 two-dimensional current data set for the area surrounding the potential spill locations. The grid used in this study consists of 800 x 800 square water segments (200 x 175 m) with 13150 water cells. The model forcing functions consist of surface elevations along the open boundaries and fresh water flow from the Columbia River. The annual average flow at the mouth of the Columbia River is 7500 m^3/s, with a monthly maximum average of 10,500 m^3/s in June (Geise and Jay, 1989). The tidal forcing for the 6 major harmonic constituents (M_2, S_2, N_2, K_1, O_1 and P_1) at Astoria obtained from NOAA was applied along the open boundary. The model predicted surface elevations were calibrated using the observed surface elevations obtained from NOAA.

<u>Reference</u>

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

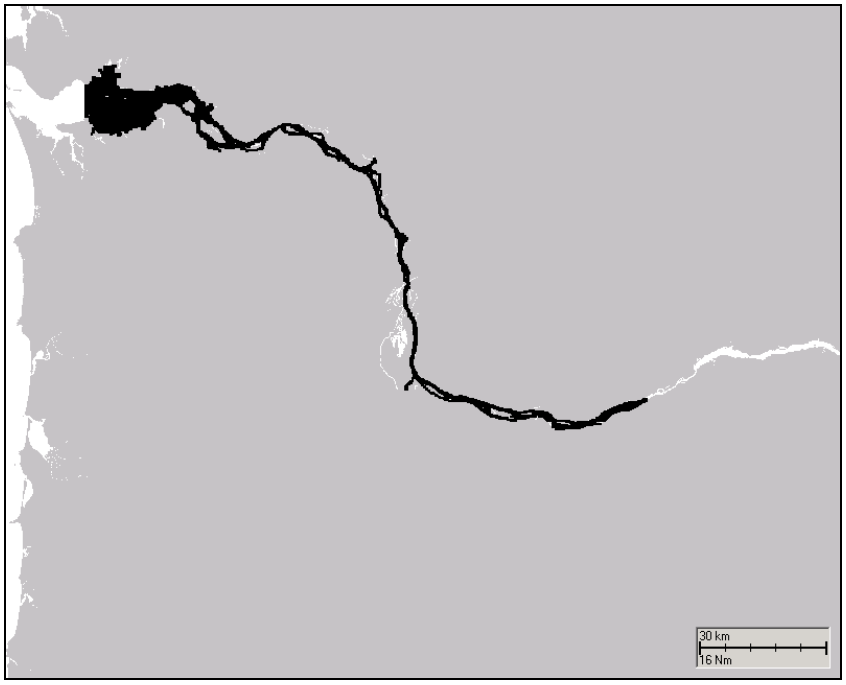


Figure XXI.C.1-1 Grid used for the hydrodynamic model-generated current data.

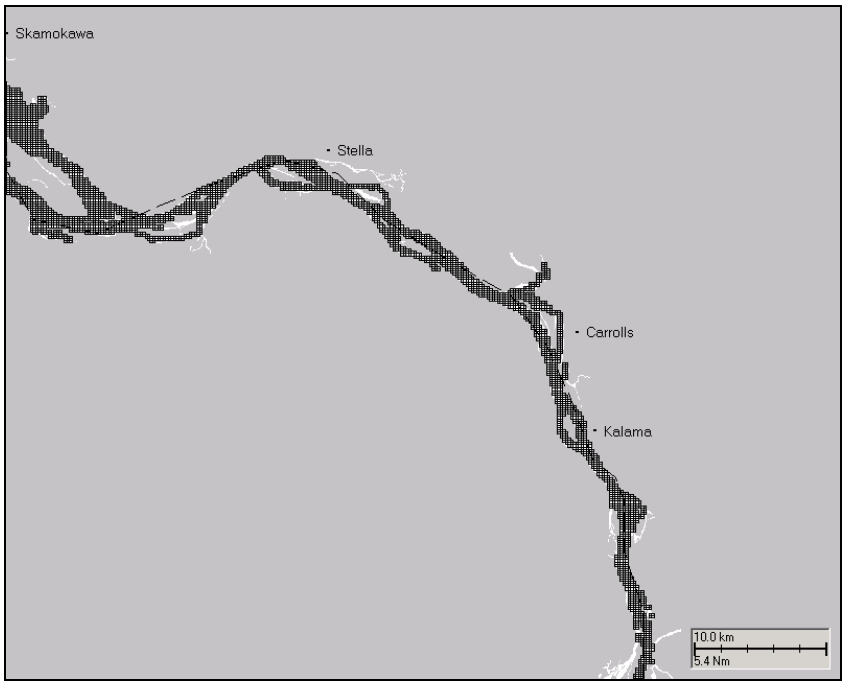


Figure XXI.C.1-2 Grid used for the hydrodynamic model-generated current data (closer view – Stella, WA).

XXI.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 dominant component, the M_2. Note that 0.5 m/sec = 1 knot.

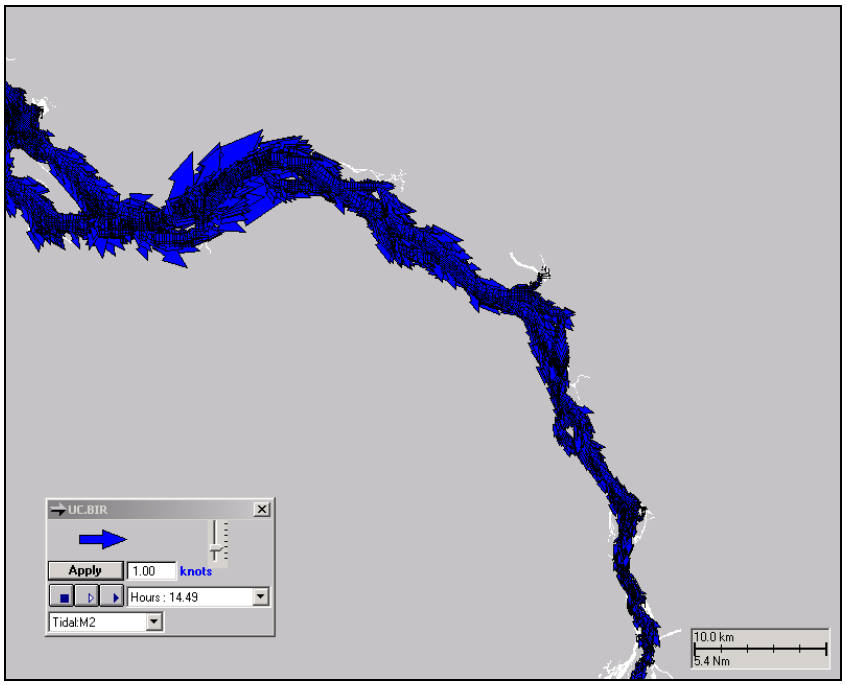


Figure XXI.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the dominant tidal component (M2) at Stella, WA.

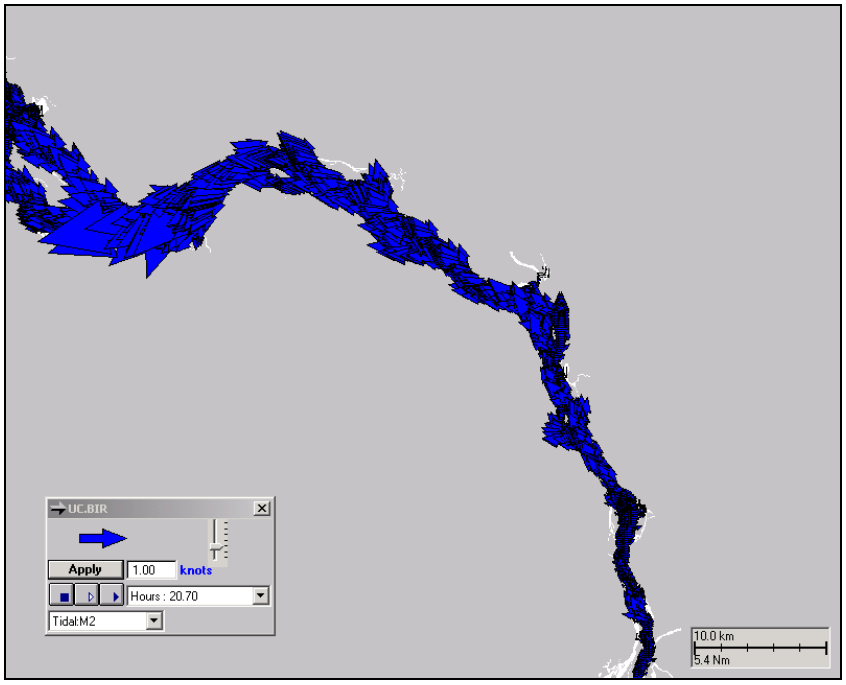


Figure XXI.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the dominant tidal component (M2) at Stella, WA.

XXI.D: OIL PROPERTIES

Table XXI.D-1. Oil properties for Bunker C assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.9749	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	3180	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27	Jokuty et al. (1999)
Pour Point (deg. C)	7	Whiticar et al. (1994)
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)	0.00	Ostazeski et al. (1997)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.036093	Ostazeski et al. (1997)
Fraction 2-ring aromatics (included in PAHs above)	0.011987	Ostazeski et al. (1997)
Fraction 3-ring aromatics (included in PAHs above)	0.024106	Ostazeski et al. (1997)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.010000	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.037013	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.088894	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	30	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] – Jokuty 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 XXI.D-2. Aromatic concentrations (mg/kg) for Bunker C.

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	752
C1-naphthalenes	3.87	4,100
C2-naphthalenes	4.37	7,135
C3-naphthalenes	5.00	5,509
C4-naphthalenes	5.55	2,746
biphenyls	3.9	74
acenaphthylene	4.07	2
acenaphthene	3.92	219
dibenzofuran	4.31	76
Fluorene	4.18	239
C1-fluorenes	4.97	659
C2-fluorenes	5.20	1,144
C3-fluorenes	5.50	1,077

*Estimates of log(K_{ow}) are from Mackay et al. (1992a,b) and Neff and Burns (1996).

Table XXI.D-2. Aromatic concentrations (mg/kg) for Bunker C (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	346
C1-dibenzothiophene	4.86	1,072
C2-dibenzothiophene	5.50	1,489
C3-dibenzothiophene	5.73	1,176
phenanthrene	4.57	743
anthracene	4.54	88
C1-phenanthrenes/anthracenes	5.14	2,031
C2-phenanthrenes/anthracenes	5.25	2,661
C3-phenanthrenes/anthracenes	6.00	1,825
C4-phenanthrenes/anthracenes	6.51	930
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total $\log(K_{ow}) \leq 5.6$	-	32,162.3

*Estimates of $\log(K_{ow})$ are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XXI.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 XXI.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	Varied from Portland to Longview
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXI.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXI.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	25,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.1
Model duration	Length of each model simulation	Days	-	28 days

Table XXI.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XXI.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 48	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 48	monthly means (see Table XXI.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 48	monthly means (see Table XXI.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

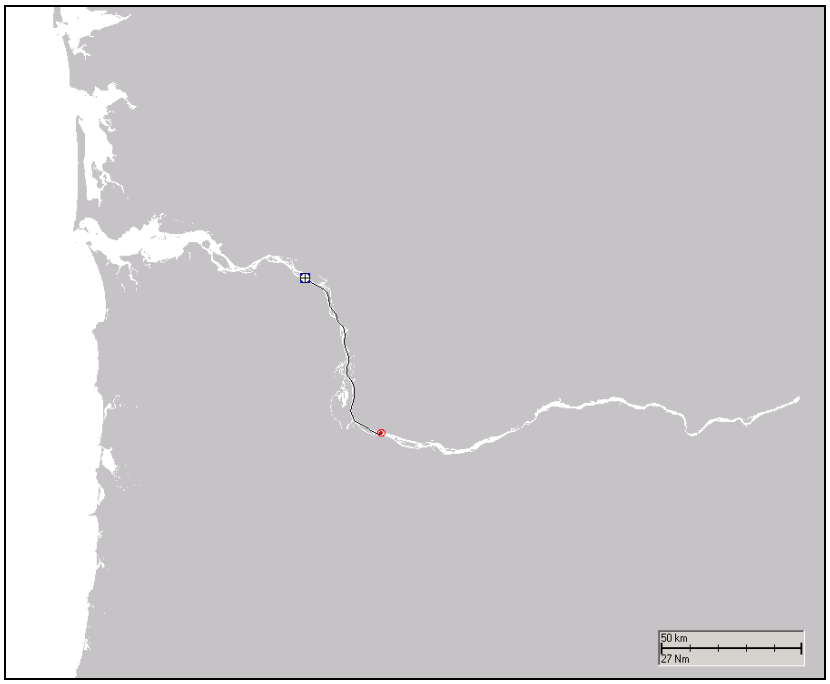


Figure XXI.E-1 Varied range of spill site from Portland to Longview.

Table XXI.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	1992	4	27	8	46.02387	122.8697
2	2003	6	3	14	45.8441	122.7858
3	1994	10	10	7	46.09368	122.9304
4	1992	9	11	18	46.0242	122.8701
5	1995	9	12	4	45.65681	122.7629
6	2000	7	21	14	45.62213	122.6843
7	2001	6	7	19	46.01503	122.8588
8	1995	8	2	7	46.06813	122.8889
9	1993	8	26	2	46.00887	122.8527
10	1992	3	26	15	45.63296	122.705
11	1995	12	1	17	45.73799	122.7598
12	1994	6	21	23	46.00874	122.8526
13	1998	7	12	22	45.75583	122.7619
14	2003	7	27	19	45.68534	122.7754
15	1992	10	21	3	46.02488	122.871
16	1994	8	20	7	46.0139	122.8574
17	2001	1	25	17	45.62838	122.6967
18	1992	9	21	16	45.70356	122.7706
19	1994	9	24	2	46.10405	122.9628
20	1994	8	28	23	46.02061	122.8657
21	2001	2	28	21	45.752	122.7615
22	1996	5	15	9	45.60987	122.6484
23	1993	12	20	15	45.92963	122.8041
24	2000	7	8	11	46.09653	122.9408
25	1997	8	1	6	45.8237	122.7957
26	1995	6	19	2	46.04856	122.879
27	1994	3	6	3	45.65511	122.7614
28	1992	1	27	15	45.96069	122.8151
29	1992	12	20	19	46.01942	122.8642
30	1994	6	24	3	45.70752	122.7692
31	1998	8	17	5	45.65585	122.7621
32	1994	10	5	11	45.71954	122.7649
33	1998	7	9	12	45.77142	122.7663
34	2002	3	2	18	45.63997	122.7234
35	1994	5	19	20	45.80482	122.7921
36	1993	12	21	23	45.78897	122.7793
37	2001	9	20	22	45.78858	122.779
38	2003	1	15	13	45.93076	122.804
39	1998	8	2	23	45.98769	122.8421
40	1994	6	26	3	45.87641	122.7929
41	1992	4	5	4	45.94345	122.8052
42	1993	10	24	22	45.94698	122.8061
43	1995	6	6	6	46.02065	122.8657
44	2003	5	20	19	45.64365	122.736
45	1992	1	28	12	45.842	122.7869
46	1992	3	25	17	45.62794	122.6959
47	1996	7	12	9	46.02317	122.8689
48	1999	6	13	15	46.00842	122.8523
49	2001	2	22	1	45.78052	122.7723
50	1993	7	26	19	46.0292	122.8745

51	1994	9	23	19	45.751	122.7613
52	2000	7	9	23	45.69104	122.7745
53	1994	8	26	22	45.94154	122.8049
54	1998	5	28	20	45.84079	122.7875
55	2003	5	27	11	45.96102	122.8154
56	1998	6	11	9	45.95793	122.8122
57	2003	11	3	15	45.83789	122.789
58	1992	1	10	15	46.08317	122.9053
59	1992	5	5	7	45.70041	122.7717
60	1995	10	30	16	45.97305	122.831
61	2000	10	2	21	45.8256	122.795
62	1997	2	8	23	45.94374	122.8053
63	1995	5	12	13	45.7057	122.7698
64	1996	5	24	5	45.92623	122.8046
65	1993	7	10	17	46.1059	122.9656
66	1994	1	2	6	45.99205	122.8443
67	1999	3	13	23	45.96893	122.8256
68	1993	12	11	6	45.75753	122.7621
69	1998	8	16	11	45.68316	122.775
70	1999	5	31	7	45.75395	122.7617
71	1996	7	27	23	46.08615	122.9122
72	1997	8	14	14	46.07565	122.8948
73	1996	7	16	8	45.98699	122.8417
74	1994	10	6	5	45.87974	122.7958
75	2003	1	12	23	45.78138	122.773
76	2002	5	28	13	45.68273	122.7749
77	1992	10	31	15	45.91203	122.8081
78	1998	8	28	9	45.8844	122.7997
79	1994	9	29	9	45.98591	122.8412
80	1993	8	1	13	46.00008	122.8484
81	1997	2	18	17	46.03993	122.8773
82	1993	12	22	19	45.63874	122.7199
83	1993	12	24	23	45.92203	122.8065
84	1999	6	12	9	45.72266	122.7638
85	1995	7	25	13	46.08564	122.911
86	1994	3	16	17	45.68752	122.7753
87	1996	8	9	19	46.09961	122.9511
88	1994	1	4	10	45.95201	122.8075
89	1997	3	21	17	45.62293	122.6866
90	1999	2	28	15	45.71039	122.7681
91	2002	4	26	23	45.76548	122.7639
92	1994	8	12	5	45.90946	122.8081
93	2001	9	9	11	45.76244	122.7632
94	2000	9	16	4	46.09078	122.9228
95	1998	6	3	23	45.61452	122.662
96	2003	1	12	14	46.02563	122.8719
97	1995	11	23	23	45.76168	122.763
98	2000	8	18	8	45.7021	122.7711
99	1995	6	7	5	45.66943	122.7708
100	2002	3	8	0	45.76585	122.764

Table XXI.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	C2_HABS.HAB
Frid W edge	124° 4.5'W
Frid S edge	45° 26.3' N
Cell size (^{o}longitude)	0.002^o W
Cell size (^{o}latitude)	0.002^o N
Cell size (m) west-east	140.19
Cell size (m) south-north	199.80
# cells west-east	1,784
# cells south-north	518
Water cell area (m^2)	28,010.92
Shore cell length (m)	167.36
Shore cell width – Rocky shore (m)	3.0
Shore cell width – Artificial shore (m)	3.0
Shore cell width – Fravel 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 XXI.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	10
February	10	8	10
March	10	8	10
April	11	8	10
May	12	8	10
June	14	8	10
July	14	7	5
August	14	7	5
September	14	7	5
October	13	7	10
November	12	7	10
December	10	7	10

Table XXI.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 XXI.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.

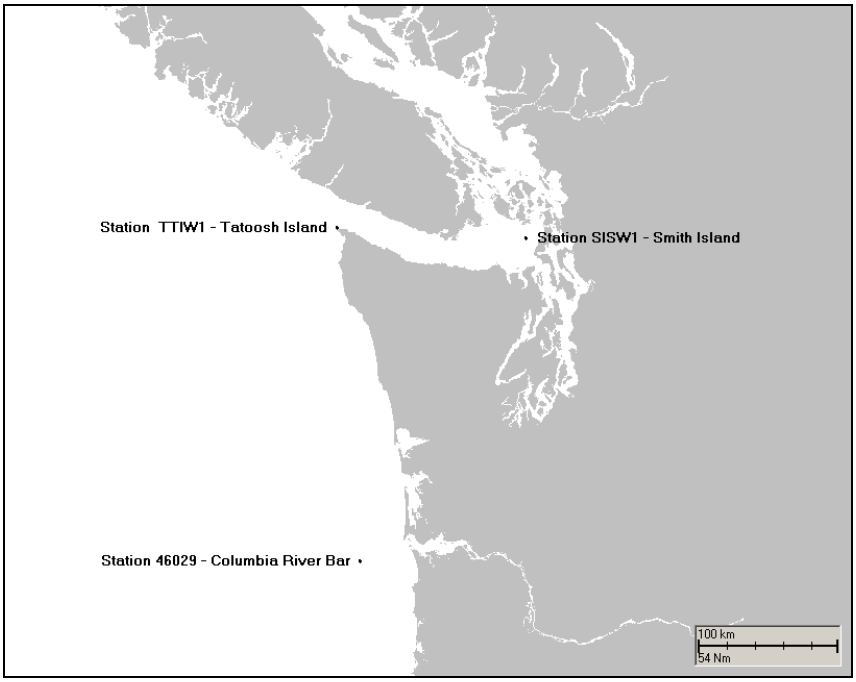


Figure XXI.E-2. Wind Station Locations.

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 XXII: Model Results for Runs Assuming No Response for Upper Columbia River – Bunker C

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

XXII.A. Introduction 1
XXII.B. Maps of Exposure Probability and Time First Exposed 1
XXII.C. Statistics for All Model Runs 3
XXII.D. Shoreline Areas Exposed by Shore Type 6
XXII.E. Exposure for Representative Individual Model Runs. 8
XXII.F. Estimated Biological Impacts: Wildlife 10
XXII.G. Estimated Biological Impacts: Fish and Invertebrates 13
XXII.H. Estimated NRDA Costs: Habitat Restoration Costs 15
XXII.I. Estimated NRDA Costs: Washington Compensation schedule 18

List of Figures

Figure XXII.B-1. Upper Columbia River – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure XXII.B-2. Upper Columbia River – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. 2
Figure XXII.C-1. Upper Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 5
Figure XXII.C-2. Upper Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill..... 5
Figure XXII.E-1. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 8
Figure XXII.E-2. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for a worst run for Ridgefield National Wildlife Refuge (#1). 9
Figure XXII.E-3. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for a worst run for Ridgefield National Wildlife Refuge (#2). 9

List of Tables

Table IV.C-1. Upper Columbia River – Bunker C, No mechanical removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 4
Table XXII.D-1. Upper Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 6
Table XXII.D-2. Upper Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 6
Table XXII.D-3. Upper Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 7
Table XXII.D-4. Upper Columbia River – Bunker C, No mechanical removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 7
Table XXII.F-1. Upper Columbia River – Bunker C, No mechanical removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose. 11
Table XXII.F-2. Upper Columbia River – Bunker C, No mechanical removal: Wildlife injury (as numbers lost). 12
Table XXII.G-1. Upper Columbia River – Bunker C, No mechanical removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column. 14
Table XXII.G-2. Upper Columbia River – Bunker C, No mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 14
Table XXII.H-1. Upper Columbia River – Bunker C, No mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 16
Table XXII.H-2. Upper Columbia River – Bunker C, No mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 17

XXII.A. INTRODUCTION

The results of the stochastic scenario for the Upper Columbia River – Bunker C 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).

XXII.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)

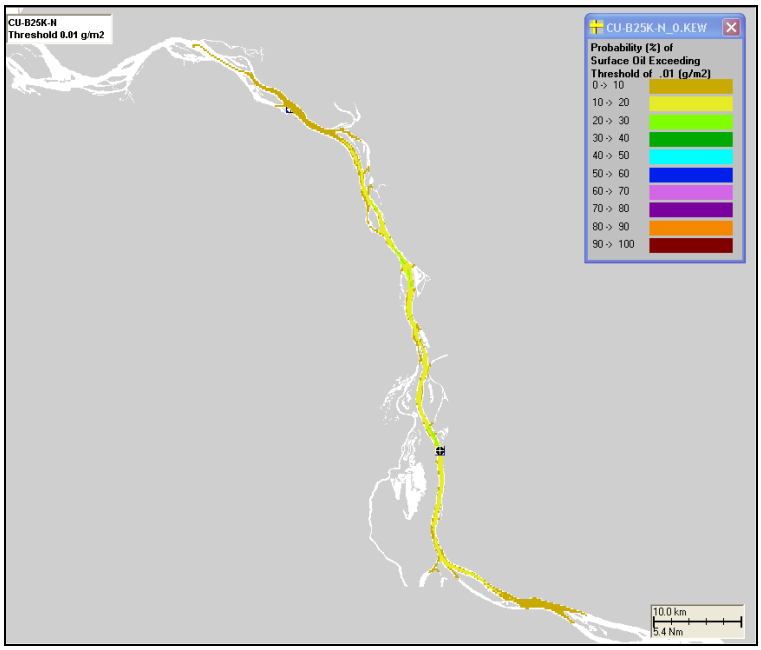


Figure XXII.B-1. Upper Columbia River – Bunker C, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

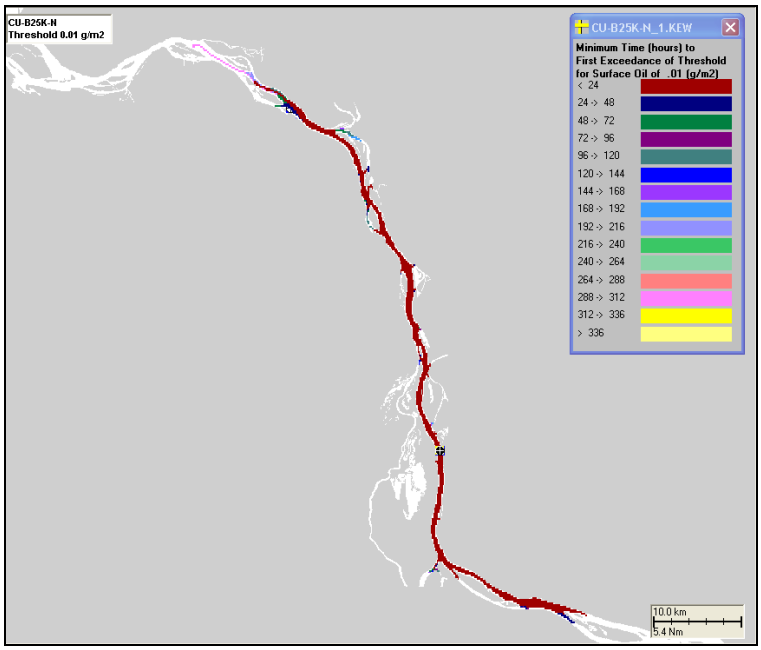


Figure XXII.B-2. Upper Columbia River – Bunker C, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed for this location, maximum water column exposure of dissolved aromatic concentration for this scenario never exceeded 1 ppb. Consequently, maps of such exceedances are not shown here.

XXII.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 IV.C-1. Upper Columbia River – Bunker C, 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)	4	5	14	0	2	13	24
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	4	5	14	0	2	13	24
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	2,040	2,451	6,942	0	1,096	6,314	11,756
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	2,040	2,451	6,942	0	1,096	6,314	11,756
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	2,040	2,451	6,942	0	1,096	6,314	11,756
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	2,040	2,451	6,942	0	1,096	6,314	11,756
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	2,040	2,451	6,942	0	1,096	6,314	11,756
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	1,388	1,417	4,222	0	977	4,374	6,812
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 (%)	69.14	9.76	88.66	0	71.19	80.92	82.66
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	38.6827	14.8461	68.3749	0	42.6256	57.4180	58.2933
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	1.63	0.94	3.51	0	1.40	3.44	4.45

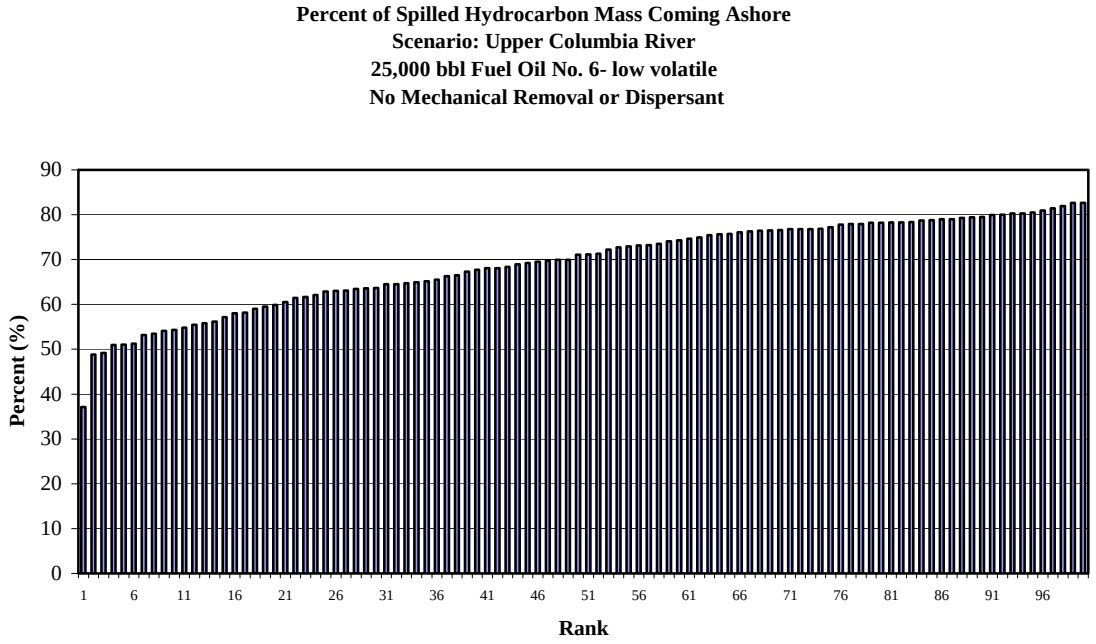


Figure XXII.C-1. Upper Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

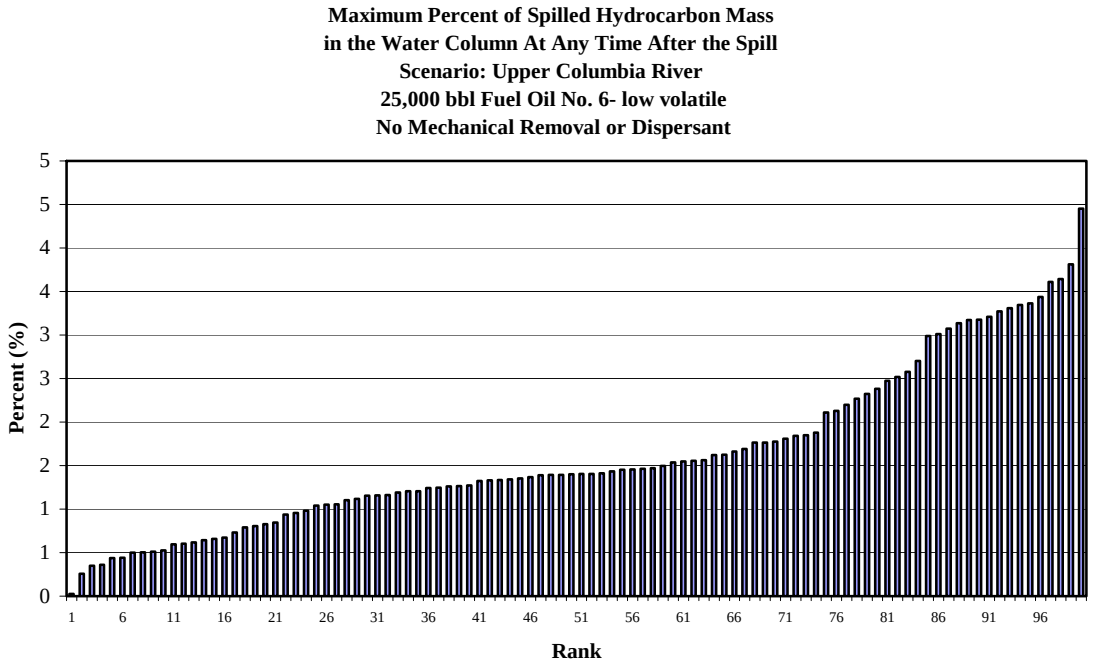


Figure XXII.C-2. Upper Columbia River – Bunker C, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

XXII.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 XXII.D-1. Upper Columbia River – Bunker C, 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	277,658	26,611	0	145,607	0	105,440	0
95th	536,236	1,506	0	148,118	0	386,612	0
Maximum	707,451	34,142	0	251,047	0	527,198	0
Mean	295,176	5,066	0	127,030	0	163,080	0
Std. Dev.	113,217	7,909	0	53,996	0	116,570	0
Mean + 2 Std. Dev.	521,610	20,884	0	235,022	0	396,220	0

Table XXII.D-2. Upper Columbia River – Bunker C, 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	276,152	5,021	0	200,838	0	70,293	0
95th	525,190	33,138	0	140,586	0	351,466	0
Maximum	704,940	34,142	0	251,047	0	527,198	0
Mean	293,745	5,066	0	126,653	0	162,026	0
Std. Dev.	112,009	7,909	0	53,839	0	115,211	0
Mean + 2 Std. Dev.	517,763	20,884	0	234,331	0	392,448	0

Table XXII.D-3. Upper Columbia River – Bunker C, 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	261,088	0	0	50,209	0	210,879	0
95th	485,525	26,109	0	143,097	0	316,319	0
Maximum	697,409	34,142	0	248,536	0	527,198	0
Mean	278,527	5,061	0	123,390	0	150,076	0
Std. Dev.	107,206	7,898	0	52,565	0	112,244	0
Mean + 2 Std. Dev.	492,939	20,857	0	228,520	0	374,564	0

Table XXII.D-4. Upper Columbia River – Bunker C, 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	168,201	0	0	27,615	0	140,586	0
95th	300,754	7,029	0	47,699	0	246,026	0
Maximum	321,340	33,138	0	143,097	0	281,173	0
Mean	178,158	4,810	0	88,293	0	85,055	0
Std. Dev.	53,468	7,625	0	33,774	0	68,345	0
Mean + 2 Std. Dev.	285,094	20,060	0	155,841	0	221,745	0

XXII.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three 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 Ridgefield National Wildlife Refuge (first run, #1); and
3. the worst case run for impacts at Ridgefield National Wildlife Refuge (second run, #2).

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.

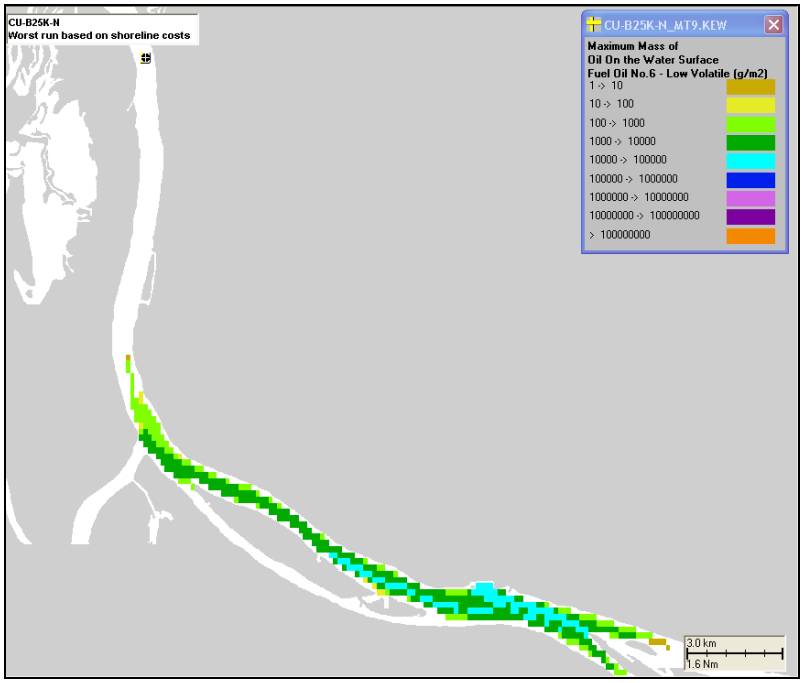


Figure XXII.E-1. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

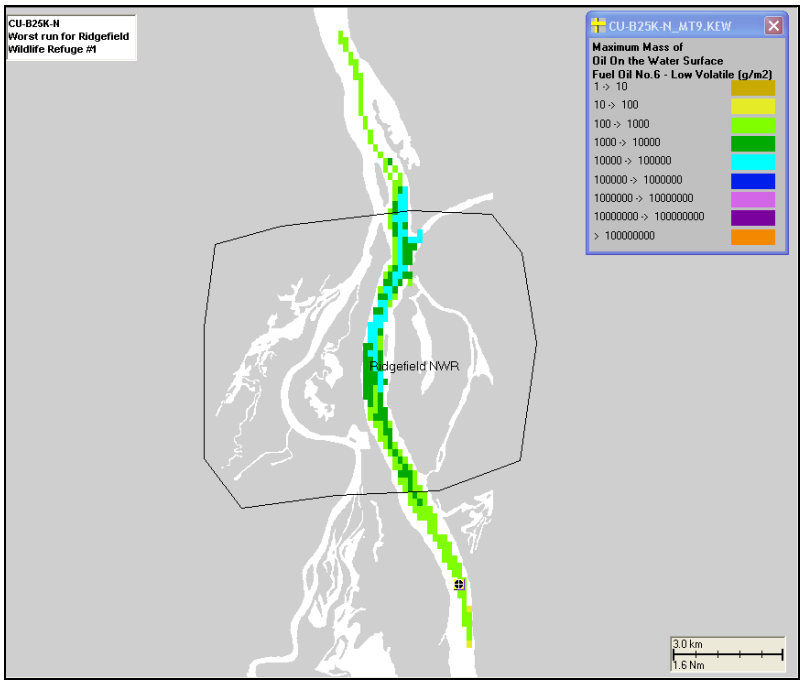


Figure XXII.E-2. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for a worst run for Ridgefield National Wildlife Refuge (#1).

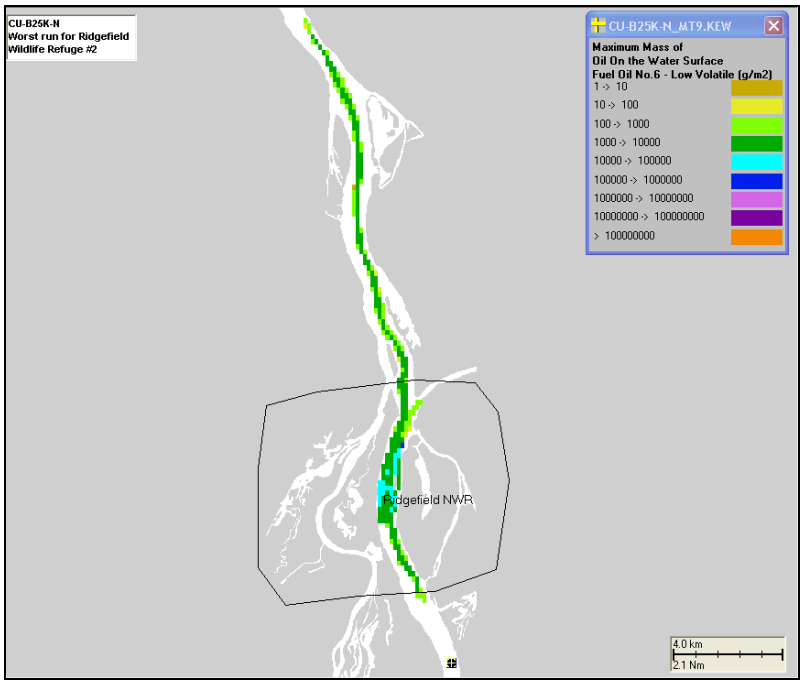


Figure XXII.E-3. Upper Columbia River, No mechanical removal: Water surface exposure to floating hydrocarbons (g/m^2) for a worst run for Ridgefield National Wildlife Refuge (#2).

XXII.F. ESTIMATED BIOLOGICAL IMPACTS: WILDLIFE

Impacts to wildlife (birds and marine or aquatic mammals) were calculated using the biological effects model for the following 12 runs selected from the stochastic model results (assuming no response).

- 5th, 50th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions;
- 5th, 50th and 95th percentile runs based on shore cost, including only Washington state shorelines;
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table XXII.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 XXII.F-1. Upper Columbia River – Bunker C, 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	-5.04E-06	54.19	46.60	0.1232	-0.3510
Seabirds	1.85E-06	9.92	12.75	0.2020	0.4495
Wading birds	4.87E-05	-5.00	4.16	0.7359	0.8579
Shorebirds	4.07E-05	-3.36	22.19	0.0640	0.2531
Raptors	3.67E-06	-0.23	0.23	0.8436	0.9185
Kingfishers[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Cetaceans[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Pinnipeds (seals)[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Other mammals	1.20E-05	70.08	97.33	0.1540	0.3924

[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 XXII.F-2. Upper Columbia River – Bunker C, 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	54	9	1	-	0	-	-	60	140	65	60.04
50th Percentile	54	9	6	694	0	-	-	95	848	764	94.77
95th Percentile	55	10	14	1,921	0	-	-	142	2,098	2,001	141.60
Mean	54	10	7	814	0	-	-	97	983	885	97.09
Std Dev (SD)	0	0	4	615	0	-	-	23	631	620	23.44
Mean - 2SD	54	9	-	-	-	-	-	50	-	-	50.21
Mean + 2SD	55	10	15	2,044	0	-	-	144	2,245	2,125	143.97

XXII.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XXII.G-1. Upper Columbia River – Bunker C, 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	0.00E+00	1.39	0.00	0.0000	0.0000
Total large pelagic fish	1.24E+01	41.88	14.89	0.2226	0.4718
Total demersal fish	3.52E+02	2743.93	625.30	0.1213	0.3483
Total demersal invertebrates[2]	0.00E+00	0.00	0.00	0.0000	0.0000
Total mollusks[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 fishes and invertebrates (i.e., the regression's intercept) was used to estimate injuries for the additional 88 stochastic runs.
[2] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table XXII.G-2. Upper Columbia River – Bunker C, 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	1.39	47.34	2,899.25	-	-	-	2,948
50th Percentile	1.39	59.24	3,238.32	-	-	-	3,299
95th Percentile	1.39	83.53	3,930.26	-	-	-	4,015
Mean	1.39	62.06	3,318.76	-	-	-	3,382
Std Dev (SD)	0.00	11.65	331.76	-	-	-	343
Mean - 2SD	1.39	38.77	2,655.24	-	-	-	2,695
Mean + 2SD	1.39	85.35	3,982.27	-	-	-	4,069

XXII.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 weights used to calculate habitat restoration costs 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.

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 XXII.H-1. Upper Columbia River – Bunker C, 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	1.4	1.4	1.4	1.4	1.4	1.4
Large pelagic fish	47.3	59.2	83.5	62.1	38.8	85.4
Demersal fish	2,899.2	3,238.3	3,930.3	3,318.8	2,655.2	3,982.3
Decapods	-	-	-	-	-	-
Molluscs	-	-	-	-	-	-
Birds:						
Waterfowl (# * kg each)	15	15	15	15	15	15
Seabirds (# * kg each)	10	10	11	10	10	11
Waders (# * kg each)	2	7	16	8	-	17
Shorebirds (# * kg each)	-	763	2,114	896	-	2,249
Raptors (# * kg each)	0.1	0.2	0.3	0.2	-	0.4
Other wildlife:						
Sea otters, other mammals	66.0	104.2	155.8	106.8	55.2	158.4
Pinnipeds	-	-	-	-	-	-
Cetaceans	-	-	-	-	-	-
Totals:						
Subtotal fish and invertebrates	2,948	3,299	4,015	3,382	2,695	4,069
Subtotal birds	27	796	2,156	929	25	2,292
Subtotal other wildlife	66	104	156	107	55	158
Total all species	3,041	4,199	6,327	4,418	2,776	6,519

Table XXII.H-2. Upper Columbia River – Bunker C, 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)	1.0	2.1	4.1	2.3	1.0	0.9	4.3
Saltmarsh Area (acres)	2.5	5.3	10.2	5.7	2.5	2.2	10.6
Saltmarsh Cost (millions of 2004$)	0.0005	0.001	1.9	1.1	0.0005	0.0004	2.0
Eelgrass Area (m^2)	0.6	1.3	2.6	1.5	0.6	0.6	2.7
Eelgrass Area (acres)	1.6	3.3	6.4	3.6	1.5	1.4	6.7
Eelgrass Cost (millions of 2004$)	0.0002	0.0004	0.0008	0.0004	0.0002	0.0002	0.0008

XXII.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

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

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 XXIII: Results of Alternative Response Scenarios for Upper Columbia River – Bunker C

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

XXIII.A. Introduction 1
XXIII.B. Oil Fate Over Time 3
XXIII.C. Estimated Biological Impacts: Wildlife 43
XXIII.D. Estimated Biological Impacts: Fish and Invertebrates 47
XXIII.E. Estimated NRDA Costs: Habitat Restoration Costs 50
XXIII.F. Estimated NRDA Costs: Washington Compensation schedule 59

List of Figures

Figure XXIII.A-1 Sensitive sites for location: Upper Columbia River. 2
Figure XXIII.B-1 Upper Columbia River - Bunker C, no removal: 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 XXIII.B-2 Upper Columbia River - Bunker C, no removal: 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 XXIII.B-3 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost)..... 6
Figure XXIII.B-4 Upper Columbia River - Bunker C, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). 7
Figure XXIII.B-5 Upper Columbia River - Bunker C, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). 8
Figure XXIII.B-6 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). 9
Figure XXIII.B-7 Upper Columbia River - Bunker C, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). 10
Figure XXIII.B-8 Upper Columbia River - Bunker C, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). 11
Figure XXIII.B-9 Upper Columbia River - Bunker C, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the The Ridgefield National Wildlife Refuge (run#2). 12
Figure XXIII.B-10 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). 13
Figure XXIII.B-11 Upper Columbia River - Bunker C, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#2). 14

List of Tables

Table XXIII.B-1 Upper Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 15
Table XXIII.B-2 Upper Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 17
Table XXIII.B-3 Upper Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost)..... 19
Table XXIII.B-4 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost)..... 21
Table XXIII.B-5 Upper Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1). 23
Table XXIII.B-6 Upper Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1). 25
Table XXIII.B-7 Upper Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1). 27
Table XXIII.B-8 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1). 29
Table XXIII.B-9 Upper Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2). 31
Table XXIII.B-10 Upper Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2). 33
Table XXIII.B-11 Upper Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2). 35
Table XXIII.B-12 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2). 37
Table XXIII.B-13 Upper Columbia River - Bunker C, 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. ... 39
Table XXIII.B-14 Upper Columbia River - Bunker C, 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. 40

Table XXIIIB-15 Upper Columbia River - Bunker C, 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. 41
Table XXIII.B-16 Upper Columbia River - Bunker C, 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. 42
Table XXIII.C-1 Upper Columbia River - Bunker C, no removal: Wildlife injury (as numbers lost)..... 43
Table XXIII.C-2 Upper Columbia River - Bunker C, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table XXIII.C-3 Upper Columbia River - Bunker C, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table XXIII.C-4 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table XXIII.D-1. Upper Columbia River - Bunker C, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XXIII.D-2. Upper Columbia River - Bunker C, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXIII.D-3. Upper Columbia River - Bunker C, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXIII.D-4. Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 49
Table XXIII.E-1. Upper Columbia River - Bunker C, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 51
Table XXIII.E-2. Upper Columbia River - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration..... 52
Table XXIII.E-3. Upper Columbia River - Bunker C, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 53
Table XXIII.E-4. Upper Columbia River - Bunker C, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 54
Table XXIII.E-5. Upper Columbia River - Bunker C, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 55
Table XXIII.E-6. Upper Columbia River - Bunker C, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 56
Table XXIII.E-7. Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 57
Table XXIII.E-8. Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 58

XXIII.A. INTRODUCTION

The results of the alternate response scenarios for the Upper Columbia River – Bunker C 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Ridgefield National Wildlife Refuge (run #1); and
3. the worst case run for impacts at Ridgefield National Wildlife Refuge (run #2).

For this location, only one sensitive site was identified, and the worst two runs to that site were examined. The location of the sensitive site is shown in Figure XXIII.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.

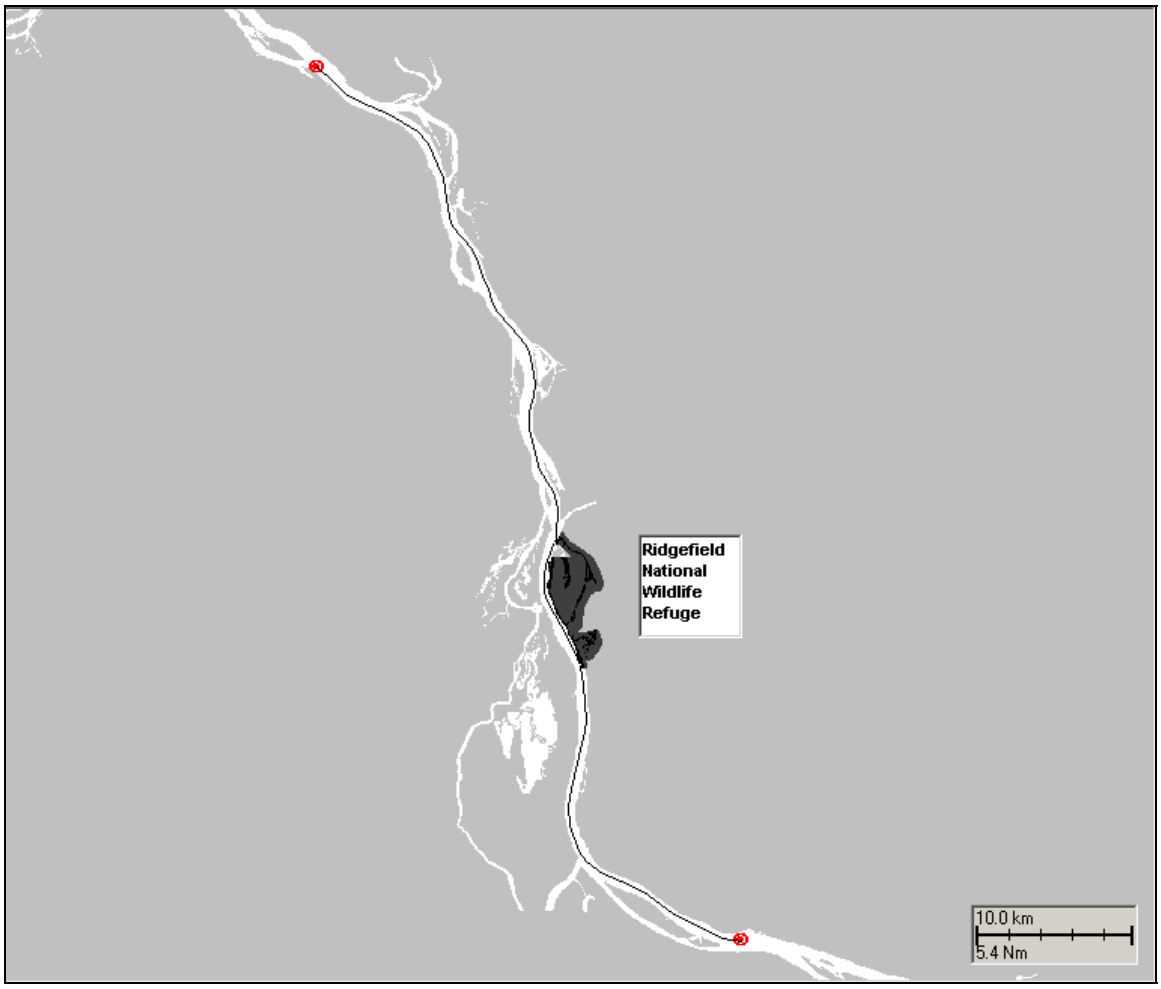


Figure XXIII.A-1 Sensitive sites for location: Upper Columbia River.

XXIII.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XXIII.B-1 to XXIII.B-12 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 XXIII.B-1 to XXIII.B-11 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 XXIII.B-13 to XXVII.B-16 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 Etkin 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.

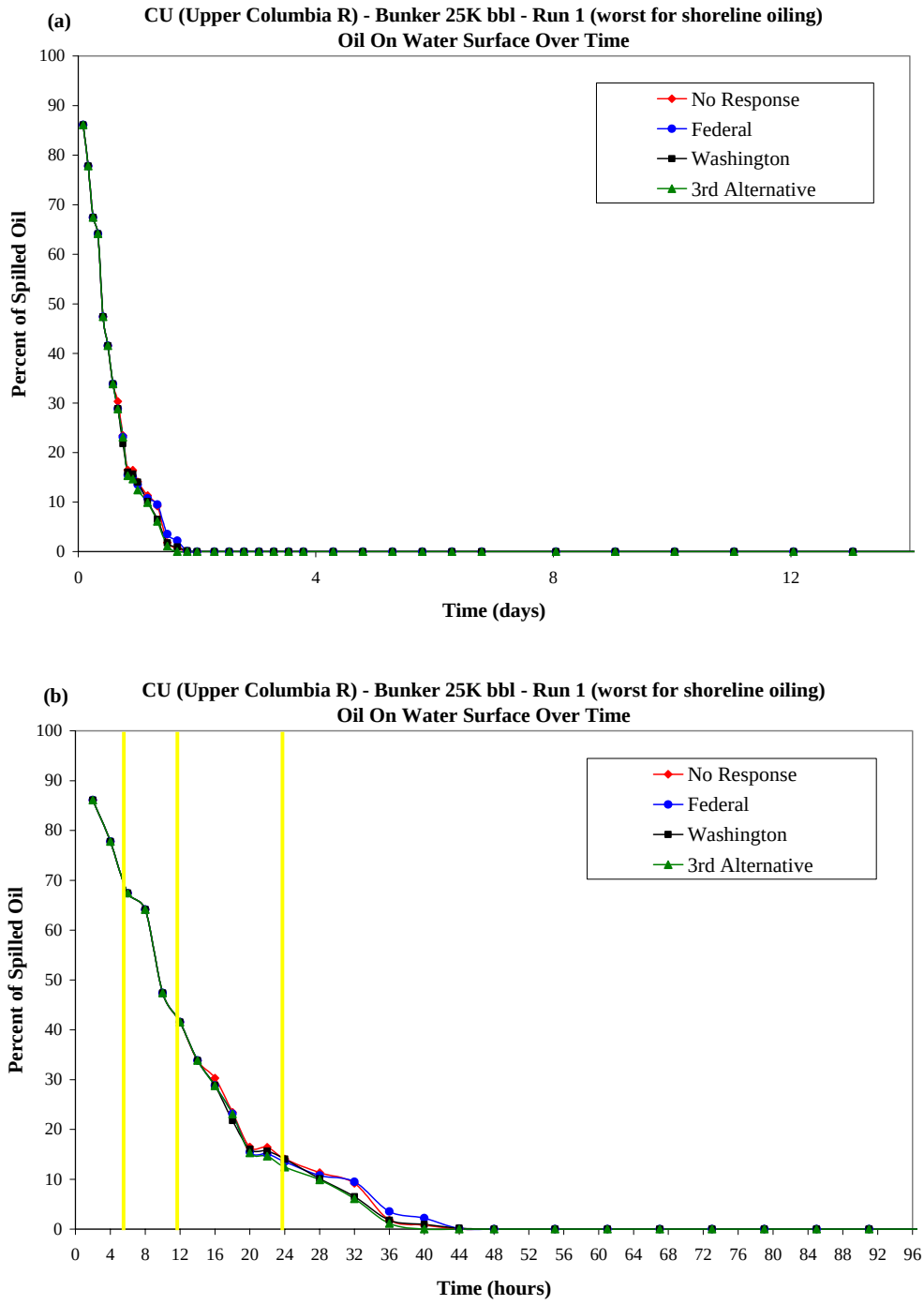
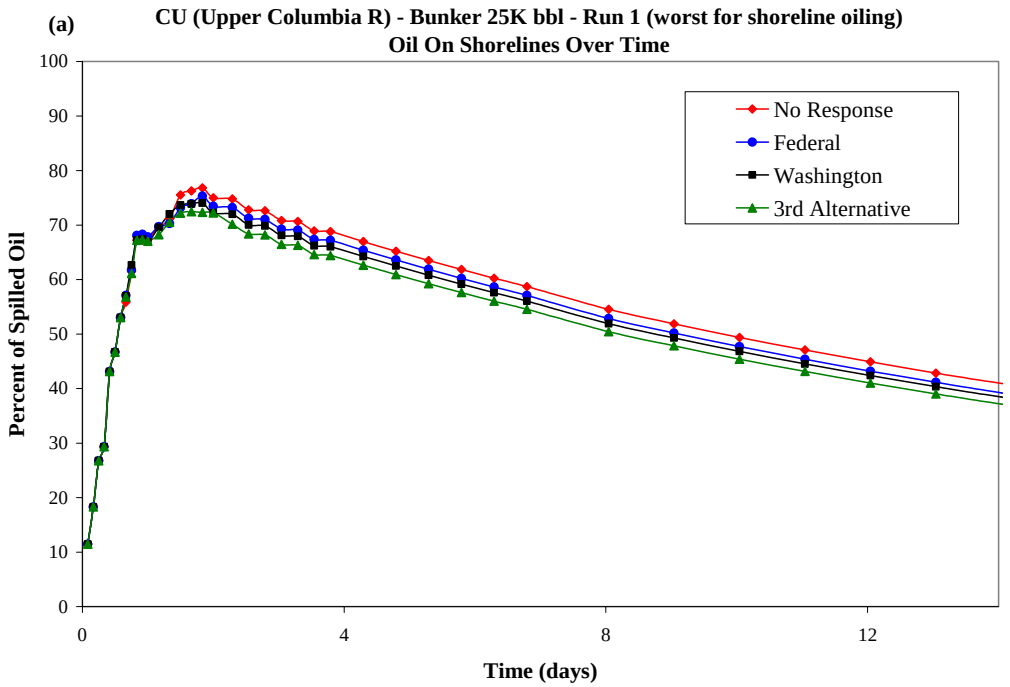


Figure XXIII.B-1 Upper Columbia River - Bunker C, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant).



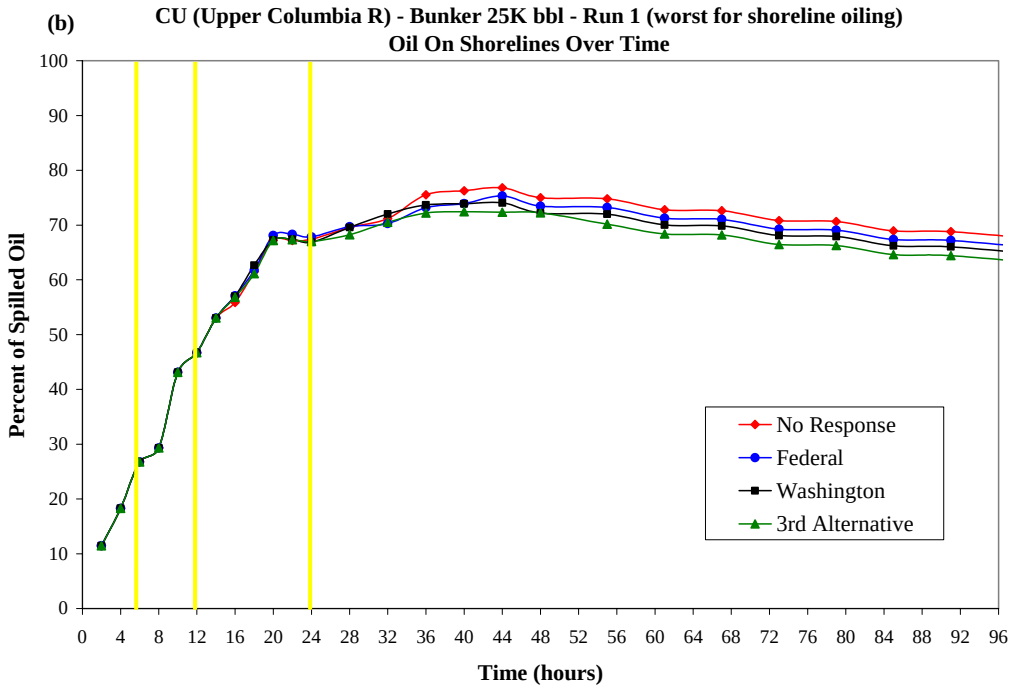


Figure XXIII.B-2 Upper Columbia River - Bunker C, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant).

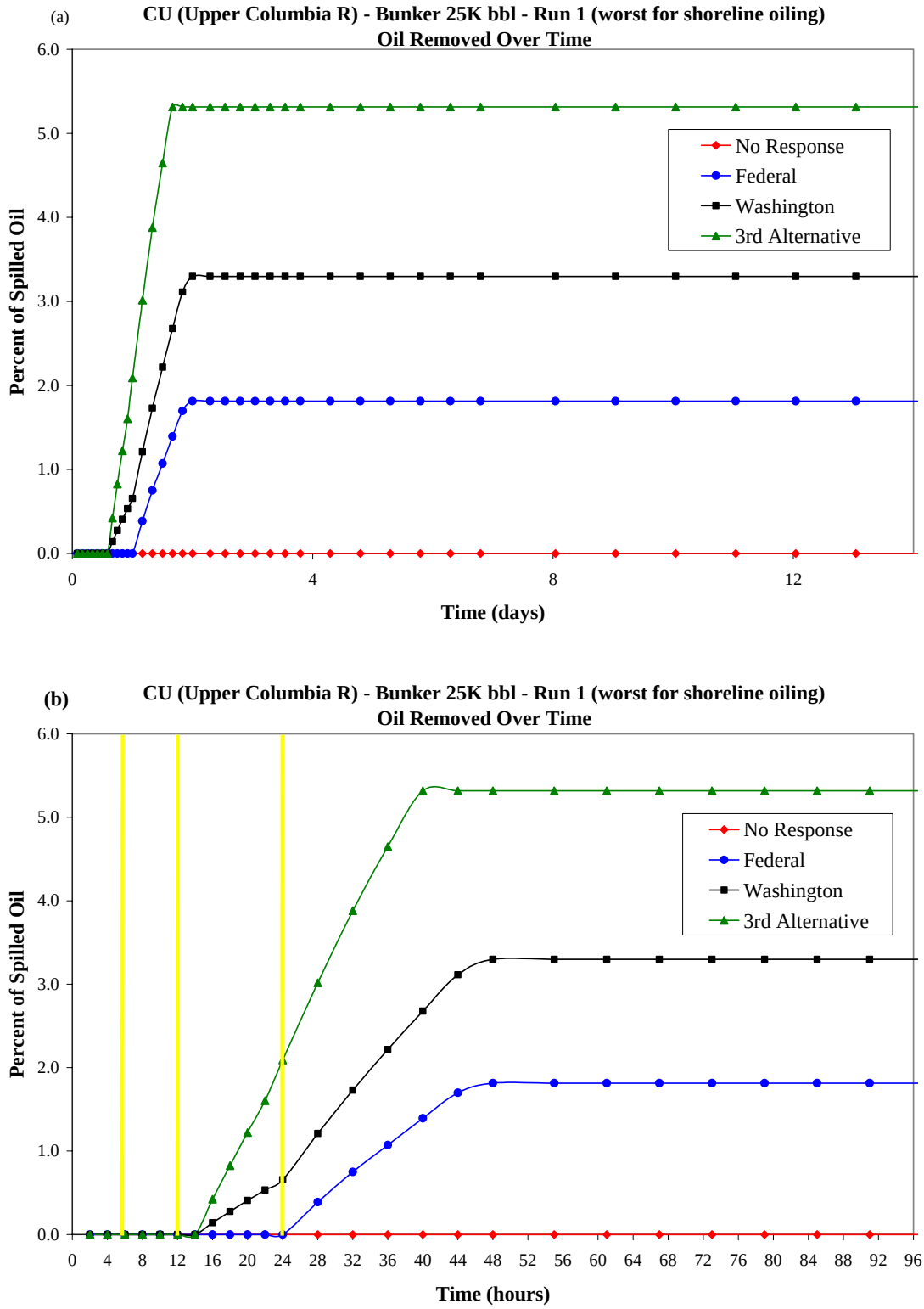
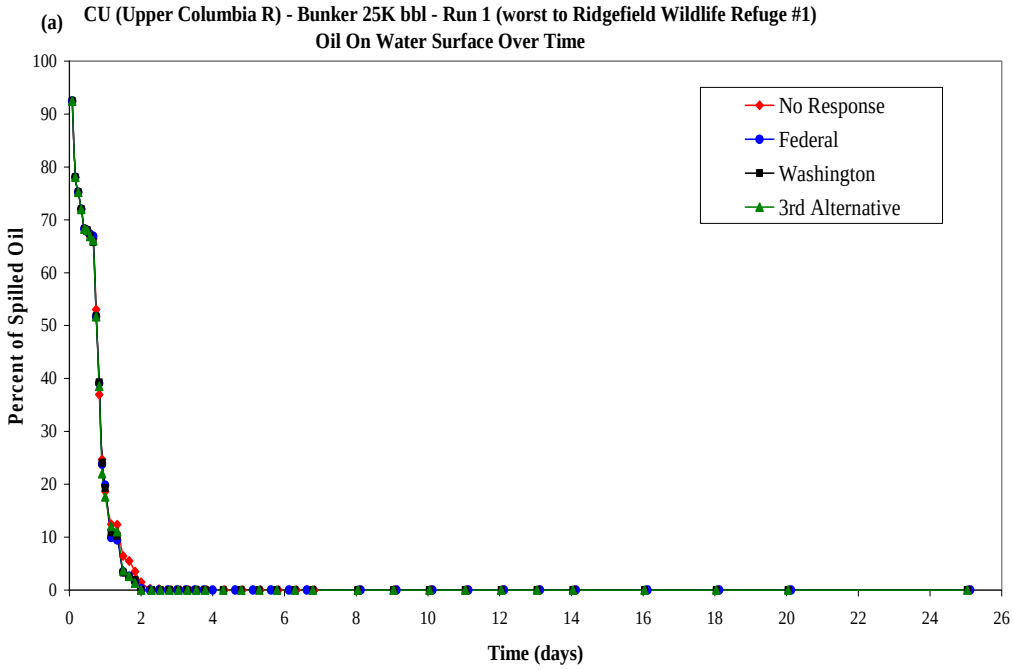


Figure XXIII.B-3 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



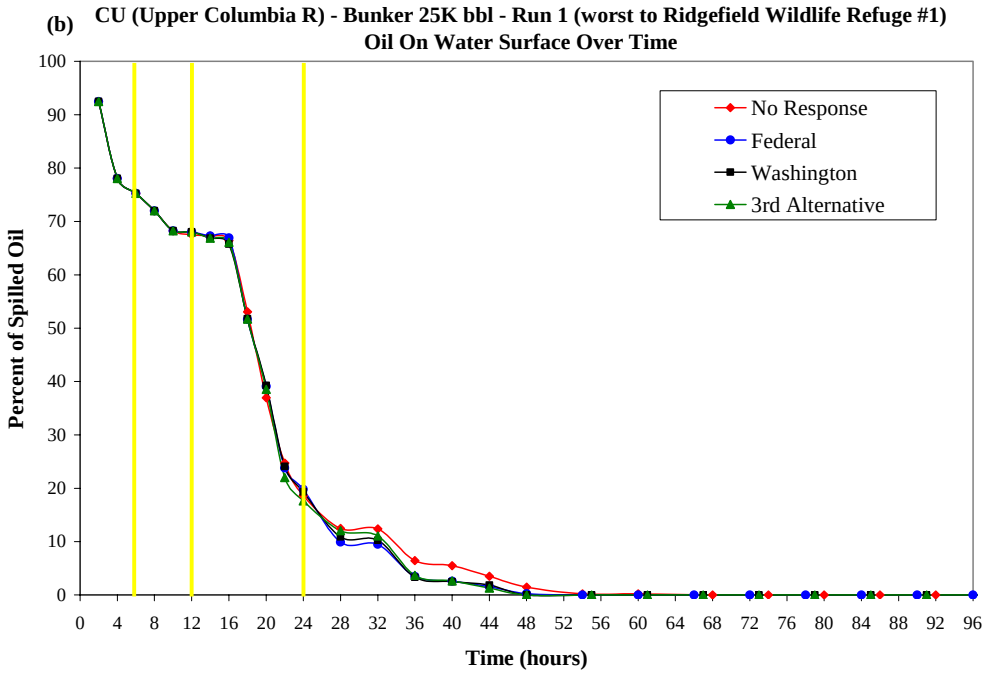
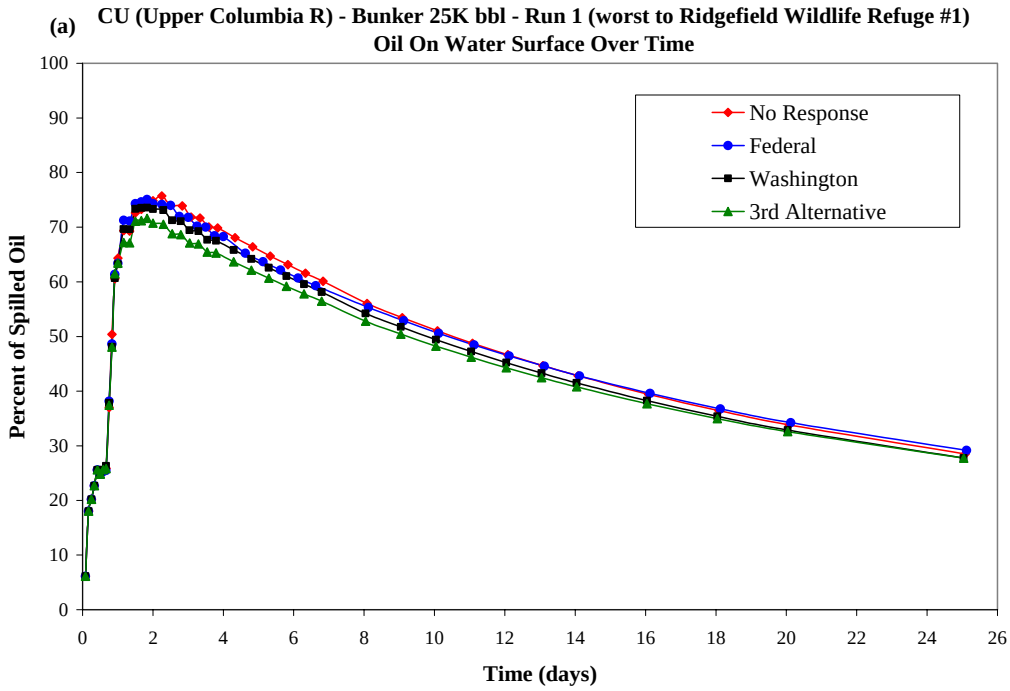


Figure XXIII.B-4 Upper Columbia River - Bunker C, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant).



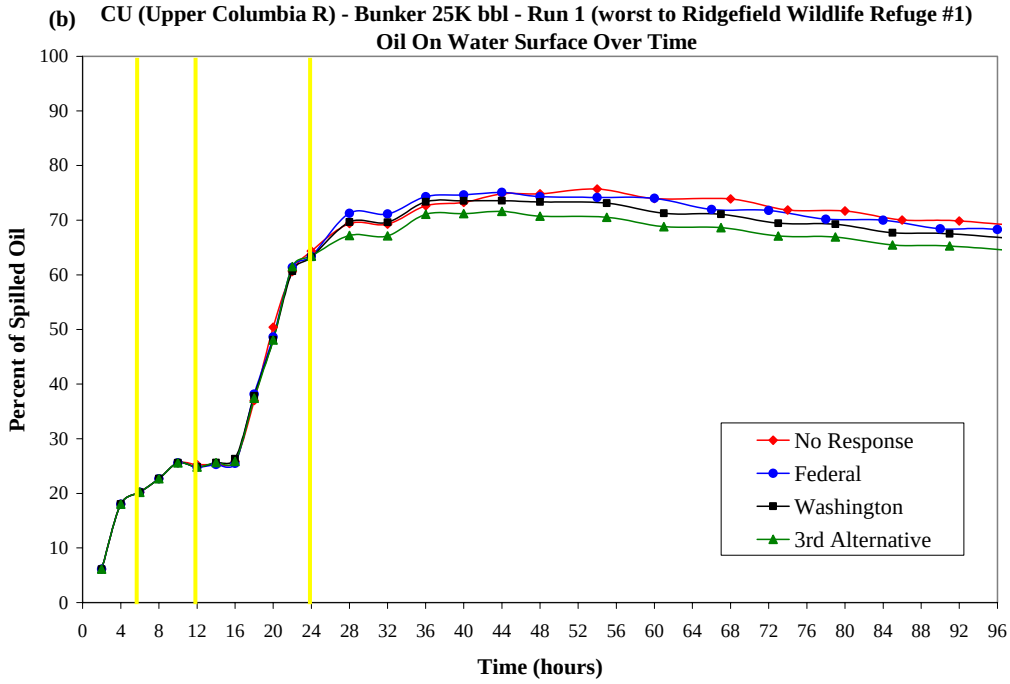
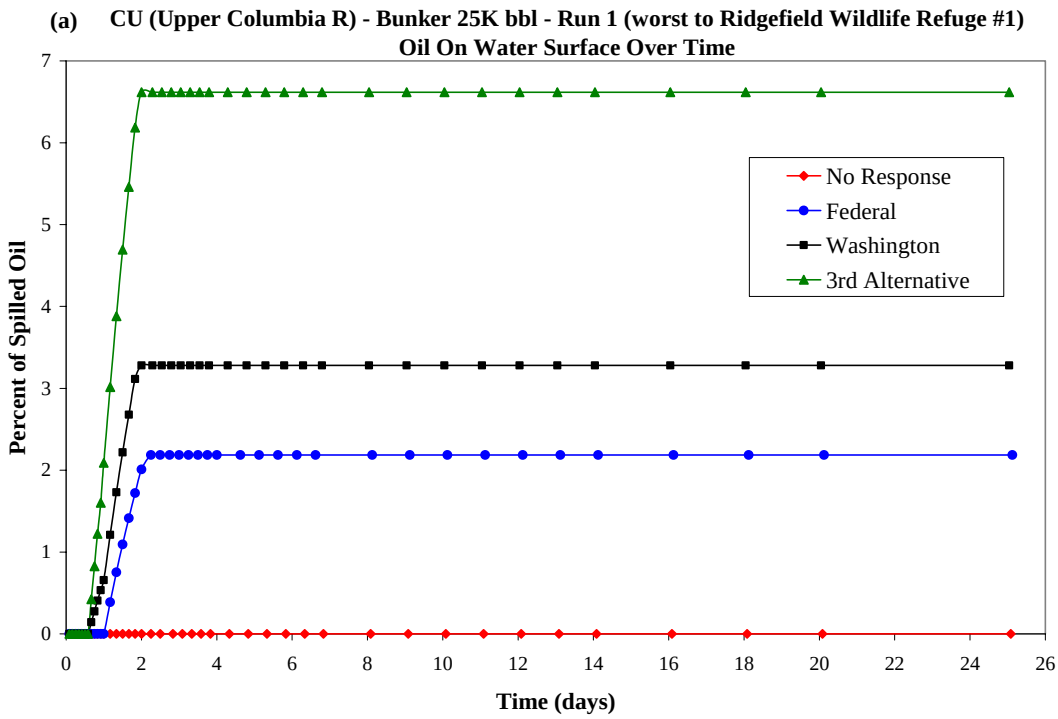


Figure XXIII.B-5 Upper Columbia River - Bunker C, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant).



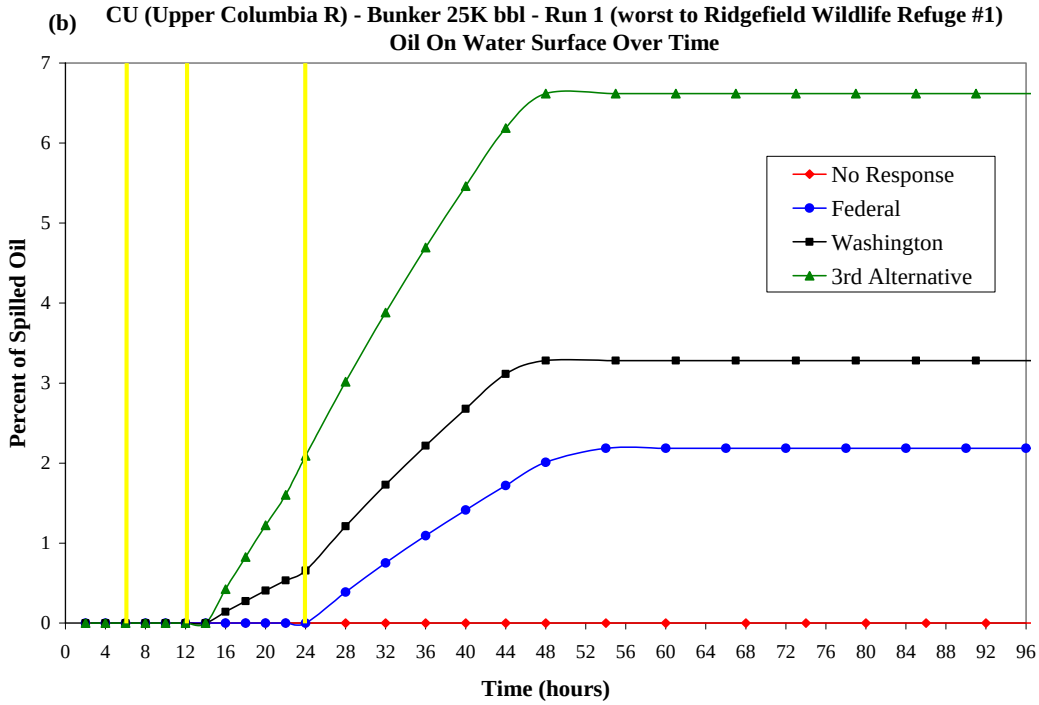
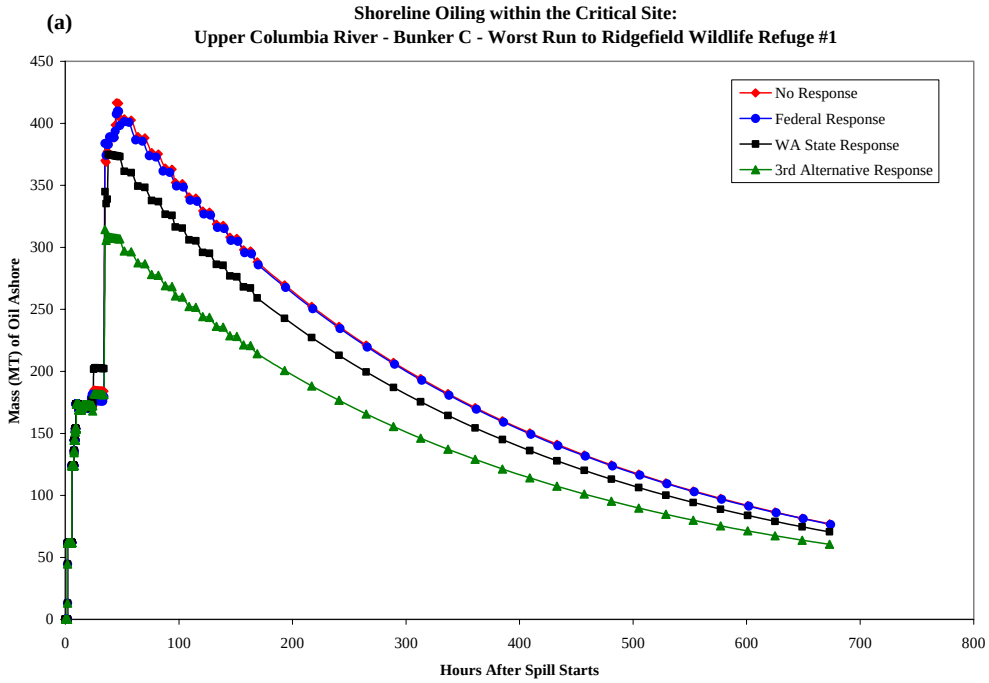


Figure XXIII.B-6 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#1). Part b is a subset of Part a.



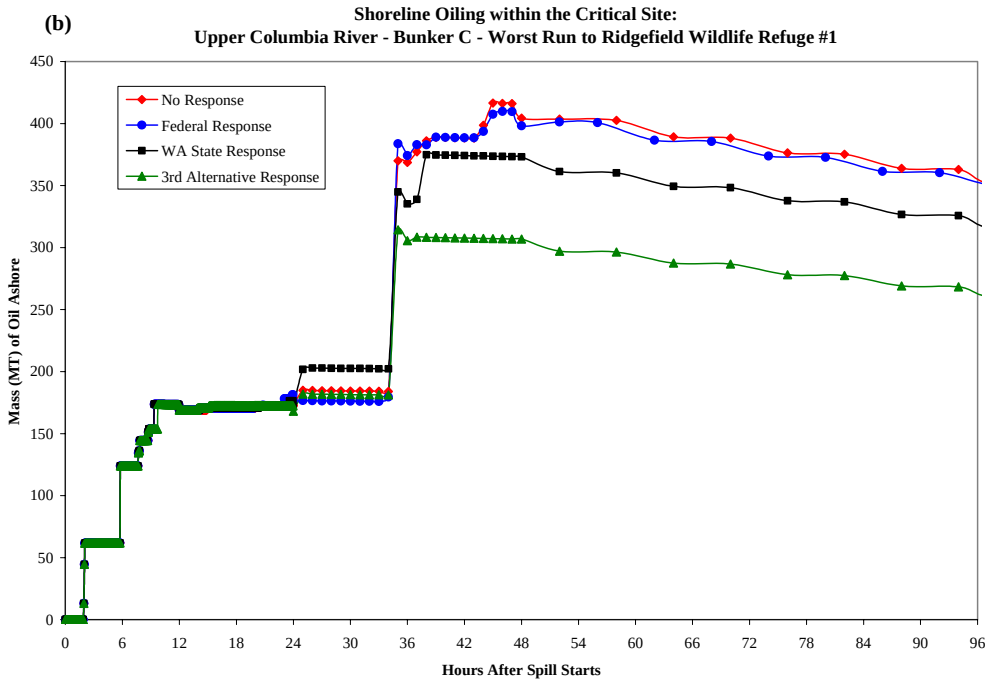
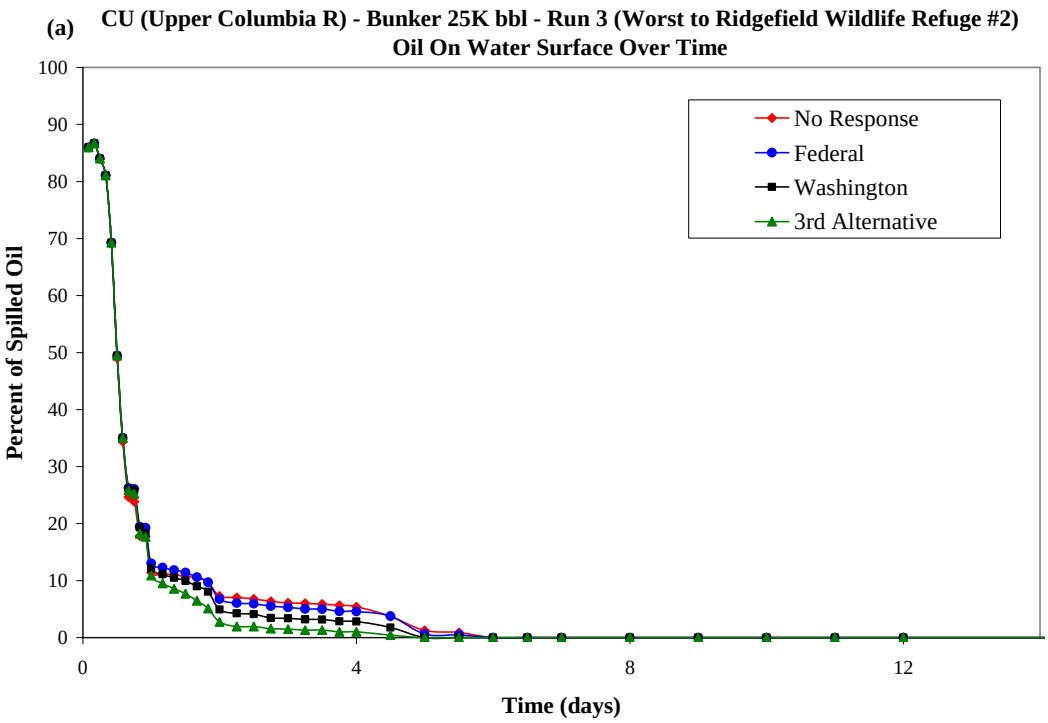


Figure XXIII.B-7 Upper Columbia River - Bunker C, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



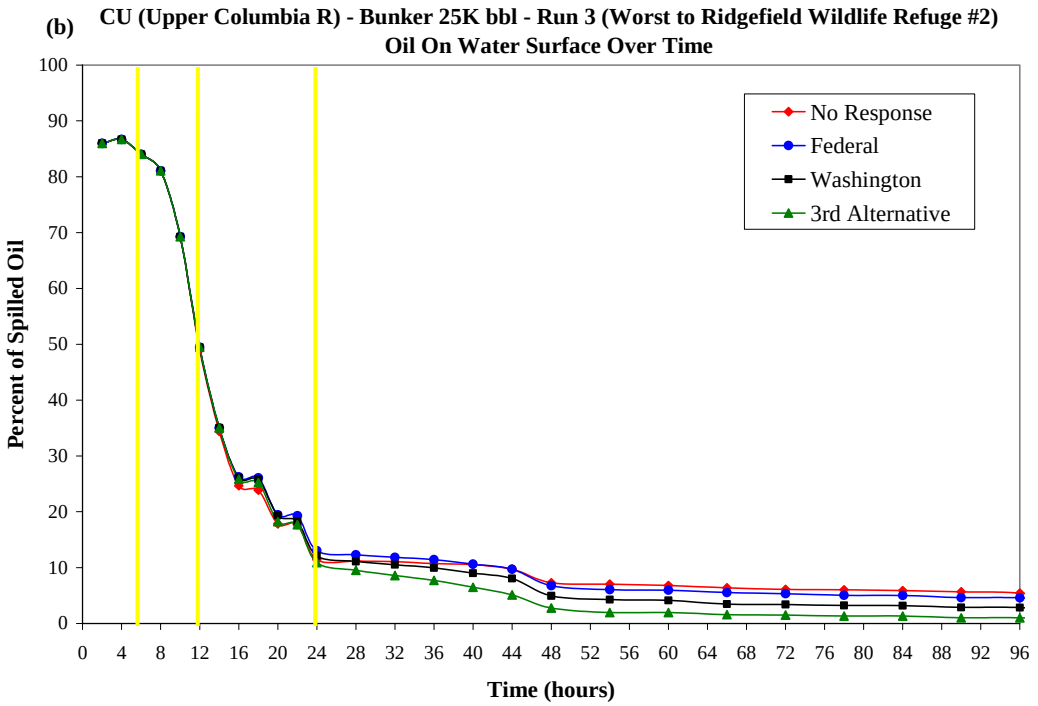


Figure XXIII.B-8 Upper Columbia River - Bunker C, no removal: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). Part b is a subset of Part a.

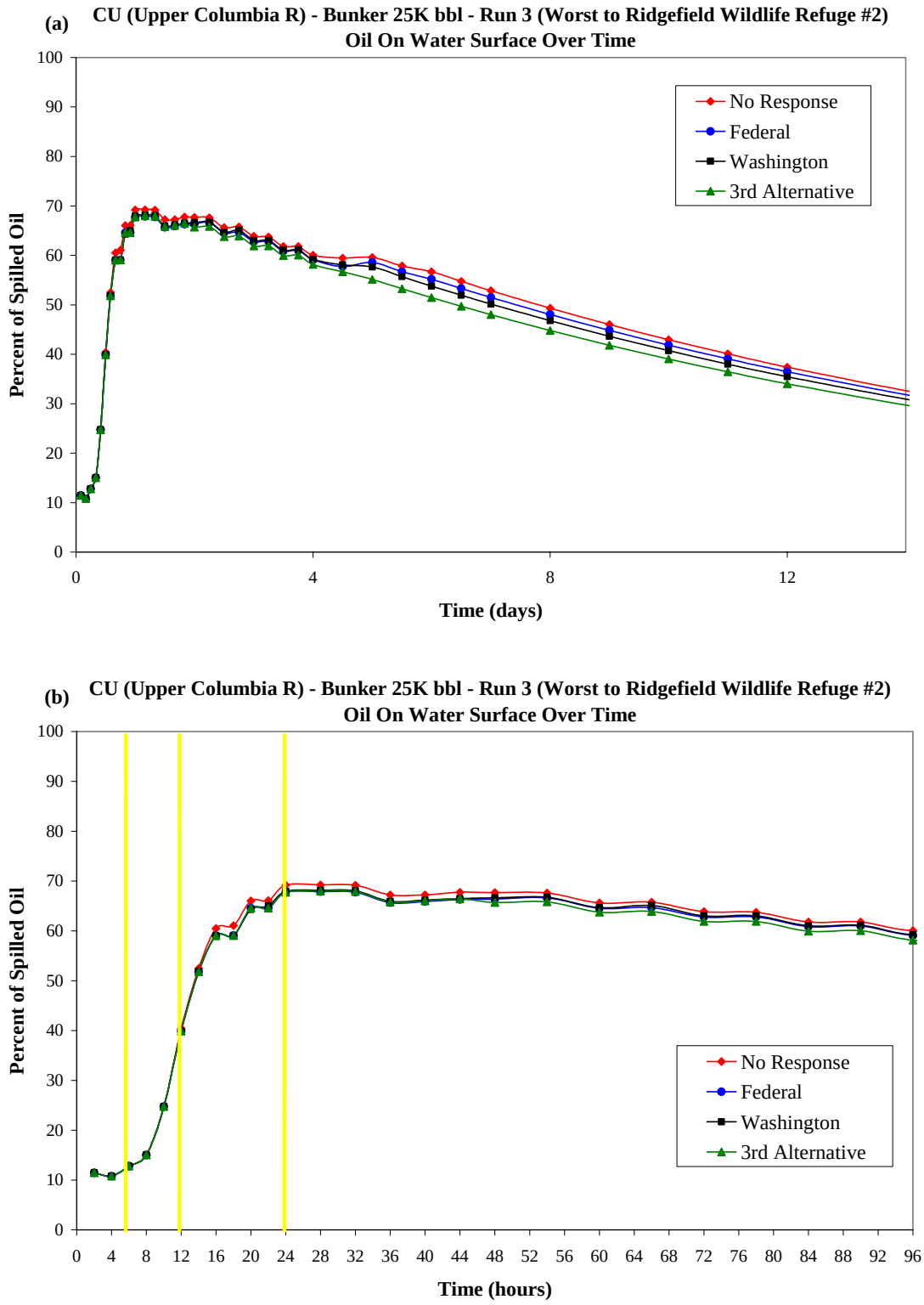
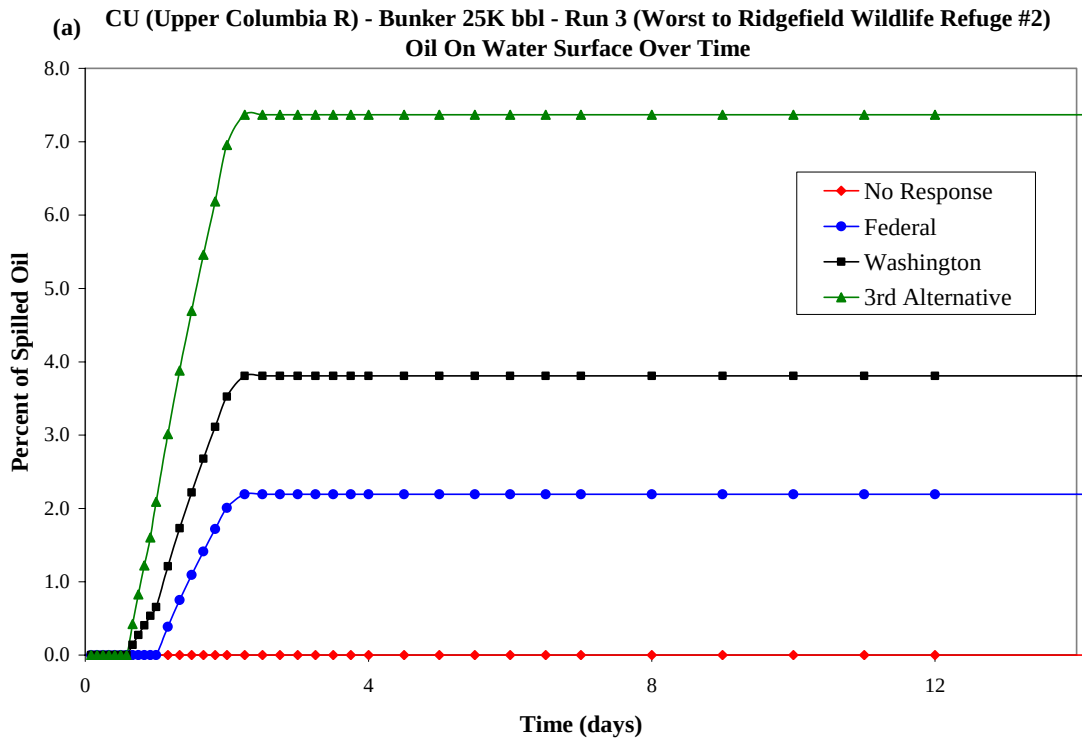


Figure XXIII.B-9 Upper Columbia River - Bunker C, no removal: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the The Ridgefield National Wildlife Refuge (run#2). Part b is a subset of Part a.



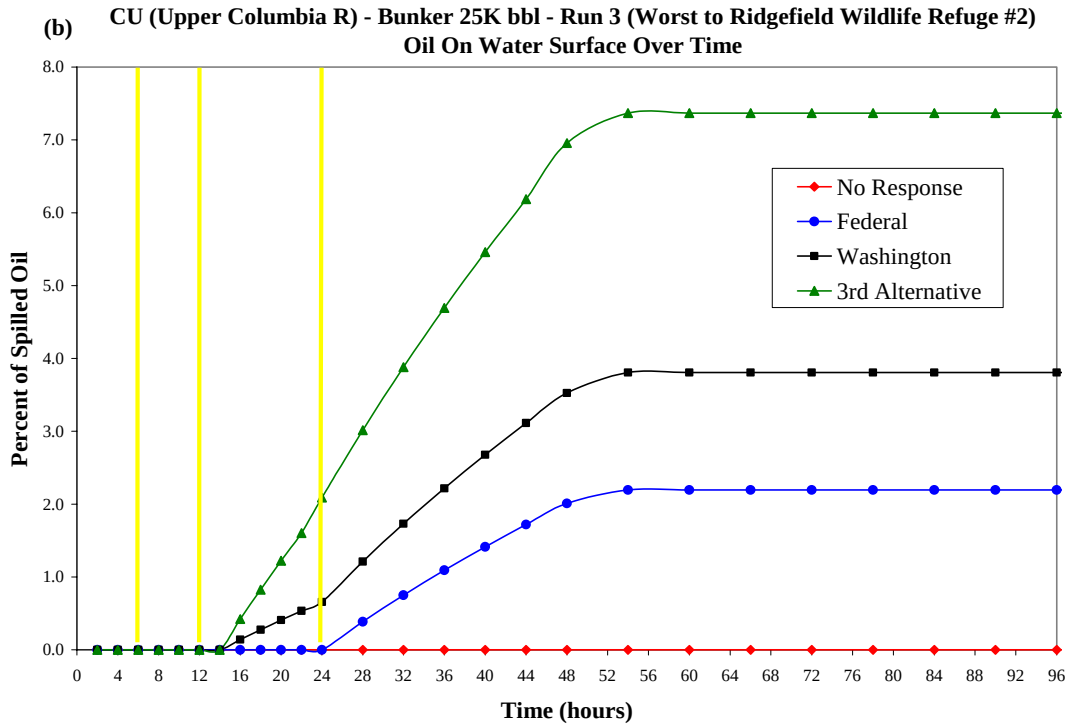
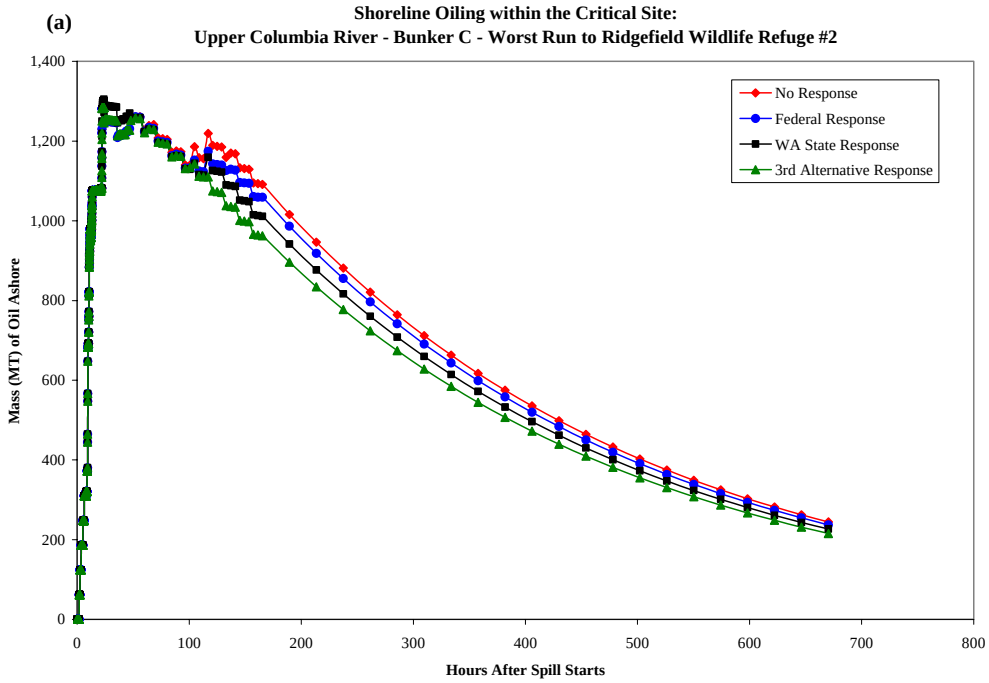


Figure XXIII.B-10 Upper Columbia River - Bunker C, no removal: Percent of oil mechanically removed over time for the 4 alternative response scenarios for The Ridgefield National Wildlife Refuge (run#2). Part b is a subset of Part a.



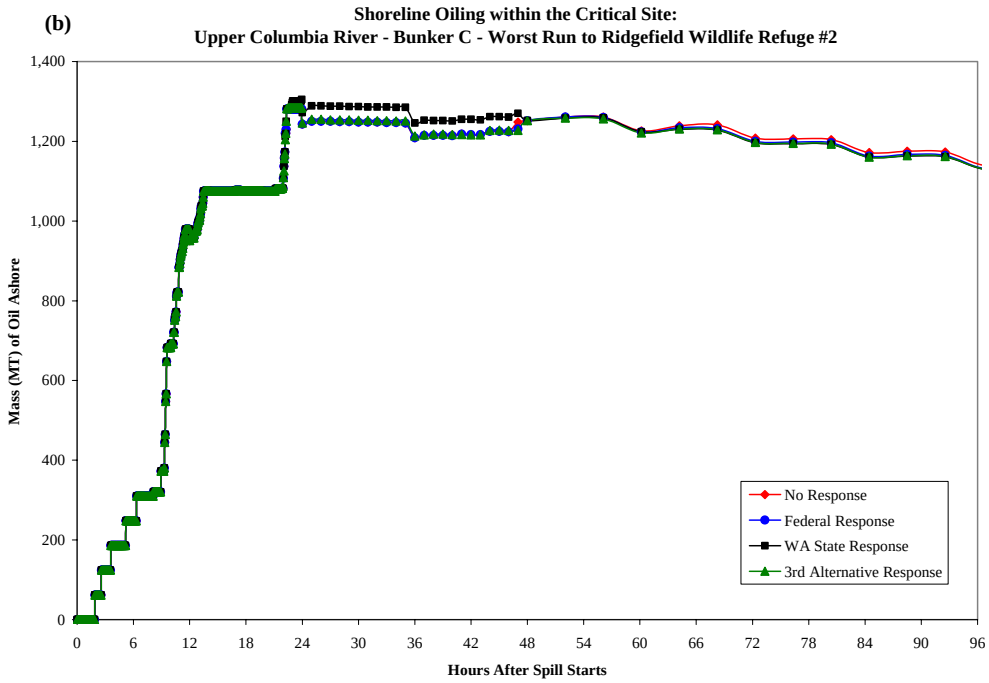


Figure XXIII.B-11 Upper Columbia River - Bunker C, no removal: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Ridgefield National Wildlife Refuge (run#2). Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

Table XXIII.B-1 Upper Columbia River - Bunker C, 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	86.08	2.41	0.00	0.00	11.46	0.04	0.00	0.00	86.08
4	0.17	77.79	3.84	0.00	0.00	18.28	0.08	0.00	0.00	77.79
6	0.25	67.42	5.67	0.00	0.00	26.75	0.16	0.00	0.00	67.42
8	0.33	64.14	6.31	0.00	0.00	29.32	0.24	0.00	0.00	64.14
10	0.42	47.39	9.19	0.00	0.00	43.10	0.32	0.00	0.00	47.39
12	0.50	41.55	10.20	1.17	0.00	46.69	0.39	0.00	0.00	41.55
14	0.58	33.81	11.52	0.11	1.05	53.04	0.47	0.00	0.00	33.81
16	0.67	30.31	12.12	0.01	1.15	55.86	0.54	0.00	0.00	30.31
18	0.75	23.42	13.28	0.00	1.15	61.52	0.62	0.00	0.00	23.42
20	0.83	16.48	14.46	0.00	1.15	67.22	0.70	0.00	0.00	16.48
22	0.92	16.43	14.49	0.00	1.14	67.17	0.77	0.00	0.00	16.43
24	1.00	14.09	14.87	1.66	1.14	67.39	0.85	0.00	0.00	14.09
28	1.17	11.32	15.35	0.00	2.79	69.55	0.99	0.00	0.00	11.32
32	1.33	9.19	15.72	0.00	2.78	71.18	1.14	0.00	0.00	9.19
36	1.50	1.84	16.85	1.75	2.76	75.52	1.29	0.00	0.00	1.84
40	1.67	0.80	17.01	0.00	4.49	76.27	1.43	0.00	0.00	0.80
44	1.83	0.00	17.13	0.00	4.48	76.82	1.57	0.00	0.00	0.00
48	2.00	0.00	17.13	1.71	4.47	74.98	1.71	0.00	0.00	0.00
54	2.25	0.00	17.13	0.01	6.15	74.76	1.95	0.00	0.00	0.00
60	2.50	0.00	17.13	1.79	6.14	72.79	2.15	0.00	0.00	0.00
66	2.75	0.00	17.13	0.05	7.86	72.61	2.35	0.00	0.00	0.00
72	3.00	0.00	17.13	1.59	7.89	70.84	2.55	0.00	0.00	0.00
78	3.25	0.00	17.13	0.04	9.42	70.66	2.75	0.00	0.00	0.00
84	3.50	0.00	17.13	1.54	9.45	68.95	2.94	0.00	0.00	0.00

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
90	3.75	0.00	17.13	0.04	10.92	68.78	3.13	0.00	0.00	0.00
96	4.00	0.00	17.13	0.28	12.13	66.96	3.50	0.00	0.00	0.00
108	4.50	0.00	17.13	0.28	13.54	65.19	3.86	0.00	0.00	0.00
120	5.00	0.00	17.13	0.27	14.90	63.49	4.22	0.00	0.00	0.00
132	5.50	0.00	17.13	0.26	16.21	61.85	4.56	0.00	0.00	0.00
144	6.00	0.00	17.13	0.25	17.47	60.25	4.90	0.00	0.00	0.00
156	6.50	0.00	17.13	0.24	18.70	58.72	5.22	0.00	0.00	0.00
168	7.00	0.00	17.13	2.50	19.83	54.53	6.01	0.00	0.00	0.00
192	8.00	0.00	17.13	2.58	21.82	51.88	6.60	0.00	0.00	0.00
216	9.00	0.00	17.13	2.44	23.87	49.39	7.17	0.00	0.00	0.00
240	10.00	0.00	17.13	2.28	25.82	47.07	7.71	0.00	0.00	0.00
264	11.00	0.00	17.13	2.12	27.64	44.89	8.22	0.00	0.00	0.00
288	12.00	0.00	17.13	1.98	29.34	42.85	8.71	0.00	0.00	0.00
336	14.00	0.00	17.13	1.85	30.92	40.94	9.17	0.00	0.00	0.00
384	16.00	0.00	17.13	1.61	33.76	37.47	10.04	0.00	0.00	0.00
432	18.00	0.00	17.13	1.40	36.23	34.42	10.82	0.00	0.00	0.00
480	20.00	0.00	17.13	1.22	38.38	31.73	11.55	0.00	0.00	0.00
600	25.00	0.00	17.13	0.86	42.59	26.32	13.11	0.00	0.00	0.00
Maximum	28.00	98.72	17.13	2.58	44.49	76.82	13.91	0.00	0.00	98.72

Table XXIII.B-2 Upper Columbia River - Bunker C, 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	86.08	2.41	0.00	0.00	11.46	0.04	0.00	0.00	86.08
4	0.17	77.79	3.84	0.00	0.00	18.28	0.08	0.00	0.00	77.79
6	0.25	67.42	5.67	0.00	0.00	26.75	0.16	0.00	0.00	67.42
8	0.33	64.14	6.31	0.00	0.00	29.32	0.24	0.00	0.00	64.14
10	0.42	47.39	9.19	0.00	0.00	43.10	0.32	0.00	0.00	47.39
12	0.50	41.55	10.20	1.17	0.00	46.69	0.39	0.00	0.00	41.55
14	0.58	33.84	11.51	0.11	1.05	53.02	0.47	0.00	0.00	33.84
16	0.67	28.81	12.37	0.01	1.15	57.11	0.54	0.00	0.00	28.81
18	0.75	23.13	13.33	0.00	1.15	61.76	0.62	0.00	0.00	23.13
20	0.83	15.45	14.63	0.00	1.15	68.08	0.70	0.00	0.00	15.45
22	0.92	15.08	14.71	0.00	1.14	68.30	0.77	0.00	0.00	15.08
24	1.00	13.53	14.97	1.66	1.14	67.85	0.85	0.00	0.00	13.53
28	1.17	10.75	15.38	0.00	2.79	69.70	0.99	0.39	0.00	10.75
32	1.33	9.51	15.55	0.00	2.78	70.27	1.14	0.75	0.00	9.51
36	1.50	3.53	16.43	1.74	2.76	73.18	1.28	1.07	0.00	3.53
40	1.67	2.21	16.59	0.00	4.48	73.90	1.42	1.39	0.00	2.21
44	1.83	0.12	16.85	0.00	4.48	75.29	1.56	1.70	0.00	0.12
48	2.00	0.00	16.85	1.73	4.46	73.43	1.70	1.81	0.00	0.00
54	2.25	0.00	16.85	0.01	6.17	73.22	1.93	1.81	0.00	0.00
60	2.50	0.00	16.85	1.81	6.16	71.23	2.13	1.81	0.00	0.00
66	2.75	0.00	16.85	0.05	7.90	71.05	2.33	1.81	0.00	0.00
72	3.00	0.00	16.85	1.61	7.93	69.26	2.52	1.81	0.00	0.00
78	3.25	0.00	16.85	0.05	9.48	69.09	2.72	1.81	0.00	0.00
84	3.50	0.00	16.85	1.56	9.51	67.36	2.90	1.81	0.00	0.00
90	3.75	0.00	16.85	0.04	11.01	67.19	3.09	1.81	0.00	0.00
96	4.00	0.00	16.85	0.28	12.23	65.36	3.45	1.81	0.00	0.00

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	0.00	16.85	0.28	13.65	63.59	3.81	1.81	0.00	0.00
120	5.00	0.00	16.85	0.27	15.03	61.88	4.15	1.81	0.00	0.00
132	5.50	0.00	16.85	0.26	16.36	60.22	4.49	1.81	0.00	0.00
144	6.00	0.00	16.85	0.25	17.64	58.62	4.81	1.81	0.00	0.00
156	6.50	0.00	16.85	0.24	18.88	57.08	5.13	1.81	0.00	0.00
168	7.00	0.00	16.85	2.53	20.04	52.87	5.89	1.81	0.00	0.00
192	8.00	0.00	16.85	2.61	22.05	50.20	6.47	1.81	0.00	0.00
216	9.00	0.00	16.85	2.47	24.13	47.71	7.02	1.81	0.00	0.00
240	10.00	0.00	16.85	2.31	26.11	45.38	7.54	1.81	0.00	0.00
264	11.00	0.00	16.85	2.15	27.95	43.20	8.03	1.81	0.00	0.00
288	12.00	0.00	16.85	2.00	29.67	41.16	8.50	1.81	0.00	0.00
336	14.00	0.00	16.85	1.87	31.27	39.25	8.95	1.81	0.00	0.00
384	16.00	0.00	16.85	1.62	34.15	35.78	9.77	1.81	0.00	0.00
432	18.00	0.00	16.85	1.41	36.66	32.74	10.53	1.81	0.00	0.00
480	20.00	0.00	16.85	1.23	38.83	30.06	11.21	1.81	0.00	0.00
600	25.00	0.00	16.85	0.87	43.10	24.68	12.69	1.81	0.00	0.00
Maximum	28.00	98.72	16.85	2.61	45.02	75.29	13.44	1.81	0.00	98.72

Table XXIII.B-3 Upper Columbia River - Bunker C, 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	86.08	2.41	0.00	0.00	11.46	0.04	0.00	0.00	86.08
4	0.17	77.79	3.84	0.00	0.00	18.28	0.08	0.00	0.00	77.79
6	0.25	67.42	5.67	0.00	0.00	26.75	0.16	0.00	0.00	67.42
8	0.33	64.14	6.31	0.00	0.00	29.32	0.24	0.00	0.00	64.14
10	0.42	47.39	9.19	0.00	0.00	43.10	0.32	0.00	0.00	47.39
12	0.50	41.55	10.20	1.17	0.00	46.69	0.39	0.00	0.00	41.55
14	0.58	33.84	11.51	0.11	1.05	53.02	0.47	0.00	0.00	33.84
16	0.67	28.82	12.35	0.01	1.15	56.98	0.54	0.14	0.00	28.82
18	0.75	21.78	13.51	0.00	1.15	62.66	0.62	0.28	0.00	21.78
20	0.83	16.05	14.46	0.00	1.15	67.24	0.70	0.41	0.00	16.05
22	0.92	15.65	14.53	0.00	1.14	67.37	0.77	0.53	0.00	15.65
24	1.00	14.04	14.78	1.66	1.14	66.88	0.85	0.66	0.00	14.04
28	1.17	10.12	15.34	0.00	2.78	69.55	0.99	1.21	0.00	10.12
32	1.33	6.51	15.86	0.00	2.77	72.00	1.13	1.73	0.00	6.51
36	1.50	1.80	16.51	1.76	2.76	73.67	1.28	2.22	0.00	1.80
40	1.67	0.95	16.57	0.00	4.51	73.87	1.41	2.68	0.00	0.95
44	1.83	0.19	16.63	0.00	4.50	74.03	1.55	3.11	0.00	0.19
48	2.00	0.00	16.63	1.71	4.48	72.19	1.69	3.30	0.00	0.00
54	2.25	0.00	16.63	0.01	6.17	71.98	1.92	3.30	0.00	0.00
60	2.50	0.00	16.63	1.79	6.16	70.02	2.12	3.30	0.00	0.00
66	2.75	0.00	16.63	0.05	7.88	69.84	2.31	3.30	0.00	0.00
72	3.00	0.00	16.63	1.59	7.91	68.08	2.50	3.30	0.00	0.00
78	3.25	0.00	16.63	0.04	9.44	67.91	2.69	3.30	0.00	0.00
84	3.50	0.00	16.63	1.54	9.47	66.20	2.87	3.30	0.00	0.00
90	3.75	0.00	16.63	0.04	10.94	66.04	3.05	3.30	0.00	0.00

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	0.00	16.63	0.28	12.16	64.23	3.41	3.30	0.00	0.00
108	4.50	0.00	16.63	0.28	13.56	62.48	3.76	3.30	0.00	0.00
120	5.00	0.00	16.63	0.27	14.92	60.79	4.10	3.30	0.00	0.00
132	5.50	0.00	16.63	0.26	16.23	59.16	4.43	3.30	0.00	0.00
144	6.00	0.00	16.63	0.25	17.50	57.58	4.75	3.30	0.00	0.00
156	6.50	0.00	16.63	0.24	18.72	56.06	5.06	3.30	0.00	0.00
168	7.00	0.00	16.63	2.50	19.86	51.91	5.81	3.30	0.00	0.00
192	8.00	0.00	16.63	2.58	21.85	49.28	6.37	3.30	0.00	0.00
216	9.00	0.00	16.63	2.44	23.91	46.82	6.91	3.30	0.00	0.00
240	10.00	0.00	16.63	2.28	25.86	44.52	7.42	3.30	0.00	0.00
264	11.00	0.00	16.63	2.12	27.68	42.36	7.91	3.30	0.00	0.00
288	12.00	0.00	16.63	1.98	29.38	40.35	8.37	3.30	0.00	0.00
336	14.00	0.00	16.63	1.85	30.96	38.46	8.80	3.30	0.00	0.00
384	16.00	0.00	16.63	1.61	33.81	35.04	9.61	3.30	0.00	0.00
432	18.00	0.00	16.63	1.40	36.29	32.04	10.35	3.30	0.00	0.00
480	20.00	0.00	16.63	1.22	38.44	29.40	11.02	3.30	0.00	0.00
600	25.00	0.00	16.63	0.86	42.66	24.10	12.46	3.30	0.00	0.00
Maximum	28.00	98.72	16.63	2.58	44.57	74.03	13.19	3.30	0.00	98.72

Table XXIII.B-4 Upper Columbia River - Bunker C, 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	86.08	2.41	0.00	0.00	11.46	0.04	0.00	0.00	86.08
4	0.17	77.79	3.84	0.00	0.00	18.28	0.08	0.00	0.00	77.79
6	0.25	67.42	5.67	0.00	0.00	26.75	0.16	0.00	0.00	67.42
8	0.33	64.14	6.31	0.00	0.00	29.32	0.24	0.00	0.00	64.14
10	0.42	47.39	9.19	0.00	0.00	43.10	0.32	0.00	0.00	47.39
12	0.50	41.55	10.20	1.17	0.00	46.69	0.39	0.00	0.00	41.55
14	0.58	33.84	11.51	0.11	1.05	53.02	0.47	0.00	0.00	33.84
16	0.67	28.76	12.31	0.01	1.15	56.80	0.54	0.42	0.00	28.76
18	0.75	23.08	13.21	0.00	1.15	61.12	0.62	0.83	0.00	23.08
20	0.83	15.32	14.44	0.00	1.15	67.17	0.69	1.22	0.00	15.32
22	0.92	14.64	14.51	0.00	1.14	67.33	0.77	1.60	0.00	14.64
24	1.00	12.43	14.80	1.69	1.14	67.01	0.84	2.09	0.00	12.43
28	1.17	9.86	15.10	0.00	2.81	68.23	0.99	3.02	0.00	9.86
32	1.33	6.11	15.58	0.00	2.80	70.50	1.13	3.88	0.00	6.11
36	1.50	1.13	16.23	1.76	2.79	72.18	1.26	4.65	0.00	1.13
40	1.67	0.00	16.30	0.00	4.53	72.45	1.40	5.32	0.00	0.00
44	1.83	0.00	16.30	0.00	4.52	72.33	1.53	5.32	0.00	0.00
48	2.00	0.00	16.30	0.00	4.51	72.21	1.66	5.32	0.00	0.00
54	2.25	0.00	16.30	0.05	6.28	70.17	1.89	5.32	0.00	0.00
60	2.50	0.00	16.30	1.64	6.31	68.35	2.08	5.32	0.00	0.00
66	2.75	0.00	16.30	0.05	7.89	68.18	2.27	5.32	0.00	0.00
72	3.00	0.00	16.30	1.58	7.91	66.43	2.46	5.32	0.00	0.00
78	3.25	0.00	16.30	0.04	9.43	66.27	2.64	5.32	0.00	0.00
84	3.50	0.00	16.30	1.53	9.46	64.58	2.82	5.32	0.00	0.00
90	3.75	0.00	16.30	0.04	10.93	64.42	3.00	5.32	0.00	0.00

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	0.00	16.30	0.28	12.13	62.63	3.35	5.32	0.00	0.00
108	4.50	0.00	16.30	0.27	13.52	60.90	3.69	5.32	0.00	0.00
120	5.00	0.00	16.30	0.27	14.88	59.23	4.01	5.32	0.00	0.00
132	5.50	0.00	16.30	0.26	16.18	57.62	4.34	5.32	0.00	0.00
144	6.00	0.00	16.30	0.25	17.44	56.05	4.65	5.32	0.00	0.00
156	6.50	0.00	16.30	0.24	18.65	54.55	4.95	5.32	0.00	0.00
168	7.00	0.00	16.30	2.48	19.79	50.44	5.68	5.32	0.00	0.00
192	8.00	0.00	16.30	2.56	21.76	47.84	6.23	5.32	0.00	0.00
216	9.00	0.00	16.30	2.42	23.80	45.41	6.75	5.32	0.00	0.00
240	10.00	0.00	16.30	2.26	25.74	43.14	7.25	5.32	0.00	0.00
264	11.00	0.00	16.30	2.11	27.55	41.01	7.72	5.32	0.00	0.00
288	12.00	0.00	16.30	1.96	29.23	39.03	8.16	5.32	0.00	0.00
336	14.00	0.00	16.30	1.83	30.80	37.17	8.58	5.32	0.00	0.00
384	16.00	0.00	16.30	1.59	33.63	33.79	9.37	5.32	0.00	0.00
432	18.00	0.00	16.30	1.38	36.09	30.84	10.08	5.32	0.00	0.00
480	20.00	0.00	16.30	1.20	38.22	28.24	10.72	5.32	0.00	0.00
600	25.00	0.00	16.30	0.85	42.40	23.03	12.10	5.32	0.00	0.00
Maximum	28.00	98.72	16.30	2.56	44.30	72.45	12.80	5.32	0.00	98.72

Table XXIII.B-5 Upper Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1).

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	92.48	1.34	0.00	0.00	6.13	0.04	0.00	0.00	92.48
4	0.17	78.05	3.84	0.00	0.00	18.03	0.08	0.00	0.00	78.05
6	0.25	75.24	4.41	0.00	0.00	20.19	0.16	0.00	0.00	75.24
8	0.33	72.01	5.09	0.00	0.00	22.66	0.24	0.00	0.00	72.01
10	0.42	68.26	5.85	0.00	0.00	25.57	0.32	0.00	0.00	68.26
12	0.50	67.52	6.09	0.61	0.15	25.24	0.40	0.00	0.00	67.52
14	0.58	67.22	6.22	0.02	0.73	25.33	0.48	0.00	0.00	67.22
16	0.67	66.44	6.39	0.00	0.75	25.87	0.56	0.00	0.00	66.44
18	0.75	53.05	8.58	0.00	0.75	36.99	0.64	0.00	0.00	53.05
20	0.83	36.97	11.18	0.00	0.74	50.39	0.71	0.00	0.00	36.97
22	0.92	24.71	13.18	0.00	0.74	60.59	0.79	0.00	0.00	24.71
24	1.00	18.64	14.17	1.03	0.96	64.33	0.87	0.00	0.00	18.64
28	1.17	12.45	15.17	0.00	1.98	69.37	1.01	0.00	0.00	12.45
32	1.33	12.39	15.21	0.00	1.97	69.27	1.16	0.00	0.00	12.39
36	1.50	6.43	16.13	1.37	2.13	72.63	1.31	0.00	0.00	6.43
40	1.67	5.51	16.28	0.02	3.47	73.27	1.45	0.00	0.00	5.51
44	1.83	3.51	16.58	0.00	3.48	74.84	1.60	0.00	0.00	3.51
48	2.00	1.47	16.88	1.51	3.56	74.83	1.74	0.00	0.00	1.47
54	2.25	0.21	17.07	0.00	5.06	75.72	1.95	0.00	0.00	0.21
60	2.50	0.20	17.07	1.41	5.22	73.94	2.16	0.00	0.00	0.20
66	2.75	0.00	17.09	0.04	6.57	73.87	2.43	0.00	0.00	0.00
72	3.00	0.00	17.09	1.82	6.58	71.87	2.63	0.00	0.00	0.00
78	3.25	0.00	17.09	0.50	7.88	71.69	2.83	0.00	0.00	0.00
84	3.50	0.00	17.09	1.55	8.29	70.04	3.03	0.00	0.00	0.00
90	3.75	0.00	17.09	0.24	9.58	69.86	3.22	0.00	0.00	0.00
96	4.00	0.00	17.09	0.27	10.94	68.10	3.60	0.00	0.00	0.00

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	0.00	17.09	0.27	12.29	66.38	3.97	0.00	0.00	0.00
120	5.00	0.00	17.09	0.26	13.59	64.73	4.33	0.00	0.00	0.00
132	5.50	0.00	17.09	0.25	14.85	63.13	4.68	0.00	0.00	0.00
144	6.00	0.00	17.09	0.24	16.06	61.58	5.02	0.00	0.00	0.00
156	6.50	0.00	17.09	0.23	17.23	60.09	5.35	0.00	0.00	0.00
168	7.00	0.00	17.09	2.40	18.32	56.03	6.16	0.00	0.00	0.00
192	8.00	0.00	17.09	2.47	20.22	53.44	6.77	0.00	0.00	0.00
216	9.00	0.00	17.09	2.34	22.19	51.03	7.35	0.00	0.00	0.00
240	10.00	0.00	17.09	2.18	24.05	48.76	7.91	0.00	0.00	0.00
264	11.00	0.00	17.09	2.03	25.79	46.64	8.44	0.00	0.00	0.00
288	12.00	0.00	17.09	1.89	27.41	44.65	8.94	0.00	0.00	0.00
336	14.00	0.00	17.09	1.77	28.92	42.79	9.43	0.00	0.00	0.00
384	16.00	0.00	17.09	1.53	31.63	39.41	10.33	0.00	0.00	0.00
432	18.00	0.00	17.09	1.33	33.98	36.43	11.16	0.00	0.00	0.00
480	20.00	0.00	17.09	1.16	36.02	33.80	11.93	0.00	0.00	0.00
600	25.00	0.00	17.09	0.82	39.98	28.49	13.61	0.00	0.00	0.00
Maximum	28.00	99.94	17.09	2.47	41.78	75.72	14.48	0.00	0.00	99.94

Table XXIII.B-6 Upper Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1).

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	92.48	1.34	0.00	0.00	6.13	0.04	0.00	0.00	92.48
4	0.17	78.05	3.84	0.00	0.00	18.03	0.08	0.00	0.00	78.05
6	0.25	75.24	4.41	0.00	0.00	20.19	0.16	0.00	0.00	75.24
8	0.33	72.01	5.09	0.00	0.00	22.66	0.24	0.00	0.00	72.01
10	0.42	68.26	5.85	0.00	0.00	25.57	0.32	0.00	0.00	68.26
12	0.50	68.03	6.01	0.75	0.00	24.81	0.40	0.00	0.00	68.03
14	0.58	67.29	6.21	0.03	0.72	25.28	0.48	0.00	0.00	67.29
16	0.67	66.91	6.31	0.00	0.75	25.47	0.56	0.00	0.00	66.91
18	0.75	51.68	8.80	0.00	0.75	38.14	0.64	0.00	0.00	51.68
20	0.83	39.10	10.84	0.00	0.74	48.61	0.71	0.00	0.00	39.10
22	0.92	23.80	13.32	0.00	0.74	61.36	0.79	0.00	0.00	23.80
24	1.00	19.81	13.99	1.21	0.73	63.40	0.87	0.00	0.00	19.81
28	1.17	9.92	15.51	0.00	1.92	71.25	1.01	0.39	0.00	9.92
32	1.33	9.50	15.54	0.00	1.91	71.14	1.16	0.75	0.00	9.50
36	1.50	3.45	16.41	1.54	1.90	74.29	1.31	1.09	0.00	3.45
40	1.67	2.59	16.50	0.02	3.41	74.62	1.45	1.41	0.00	2.59
44	1.83	1.58	16.61	0.00	3.42	75.09	1.59	1.72	0.00	1.58
48	2.00	0.24	16.76	1.54	3.41	74.31	1.73	2.01	0.00	0.24
54	2.25	0.00	16.77	0.05	4.88	74.18	1.93	2.19	0.00	0.00
60	2.50	0.00	16.77	0.01	4.91	73.99	2.14	2.19	0.00	0.00
66	2.75	0.00	16.77	0.88	5.87	71.95	2.34	2.19	0.00	0.00
72	3.00	0.00	16.77	0.21	6.52	71.78	2.54	2.19	0.00	0.00
78	3.25	0.00	16.77	0.76	7.37	70.17	2.73	2.19	0.00	0.00
84	3.50	0.00	16.77	0.12	8.00	70.00	2.92	2.19	0.00	0.00
90	3.75	0.00	16.77	0.72	8.76	68.45	3.11	2.19	0.00	0.00
96	4.00	0.00	16.77	0.12	9.35	68.28	3.30	2.19	0.00	0.00

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	0.00	16.77	1.32	10.71	65.24	3.76	2.19	0.00	0.00
120	5.00	0.00	16.77	1.28	11.97	63.68	4.12	2.19	0.00	0.00
132	5.50	0.00	16.77	1.23	13.17	62.17	4.47	2.19	0.00	0.00
144	6.00	0.00	16.77	1.19	14.34	60.71	4.81	2.19	0.00	0.00
156	6.50	0.00	16.77	1.15	15.46	59.29	5.14	2.19	0.00	0.00
168	7.00	0.00	16.77	2.24	17.39	55.32	6.09	2.19	0.00	0.00
192	8.00	0.00	16.77	2.31	19.16	52.88	6.70	2.19	0.00	0.00
216	9.00	0.00	16.77	2.18	21.00	50.59	7.27	2.19	0.00	0.00
240	10.00	0.00	16.77	2.04	22.73	48.45	7.83	2.19	0.00	0.00
264	11.00	0.00	16.77	1.90	24.35	46.44	8.35	2.19	0.00	0.00
288	12.00	0.00	16.77	1.77	25.86	44.56	8.86	2.19	0.00	0.00
336	14.00	0.00	16.77	1.65	27.27	42.79	9.34	2.19	0.00	0.00
384	16.00	0.00	16.77	1.61	29.61	39.57	10.25	2.19	0.00	0.00
432	18.00	0.00	16.77	1.24	31.98	36.74	11.08	2.19	0.00	0.00
480	20.00	0.00	16.77	1.08	33.87	34.23	11.86	2.19	0.00	0.00
600	25.00	0.00	16.77	0.76	37.58	29.14	13.56	2.19	0.00	0.00
Maximum	28.00	99.94	16.77	2.31	39.24	75.09	14.45	2.19	0.00	99.94

Table XXIII.B-7 Upper Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1).

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	92.48	1.34	0.00	0.00	6.13	0.04	0.00	0.00	92.48
4	0.17	78.05	3.84	0.00	0.00	18.03	0.08	0.00	0.00	78.05
6	0.25	75.24	4.41	0.00	0.00	20.19	0.16	0.00	0.00	75.24
8	0.33	72.01	5.09	0.00	0.00	22.66	0.24	0.00	0.00	72.01
10	0.42	68.26	5.85	0.00	0.00	25.57	0.32	0.00	0.00	68.26
12	0.50	68.03	6.01	0.75	0.00	24.81	0.40	0.00	0.00	68.03
14	0.58	66.87	6.28	0.03	0.72	25.63	0.48	0.00	0.00	66.87
16	0.67	65.77	6.47	0.00	0.75	26.31	0.56	0.14	0.00	65.77
18	0.75	51.76	8.74	0.00	0.75	37.84	0.63	0.28	0.00	51.76
20	0.83	39.29	10.75	0.00	0.74	48.10	0.71	0.41	0.00	39.29
22	0.92	24.08	13.19	0.00	0.74	60.67	0.79	0.53	0.00	24.08
24	1.00	19.32	13.96	1.27	0.73	63.20	0.86	0.66	0.00	19.32
28	1.17	10.90	15.23	0.00	1.98	69.66	1.01	1.21	0.00	10.90
32	1.33	10.25	15.27	0.00	1.98	69.62	1.16	1.73	0.00	10.25
36	1.50	3.32	16.26	1.58	1.96	73.36	1.30	2.22	0.00	3.32
40	1.67	2.50	16.32	0.02	3.51	73.54	1.44	2.68	0.00	2.50
44	1.83	1.86	16.35	0.00	3.52	73.57	1.58	3.11	0.00	1.86
48	2.00	0.00	16.60	1.58	3.50	73.32	1.72	3.28	0.00	0.00
54	2.25	0.00	16.60	0.38	4.68	73.10	1.95	3.28	0.00	0.00
60	2.50	0.00	16.60	1.70	4.99	71.27	2.15	3.28	0.00	0.00
66	2.75	0.00	16.60	0.32	6.35	71.10	2.35	3.28	0.00	0.00
72	3.00	0.00	16.60	1.53	6.59	69.45	2.54	3.28	0.00	0.00
78	3.25	0.00	16.60	0.38	7.73	69.28	2.74	3.28	0.00	0.00
84	3.50	0.00	16.60	1.47	8.03	67.69	2.93	3.28	0.00	0.00
90	3.75	0.00	16.60	0.18	9.31	67.52	3.11	3.28	0.00	0.00

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	0.00	16.60	0.26	10.55	65.82	3.48	3.28	0.00	0.00
108	4.50	0.00	16.60	0.26	11.85	64.18	3.84	3.28	0.00	0.00
120	5.00	0.00	16.60	0.25	13.10	62.59	4.18	3.28	0.00	0.00
132	5.50	0.00	16.60	0.24	14.30	61.06	4.52	3.28	0.00	0.00
144	6.00	0.00	16.60	0.23	15.47	59.57	4.85	3.28	0.00	0.00
156	6.50	0.00	16.60	0.22	16.59	58.13	5.17	3.28	0.00	0.00
168	7.00	0.00	16.60	2.30	17.63	54.23	5.95	3.28	0.00	0.00
192	8.00	0.00	16.60	2.37	19.45	51.75	6.55	3.28	0.00	0.00
216	9.00	0.00	16.60	2.24	21.34	49.43	7.11	3.28	0.00	0.00
240	10.00	0.00	16.60	2.09	23.13	47.25	7.65	3.28	0.00	0.00
264	11.00	0.00	16.60	1.95	24.79	45.21	8.16	3.28	0.00	0.00
288	12.00	0.00	16.60	1.82	26.34	43.30	8.65	3.28	0.00	0.00
336	14.00	0.00	16.60	1.69	27.79	41.51	9.12	3.28	0.00	0.00
384	16.00	0.00	16.60	1.47	30.39	38.26	10.00	3.28	0.00	0.00
432	18.00	0.00	16.60	1.28	32.64	35.39	10.81	3.28	0.00	0.00
480	20.00	0.00	16.60	1.11	34.59	32.86	11.55	3.28	0.00	0.00
600	25.00	0.00	16.60	0.78	38.40	27.75	13.19	3.28	0.00	0.00
Maximum	28.00	99.94	16.60	2.37	40.12	73.57	14.03	3.28	0.00	99.94

Table XXIII.B-8 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #1).

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	92.48	1.34	0.00	0.00	6.13	0.04	0.00	0.00	92.48
4	0.17	78.05	3.84	0.00	0.00	18.03	0.08	0.00	0.00	78.05
6	0.25	75.24	4.41	0.00	0.00	20.19	0.16	0.00	0.00	75.24
8	0.33	72.01	5.09	0.00	0.00	22.66	0.24	0.00	0.00	72.01
10	0.42	68.26	5.85	0.00	0.00	25.57	0.32	0.00	0.00	68.26
12	0.50	68.03	6.01	0.75	0.00	24.81	0.40	0.00	0.00	68.03
14	0.58	66.87	6.28	0.03	0.72	25.63	0.48	0.00	0.00	66.87
16	0.67	66.07	6.38	0.00	0.75	25.82	0.56	0.42	0.00	66.07
18	0.75	51.69	8.67	0.00	0.75	37.43	0.63	0.83	0.00	51.69
20	0.83	38.53	10.74	0.00	0.74	48.05	0.71	1.22	0.00	38.53
22	0.92	22.00	13.35	0.00	0.74	61.52	0.79	1.60	0.00	22.00
24	1.00	17.64	14.00	1.25	0.73	63.43	0.86	2.09	0.00	17.64
28	1.17	12.04	14.77	0.00	1.97	67.20	1.01	3.02	0.00	12.04
32	1.33	11.06	14.81	0.00	1.96	67.15	1.15	3.88	0.00	11.06
36	1.50	3.67	15.82	1.48	1.95	71.10	1.29	4.69	0.00	3.67
40	1.67	2.62	15.87	0.02	3.39	71.21	1.42	5.46	0.00	2.62
44	1.83	1.29	15.96	0.00	3.40	71.60	1.56	6.19	0.00	1.29
48	2.00	0.00	16.09	1.48	3.39	70.73	1.69	6.62	0.00	0.00
54	2.25	0.00	16.09	0.36	4.49	70.53	1.92	6.62	0.00	0.00
60	2.50	0.00	16.09	1.59	4.78	68.81	2.11	6.62	0.00	0.00
66	2.75	0.00	16.09	0.30	6.05	68.64	2.30	6.62	0.00	0.00
72	3.00	0.00	16.09	1.43	6.27	67.10	2.49	6.62	0.00	0.00
78	3.25	0.00	16.09	0.35	7.33	66.93	2.68	6.62	0.00	0.00
84	3.50	0.00	16.09	1.37	7.62	65.44	2.86	6.62	0.00	0.00
90	3.75	0.00	16.09	0.17	8.81	65.28	3.04	6.62	0.00	0.00

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	0.00	16.09	0.24	9.97	63.68	3.39	6.62	0.00	0.00
108	4.50	0.00	16.09	0.24	11.18	62.14	3.74	6.62	0.00	0.00
120	5.00	0.00	16.09	0.23	12.34	60.64	4.08	6.62	0.00	0.00
132	5.50	0.00	16.09	0.22	13.47	59.20	4.40	6.62	0.00	0.00
144	6.00	0.00	16.09	0.21	14.55	57.80	4.72	6.62	0.00	0.00
156	6.50	0.00	16.09	0.21	15.60	56.45	5.04	6.62	0.00	0.00
168	7.00	0.00	16.09	2.15	16.57	52.78	5.79	6.62	0.00	0.00
192	8.00	0.00	16.09	2.21	18.27	50.44	6.37	6.62	0.00	0.00
216	9.00	0.00	16.09	2.09	20.03	48.25	6.92	6.62	0.00	0.00
240	10.00	0.00	16.09	1.95	21.70	46.19	7.45	6.62	0.00	0.00
264	11.00	0.00	16.09	1.82	23.25	44.27	7.95	6.62	0.00	0.00
288	12.00	0.00	16.09	1.70	24.70	42.46	8.43	6.62	0.00	0.00
336	14.00	0.00	16.09	1.58	26.05	40.77	8.89	6.62	0.00	0.00
384	16.00	0.00	16.09	1.37	28.47	37.69	9.75	6.62	0.00	0.00
432	18.00	0.00	16.09	1.19	30.58	34.98	10.55	6.62	0.00	0.00
480	20.00	0.00	16.09	1.04	32.40	32.58	11.28	6.62	0.00	0.00
600	25.00	0.00	16.09	0.73	35.95	27.71	12.91	6.62	0.00	0.00
Maximum	28.00	99.94	16.09	2.21	37.55	71.60	13.76	6.62	0.00	99.94

Table XXIII.B-9 Upper Columbia River - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2).

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	85.99	2.49	0.00	0.00	11.48	0.04	0.00	0.00	85.99
4	0.17	86.69	2.43	0.00	0.00	10.79	0.08	0.00	0.00	86.69
6	0.25	84.01	3.03	0.00	0.00	12.80	0.16	0.00	0.00	84.01
8	0.33	81.07	3.65	0.00	0.00	15.03	0.24	0.00	0.00	81.07
10	0.42	69.25	5.67	0.00	0.00	24.76	0.32	0.00	0.00	69.25
12	0.50	49.04	9.11	0.68	0.40	40.36	0.40	0.00	0.00	49.04
14	0.58	34.40	11.58	0.00	1.07	52.46	0.48	0.00	0.00	34.40
16	0.67	24.68	13.19	0.00	1.07	60.50	0.55	0.00	0.00	24.68
18	0.75	23.88	13.38	0.00	1.06	61.05	0.63	0.00	0.00	23.88
20	0.83	17.85	14.35	0.00	1.06	66.04	0.71	0.00	0.00	17.85
22	0.92	17.71	14.40	0.00	1.05	66.06	0.78	0.00	0.00	17.71
24	1.00	11.41	15.39	1.44	1.71	69.19	0.86	0.00	0.00	11.41
28	1.17	11.17	15.46	0.00	3.14	69.24	1.00	0.00	0.00	11.17
32	1.33	11.08	15.50	0.00	3.13	69.14	1.15	0.00	0.00	11.08
36	1.50	10.72	15.60	1.40	3.75	67.23	1.29	0.00	0.00	10.72
40	1.67	10.52	15.66	0.00	5.14	67.24	1.43	0.00	0.00	10.52
44	1.83	9.72	15.81	0.00	5.13	67.77	1.57	0.00	0.00	9.72
48	2.00	7.28	16.16	1.32	5.85	67.67	1.71	0.00	0.00	7.28
54	2.25	7.05	16.25	0.00	7.16	67.63	1.92	0.00	0.00	7.05
60	2.50	6.79	16.33	1.13	8.01	65.62	2.12	0.00	0.00	6.79
66	2.75	6.39	16.43	0.00	9.11	65.75	2.32	0.00	0.00	6.39
72	3.00	6.10	16.50	1.07	9.97	63.86	2.51	0.00	0.00	6.10
78	3.25	6.04	16.53	0.00	11.02	63.71	2.70	0.00	0.00	6.04
84	3.50	5.88	16.56	1.24	11.64	61.79	2.89	0.00	0.00	5.88
90	3.75	5.67	16.59	0.00	12.86	61.80	3.08	0.00	0.00	5.67
96	4.00	5.42	16.63	1.36	13.30	60.03	3.26	0.00	0.00	5.42

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	3.74	16.78	1.41	15.02	59.43	3.62	0.00	0.00	3.74
120	5.00	1.26	16.99	1.35	16.85	59.59	3.96	0.00	0.00	1.26
132	5.50	0.90	17.02	1.56	18.36	57.86	4.29	0.00	0.00	0.90
144	6.00	0.00	17.09	1.51	20.10	56.68	4.61	0.00	0.00	0.00
156	6.50	0.00	17.09	1.28	21.97	54.74	4.92	0.00	0.00	0.00
168	7.00	0.00	17.09	1.28	23.54	52.87	5.22	0.00	0.00	0.00
192	8.00	0.00	17.09	0.94	26.86	49.33	5.79	0.00	0.00	0.00
216	9.00	0.00	17.09	0.79	29.78	46.02	6.31	0.00	0.00	0.00
240	10.00	0.00	17.09	1.12	32.04	42.95	6.80	0.00	0.00	0.00
264	11.00	0.00	17.09	0.95	34.61	40.08	7.26	0.00	0.00	0.00
288	12.00	0.00	17.09	0.78	37.02	37.42	7.69	0.00	0.00	0.00
336	14.00	0.00	17.09	0.46	41.37	32.62	8.45	0.00	0.00	0.00
384	16.00	0.00	17.09	0.48	44.85	28.46	9.12	0.00	0.00	0.00
432	18.00	0.00	17.09	0.33	48.03	24.85	9.70	0.00	0.00	0.00
480	20.00	0.00	17.09	0.46	50.53	21.72	10.20	0.00	0.00	0.00
600	25.00	0.00	17.09	0.35	55.79	15.59	11.18	0.00	0.00	0.00
Maximum	28.00	89.70	17.09	1.56	58.29	69.24	11.62	0.00	0.00	89.70

Table XXIII.B-10 Upper Columbia River - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2).

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	85.99	2.49	0.00	0.00	11.48	0.04	0.00	0.00	85.99
4	0.17	86.69	2.43	0.00	0.00	10.79	0.08	0.00	0.00	86.69
6	0.25	84.01	3.03	0.00	0.00	12.80	0.16	0.00	0.00	84.01
8	0.33	81.07	3.65	0.00	0.00	15.03	0.24	0.00	0.00	81.07
10	0.42	69.25	5.67	0.00	0.00	24.76	0.32	0.00	0.00	69.25
12	0.50	49.46	9.05	1.22	0.00	39.88	0.40	0.00	0.00	49.46
14	0.58	35.00	11.49	0.00	1.21	51.82	0.48	0.00	0.00	35.00
16	0.67	26.25	12.94	0.00	1.21	59.04	0.55	0.00	0.00	26.25
18	0.75	26.07	13.04	0.00	1.21	59.06	0.63	0.00	0.00	26.07
20	0.83	19.44	14.11	0.00	1.20	64.55	0.71	0.00	0.00	19.44
22	0.92	19.29	14.16	0.00	1.19	64.58	0.78	0.00	0.00	19.29
24	1.00	13.05	15.14	2.06	1.19	67.71	0.86	0.00	0.00	13.05
28	1.17	12.30	15.23	0.00	3.23	67.85	1.00	0.39	0.00	12.30
32	1.33	11.85	15.28	0.00	3.22	67.75	1.15	0.75	0.00	11.85
36	1.50	11.42	15.34	1.99	3.21	65.66	1.29	1.09	0.00	11.42
40	1.67	10.61	15.45	0.00	5.19	65.91	1.43	1.41	0.00	10.61
44	1.83	9.70	15.57	0.00	5.18	66.27	1.57	1.72	0.00	9.70
48	2.00	6.78	15.95	2.01	5.17	66.38	1.70	2.01	0.00	6.78
54	2.25	6.05	16.07	0.00	7.16	66.62	1.90	2.19	0.00	6.05
60	2.50	5.96	16.13	1.96	7.15	64.52	2.10	2.19	0.00	5.96
66	2.75	5.53	16.22	0.00	9.09	64.68	2.29	2.19	0.00	5.53
72	3.00	5.31	16.28	1.90	9.07	62.76	2.48	2.19	0.00	5.31
78	3.25	5.05	16.32	0.00	10.95	62.81	2.67	2.19	0.00	5.05
84	3.50	5.00	16.34	1.84	10.94	60.83	2.85	2.19	0.00	5.00
90	3.75	4.63	16.39	0.00	12.76	60.99	3.03	2.19	0.00	4.63
96	4.00	4.58	16.40	1.79	12.75	59.08	3.21	2.19	0.00	4.58

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	3.78	16.48	1.74	14.50	57.74	3.56	2.19	0.00	3.78
120	5.00	0.62	16.75	1.77	16.22	58.56	3.89	2.19	0.00	0.62
132	5.50	0.50	16.76	1.71	17.96	56.67	4.21	2.19	0.00	0.50
144	6.00	0.00	16.80	1.66	19.64	55.18	4.53	2.19	0.00	0.00
156	6.50	0.00	16.80	1.61	21.28	53.30	4.83	2.19	0.00	0.00
168	7.00	0.00	16.80	1.55	22.85	51.49	5.12	2.19	0.00	0.00
192	8.00	0.00	16.80	1.44	25.85	48.05	5.67	2.19	0.00	0.00
216	9.00	0.00	16.80	1.34	28.64	44.85	6.18	2.19	0.00	0.00
240	10.00	0.00	16.80	1.25	31.23	41.86	6.66	2.19	0.00	0.00
264	11.00	0.00	16.80	1.17	33.65	39.09	7.11	2.19	0.00	0.00
288	12.00	0.00	16.80	1.09	35.90	36.50	7.53	2.19	0.00	0.00
336	14.00	0.00	16.80	0.90	39.99	31.84	8.27	2.19	0.00	0.00
384	16.00	0.00	16.80	0.79	43.49	27.81	8.92	2.19	0.00	0.00
432	18.00	0.00	16.80	0.67	46.54	24.30	9.49	2.19	0.00	0.00
480	20.00	0.00	16.80	0.60	49.16	21.27	9.98	2.19	0.00	0.00
600	25.00	0.00	16.80	0.42	54.33	15.32	10.94	2.19	0.00	0.00
Maximum	28.00	89.70	16.80	2.06	56.68	67.85	11.38	2.19	0.00	89.70

Table XXIII.B-11 Upper Columbia River - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2).

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	85.99	2.49	0.00	0.00	11.48	0.04	0.00	0.00	85.99
4	0.17	86.69	2.43	0.00	0.00	10.79	0.08	0.00	0.00	86.69
6	0.25	84.01	3.03	0.00	0.00	12.80	0.16	0.00	0.00	84.01
8	0.33	81.07	3.65	0.00	0.00	15.03	0.24	0.00	0.00	81.07
10	0.42	69.25	5.67	0.00	0.00	24.76	0.32	0.00	0.00	69.25
12	0.50	49.46	9.05	1.22	0.00	39.88	0.40	0.00	0.00	49.46
14	0.58	35.00	11.49	0.00	1.21	51.82	0.48	0.00	0.00	35.00
16	0.67	26.11	12.94	0.00	1.21	59.04	0.55	0.14	0.00	26.11
18	0.75	25.80	13.04	0.00	1.21	59.06	0.63	0.28	0.00	25.80
20	0.83	19.35	14.06	0.00	1.20	64.29	0.70	0.41	0.00	19.35
22	0.92	18.25	14.23	0.00	1.19	65.01	0.78	0.53	0.00	18.25
24	1.00	12.11	15.18	2.08	1.19	67.93	0.85	0.66	0.00	12.11
28	1.17	11.11	15.28	0.00	3.25	68.15	1.00	1.21	0.00	11.11
32	1.33	10.51	15.33	0.00	3.24	68.05	1.14	1.73	0.00	10.51
36	1.50	9.94	15.38	2.01	3.23	65.94	1.28	2.22	0.00	9.94
40	1.67	9.02	15.48	0.00	5.23	66.18	1.42	2.68	0.00	9.02
44	1.83	8.05	15.58	0.00	5.22	66.48	1.56	3.11	0.00	8.05
48	2.00	4.96	15.97	2.03	5.21	66.62	1.69	3.53	0.00	4.96
54	2.25	4.28	16.05	0.00	7.22	66.75	1.89	3.81	0.00	4.28
60	2.50	4.15	16.10	1.97	7.21	64.68	2.08	3.81	0.00	4.15
66	2.75	3.47	16.21	0.00	9.16	65.09	2.27	3.81	0.00	3.47
72	3.00	3.41	16.24	1.92	9.15	63.02	2.45	3.81	0.00	3.41
78	3.25	3.21	16.27	0.00	11.05	63.02	2.64	3.81	0.00	3.21
84	3.50	3.18	16.28	1.86	11.04	61.02	2.82	3.81	0.00	3.18
90	3.75	2.88	16.32	0.00	12.88	61.13	2.99	3.81	0.00	2.88

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	2.84	16.32	1.80	12.86	59.19	3.17	3.81	0.00	2.84
108	4.50	1.78	16.42	1.77	14.64	58.08	3.50	3.81	0.00	1.78
120	5.00	0.00	16.57	1.75	16.37	57.67	3.83	3.81	0.00	0.00
132	5.50	0.00	16.57	1.69	18.10	55.69	4.15	3.81	0.00	0.00
144	6.00	0.00	16.57	1.63	19.76	53.78	4.45	3.81	0.00	0.00
156	6.50	0.00	16.57	1.58	21.37	51.94	4.74	3.81	0.00	0.00
168	7.00	0.00	16.57	1.52	22.92	50.16	5.03	3.81	0.00	0.00
192	8.00	0.00	16.57	1.42	25.86	46.79	5.56	3.81	0.00	0.00
216	9.00	0.00	16.57	1.32	28.59	43.65	6.06	3.81	0.00	0.00
240	10.00	0.00	16.57	1.23	31.14	40.72	6.53	3.81	0.00	0.00
264	11.00	0.00	16.57	1.14	33.52	38.00	6.96	3.81	0.00	0.00
288	12.00	0.00	16.57	1.07	35.73	35.46	7.37	3.81	0.00	0.00
336	14.00	0.00	16.57	0.88	39.74	30.90	8.10	3.81	0.00	0.00
384	16.00	0.00	16.57	0.78	43.18	26.95	8.73	3.81	0.00	0.00
432	18.00	0.00	16.57	0.66	46.17	23.52	9.27	3.81	0.00	0.00
480	20.00	0.00	16.57	0.59	48.74	20.54	9.75	3.81	0.00	0.00
600	25.00	0.00	16.57	0.41	53.82	14.72	10.67	3.81	0.00	0.00
Maximum	28.00	89.70	16.57	2.08	56.13	68.15	11.09	3.81	0.00	89.70

Table XXIII.B-12 Upper Columbia River - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Ridgefield National Wildlife Refuge (run #2).

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	85.99	2.49	0.00	0.00	11.48	0.04	0.00	0.00	85.99
4	0.17	86.69	2.43	0.00	0.00	10.79	0.08	0.00	0.00	86.69
6	0.25	84.01	3.03	0.00	0.00	12.80	0.16	0.00	0.00	84.01
8	0.33	81.07	3.65	0.00	0.00	15.03	0.24	0.00	0.00	81.07
10	0.42	69.25	5.67	0.00	0.00	24.76	0.32	0.00	0.00	69.25
12	0.50	49.46	9.05	1.22	0.00	39.88	0.40	0.00	0.00	49.46
14	0.58	35.00	11.49	0.00	1.21	51.82	0.48	0.00	0.00	35.00
16	0.67	25.83	12.94	0.00	1.21	59.04	0.55	0.42	0.00	25.83
18	0.75	25.25	13.03	0.00	1.21	59.06	0.63	0.83	0.00	25.25
20	0.83	18.22	14.10	0.00	1.20	64.55	0.70	1.22	0.00	18.22
22	0.92	17.69	14.15	0.00	1.19	64.58	0.78	1.60	0.00	17.69
24	1.00	10.92	15.14	2.06	1.19	67.76	0.85	2.09	0.00	10.92
28	1.17	9.53	15.24	0.00	3.23	67.98	0.99	3.02	0.00	9.53
32	1.33	8.60	15.28	0.00	3.22	67.89	1.13	3.88	0.00	8.60
36	1.50	7.71	15.32	2.00	3.21	65.79	1.27	4.69	0.00	7.71
40	1.67	6.50	15.41	0.00	5.19	66.03	1.40	5.46	0.00	6.50
44	1.83	5.11	15.53	0.00	5.18	66.46	1.53	6.19	0.00	5.11
48	2.00	2.76	15.76	1.99	5.17	65.70	1.66	6.96	0.00	2.76
54	2.25	1.98	15.82	0.00	7.15	65.83	1.85	7.37	0.00	1.98
60	2.50	1.95	15.84	1.93	7.13	63.75	2.04	7.37	0.00	1.95
66	2.75	1.56	15.90	0.00	9.05	63.91	2.22	7.37	0.00	1.56
72	3.00	1.52	15.91	1.87	9.03	61.90	2.39	7.37	0.00	1.52
78	3.25	1.34	15.93	0.00	10.89	61.90	2.57	7.37	0.00	1.34
84	3.50	1.32	15.94	1.81	10.87	59.94	2.74	7.37	0.00	1.32
90	3.75	1.03	15.97	0.00	12.67	60.05	2.91	7.37	0.00	1.03

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	1.01	15.97	1.76	12.66	58.16	3.08	7.37	0.00	1.01
108	4.50	0.45	16.02	1.71	14.38	56.67	3.40	7.37	0.00	0.45
120	5.00	0.00	16.06	1.66	16.07	55.13	3.71	7.37	0.00	0.00
132	5.50	0.00	16.06	1.61	17.70	53.26	4.01	7.37	0.00	0.00
144	6.00	0.00	16.06	1.55	19.28	51.44	4.30	7.37	0.00	0.00
156	6.50	0.00	16.06	1.50	20.80	49.69	4.58	7.37	0.00	0.00
168	7.00	0.00	16.06	1.44	22.27	48.00	4.86	7.37	0.00	0.00
192	8.00	0.00	16.06	1.34	25.06	44.80	5.37	7.37	0.00	0.00
216	9.00	0.00	16.06	1.25	27.66	41.82	5.85	7.37	0.00	0.00
240	10.00	0.00	16.06	1.17	30.08	39.04	6.29	7.37	0.00	0.00
264	11.00	0.00	16.06	1.09	32.33	36.45	6.71	7.37	0.00	0.00
288	12.00	0.00	16.06	1.01	34.42	34.04	7.10	7.37	0.00	0.00
336	14.00	0.00	16.06	0.84	38.23	29.71	7.80	7.37	0.00	0.00
384	16.00	0.00	16.06	0.74	41.49	25.95	8.40	7.37	0.00	0.00
432	18.00	0.00	16.06	0.63	44.33	22.69	8.93	7.37	0.00	0.00
480	20.00	0.00	16.06	0.56	46.77	19.86	9.39	7.37	0.00	0.00
600	25.00	0.00	16.06	0.39	51.59	14.31	10.29	7.37	0.00	0.00
Maximum	28.00	89.70	16.06	2.06	53.77	67.98	10.69	7.37	0.00	89.70

Table XXIII.B-13 Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	13	7	8
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	13	7	8
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	743	309	196
Shoreline length (km) oiled by > 100 g/m^2	705	274	196
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	294,230	80,335	42,678
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	448,370	228,950	153,140
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	81	30	15

Table XXIII.B-14 Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	13	6	8
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	12	6	8
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	668	289	183
Shoreline length (km) oiled by > 100 g/m^2	665	254	183
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	261,090	50,209	40,168
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	406,700	239,000	143,100
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	72	32	14

Table XXIIIB-15 Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	13	7	8
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	13	7	7
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	595	294	149
Shoreline length (km) oiled by > 100 g/m^2	593	257	149
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	153,640	85,356	502
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	441,840	208,870	148,120
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	69	29	12

Table XXIII.B-16 Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	12	7	8
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	12	7	8
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	617	299	178
Shoreline length (km) oiled by > 100 g/m^2	579	262	178
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	289,210	52,720	35,147
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	327,870	246,530	143,100
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	61	32	14

XXIII.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 XXIII.C-1 Upper Columbia River - Bunker C, 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)	56	10	25	3,438	1	-	-	156	3,685	3,529	156
Worst run for Ridgefield National Wildlife Refuge (run #1)	54	10	7	874	0	-	-	107	1,053	946	107
Worst run for Ridgefield National Wildlife Refuge (run #2)	54	9	3	280	0	-	-	115	462	347	115

Table XXIII.C-2 Upper Columbia River - Bunker C, 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)	92	31	23	3,216	0	-	-	154	3,517	3,363	154
Worst run for Ridgefield National Wildlife Refuge (run #1)	73	20	7	762	0	-	-	103	965	862	103
Worst run for Ridgefield National Wildlife Refuge (run #2)	77	23	3	210	0	-	-	115	428	313	115

Table XXIII.C-3 Upper Columbia River - Bunker C, 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)	92	31	20	2,812	0	-	-	154	3,111	2,956	154
Worst run for Ridgefield National Wildlife Refuge (run #1)	75	21	7	776	0	-	-	109	989	880	109
Worst run for Ridgefield National Wildlife Refuge (run #2)	76	22	2	17	0	-	-	110	226	116	110

Table XXIII.C-4 Upper Columbia River - Bunker C, 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)	92	31	20	2,736	0	-	-	153	3,032	2,879	153
Worst run for Ridgefield National Wildlife Refuge (run #1)	74	20	7	804	0	-	-	105	1,010	905	105
Worst run for Ridgefield National Wildlife Refuge (run #2)	76	22	3	182	0	-	-	112	395	283	112

XXIII.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 XXIII.D-1. Upper Columbia River - Bunker C, 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)	1.4	74	3,653	-	-	-	3,728
Worst run for Ridgefield National Wildlife Refuge (run #1)	1.4	72	3,615	-	-	-	3,689
Worst run for Ridgefield National Wildlife Refuge (run #2)	1.4	61	3,295	-	-	-	3,357

Table XXIII.D-2. Upper Columbia River - Bunker C, 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)	1.4	74	3,664	-	-	-	3,740
Worst run for Ridgefield National Wildlife Refuge (run #1)	1.4	70	3,557	-	-	-	3,629
Worst run for Ridgefield National Wildlife Refuge (run #2)	1.4	67	3,468	-	-	-	3,537

Table XXIII.D-3. Upper Columbia River - Bunker C, 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)	1.4	74	3,653	-	-	-	3,728
Worst run for Ridgefield National Wildlife Refuge (run #1)	1.4	71	3,580	-	-	-	3,652
Worst run for Ridgefield National Wildlife Refuge (run #2)	1.4	68	3,475	-	-	-	3,544

Table XXIII.D-4. Upper Columbia River - Bunker C, 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)	1.4	74	3,646	-	-	-	3,721
Worst run for Ridgefield National Wildlife Refuge (run #1)	1.4	69	3,524	-	-	-	3,595
Worst run for Ridgefield National Wildlife Refuge (run #2)	1.4	67	3,469	-	-	-	3,537

XXIII.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 XXIII.E-1. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Fish and Invertebrates:			
Small pelagic fish	1.4	1.4	1.4
Large pelagic fish	74	73	61
Demersal fish	3,653	3,615	3,295
Decapods	-	-	-
Molluscs	-	-	-
Birds:			
Waterfowl (# * kg each)	16	15	15
Seabirds (# * kg each)	11	10	10
Waders (# * kg each)	27	8	4
Shorebirds (# * kg each)	3,781	962	308
Raptors (# * kg each)	0.6	0.2	0.1
Other wildlife:			
Sea otters, other mammals	172	118	127
Pinnipeds	-	-	-
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	3,728	3,689	3,357
Subtotal birds	3,836	996	338
Subtotal other wildlife	172	118	126
Total all species	7,736	4,803	3,822

Table XXIII.E-2. Upper Columbia River - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Saltmarsh Area (ha)	6.1	2.5	1.6
Saltmarsh Area (acres)	15	6.2	4.0
Saltmarsh Cost (millions of 2004$)	2.8	1.2	0.7
Eelgrass Area (m2)	3.8	1.6	1.0
Eelgrass Area (acres)	9.5	3.9	2.5
Eelgrass Cost (millions of 2004$)	1.1	0.5	0.3

Table XXIII.E-3. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Fish and Invertebrates:			
Small pelagic fish	1.4	1.4	1.4
Large pelagic fish	74	70	67
Demersal fish	3,664	3,557	3,468
Decapods	-	-	-
Molluscs	-	-	-
Birds:			
Waterfowl (# * kg each)	26	20	22
Seabirds (# * kg each)	34	22	25
Waders (# * kg each)	25	7	3
Shorebirds (# * kg each)	3,538	838	231
Raptors (# * kg each)	0.5	0.2	0.1
Other wildlife:			
Sea otters, other mammals	170	113	126
Pinnipeds	-	-	-
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	3,740	3,629	3,537
Subtotal birds	3,623	888	281
Subtotal other wildlife	170	113	126
Total all species	7,533	4,631	3,944

Table XXIII.E-4. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Saltmarsh Area (ha)	6.0	2.4	1.7
Saltmarsh Area (acres)	15	6.0	4.1
Saltmarsh Cost (millions of 2004$)	2.8	1.1	0.8
Eelgrass Area (m2)	3.7	1.5	1.0
Eelgrass Area (acres)	9.2	3.7	2.6
Eelgrass Cost (millions of 2004$)	1.1	0.4	0.3

Table XXIII.E-5. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Fish and Invertebrates:			
Small pelagic fish	1.4	1.4	1.4
Large pelagic fish	74	71	68
Demersal fish	3,653	3,580	3,475
Decapods	-	-	-
Molluscs	-	-	-
Birds:			
Waterfowl (# * kg each)	26	21	21
Seabirds (# * kg each)	34	24	24
Waders (# * kg each)	22	7	2
Shorebirds (# * kg each)	3,093	854	18
Raptors (# * kg each)	0.5	0.2	0.1
Other wildlife:			
Sea otters, other mammals	170	120	122
Pinnipeds	-	-	-
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	3,728	3,652	3,544
Subtotal birds	3,176	906	65
Subtotal other wildlife	170	120	121
Total all species	7,074	4,678	3,731

Table XXIII.E-6. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Saltmarsh Area (ha)	5.4	2.5	1.4
Saltmarsh Area (acres)	13	6.1	3.4
Saltmarsh Cost (millions of 2004$)	2.5	1.1	0.6
Eelgrass Area (m2)	3.4	1.5	0.9
Eelgrass Area (acres)	8.4	3.8	2.1
Eelgrass Cost (millions of 2004$)	1.0	0.4	0.3

Table XXIII.E-7. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Fish and Invertebrates:			
Small pelagic fish	1.4	1.4	1.4
Large pelagic fish	74	69	67
Demersal fish	3,646	3,524	3,469
Decapods	-	-	-
Molluscs	-	-	-
Birds:			
Waterfowl (# * kg each)	26	21	21
Seabirds (# * kg each)	34	23	24
Waders (# * kg each)	22	8	3
Shorebirds (# * kg each)	3,010	885	200
Raptors (# * kg each)	0.5	0.2	0.1
Other wildlife:			
Sea otters, other mammals	168	115	123
Pinnipeds	-	-	-
Cetaceans	-	-	-
Totals:			
Subtotal fish and invertebrates	3,721	3,595	3,537
Subtotal birds	3,092	936	249
Subtotal other wildlife	168	115	123
Total all species	6,981	4,646	3,909

Table XXIII.E-8. Upper Columbia River - Bunker C, 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 Ridgefield National Wildlife Refuge (run #1)	Worst run for Ridgefield National Wildlife Refuge (run #2)
Saltmarsh Area (ha)	5.3	2.5	1.6
Saltmarsh Area (acres)	13	6.1	4.0
Saltmarsh Cost (millions of 2004$)	2.5	1.1	0.8
Eelgrass Area (m2)	3.3	1.5	1.0
Eelgrass Area (acres)	8.2	3.8	2.5
Eelgrass Cost (millions of 2004$)	1.0	0.5	0.3

XXIII.F. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

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

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 XXIV: Model Inputs for Outer Coast Sea Lanes – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXIV.A. Introduction 1
XXIV.B. Geographical Data 2
XXIV.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XXIV.B.2. Gridded Habitat Mapping 3
XXIV.B-3. Gridded Depth Data 4
XXIV.B-4. Areas Where Response Actions Assumed 5
XXIV.C. Current Data 7
XXIV.C.1. Basis of Current Data 7
XXIV.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations ... 9
XXIV.D: Oil Properties 12
XXIV.E: Inputs to the SIMAP Physical Fates Model 15

List of Figures

Figure XXIV.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XXIV.B.2-1 Habitat grid used for modeling the potential spills. 3
Figure XXIV.B.2-2 Habitat grid used for modeling the potential spills (closer view). 3
Figure XXIV.B.3-1 Depth grid used for modeling the potential spills. 4
Figure XXIV.B.3-2 Depth grid used for modeling the potential spills (closer view). 4
Figure XXIV.B.4-1 Jurisdictions in the area of the potential spills..... 5
Figure XXIV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XXIV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XXIV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XXIV.C.1-1 Grid used for the hydrodynamic model-generated current data. 8
Figure XXIV.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – 3 miles off the coast of Washington – Outer Coast, Sea Lanes). 8
Figure XXIV.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 3 miles off the coast of Washington – Outer Coast, Sea Lanes. 9
Figure XXIV.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 3 miles off the coast of Washington – Outer Coast, Sea Lanes. 10
Figure XXIV.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 3 miles off the coast of Washington – Outer Coast, Sea Lanes. 10
Figure XXIV.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 3 miles off the coast of Washington – Outer Coast, Sea Lanes. 11
Figure XXIV.E-1. Varied spill site, along line 3 miles off the coast of Washington on-shore of the shipping lanes. 18
Figure XXIV.E-2. Wind Station Location. 22

List of Tables

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

XXIV.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.

XXIV.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.

XXIV.B.1. Maps of the Vicinity of the Modeled Spill Locations

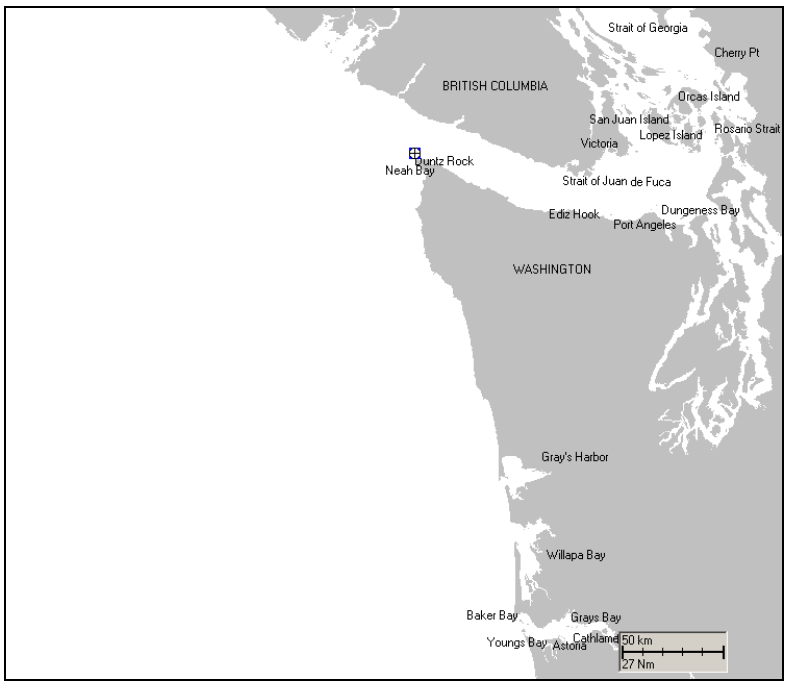


Figure XXIV.B.1-1 Map of the vicinity of the potential spill locations.

XXIV.B.2. Gridded Habitat Mapping

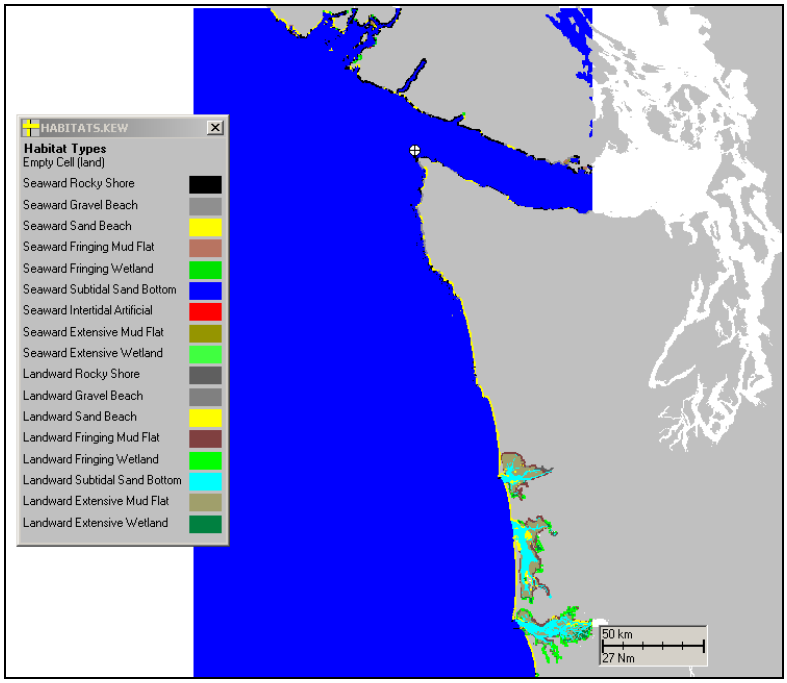


Figure XXIV.B.2-1 Habitat grid used for modeling the potential spills.

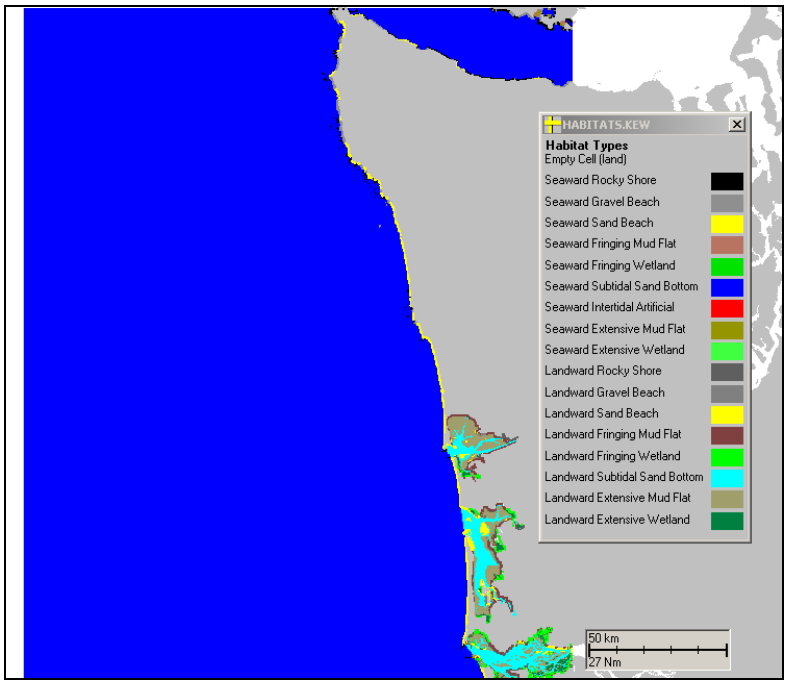


Figure XXIV.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XXIV.B-3. Gridded Depth Data

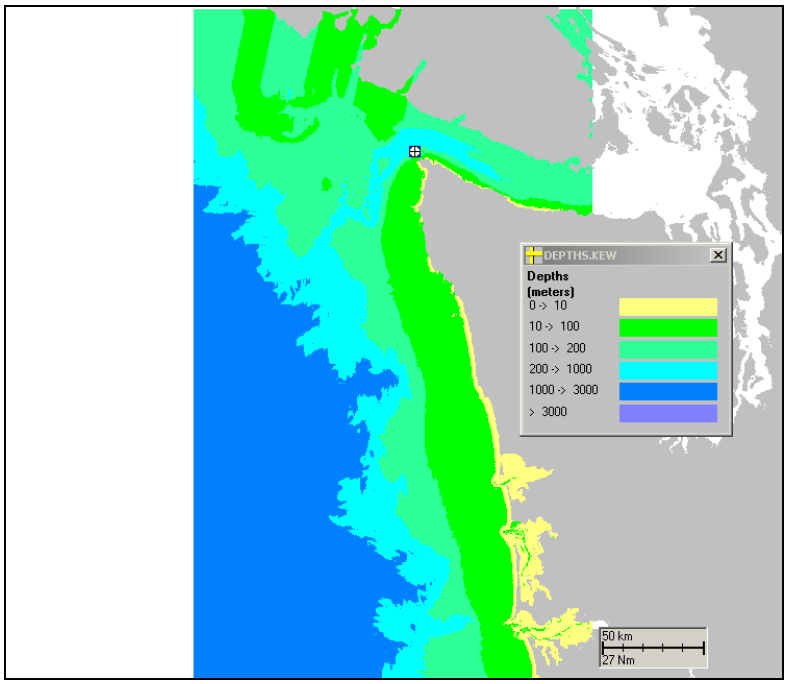


Figure XXIV.B.3-1 Depth grid used for modeling the potential spills.

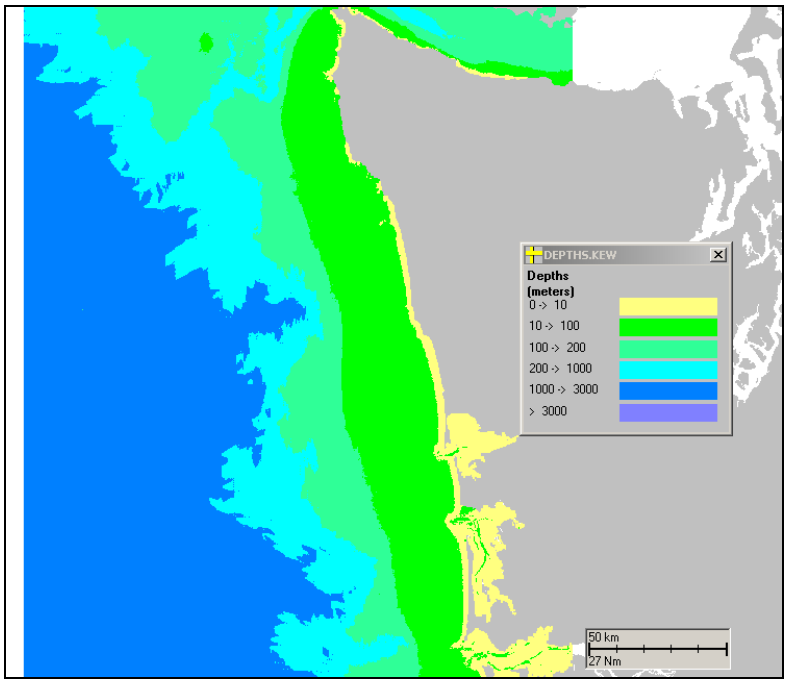


Figure XXIV.B.3-2 Depth grid used for modeling the potential spills (closer view).

XXIV.B-4. Areas Where Response Actions Assumed

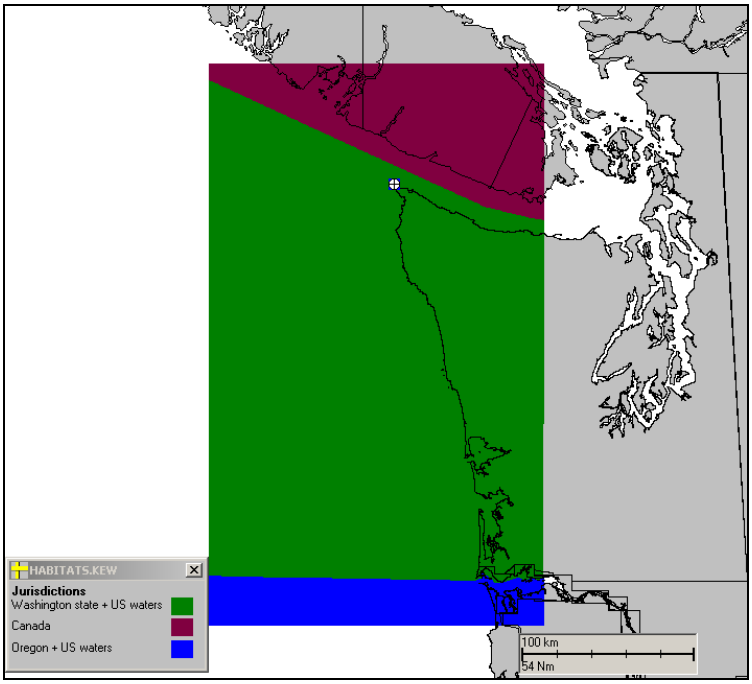


Figure XXIV.B.4-1 Jurisdictions in the area of the potential spills.

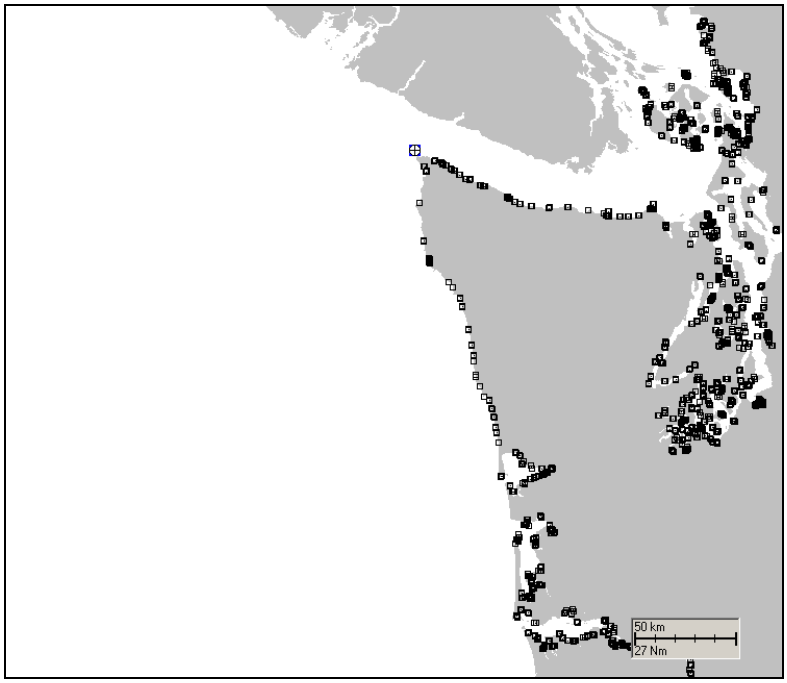


Figure XXIV.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills.

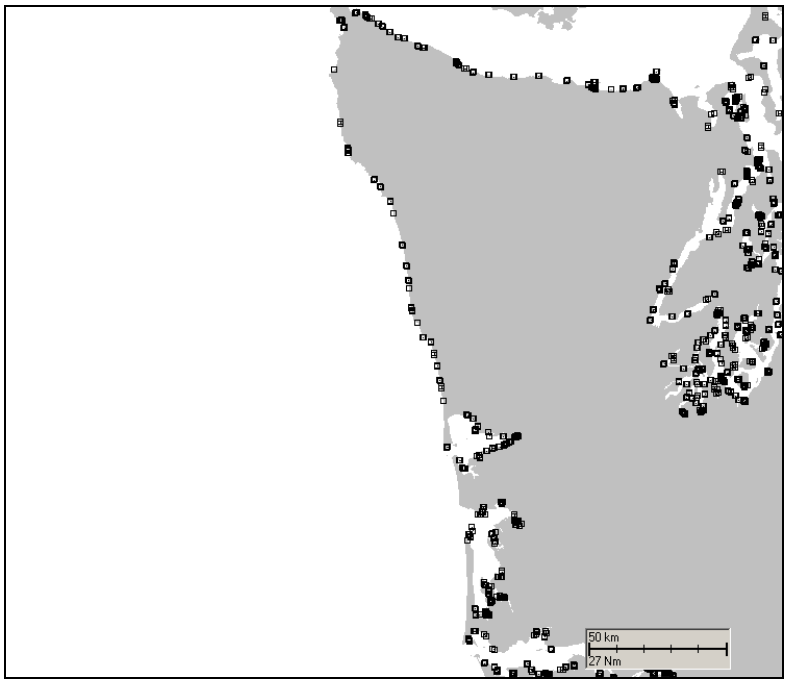


Figure XXIV.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view).

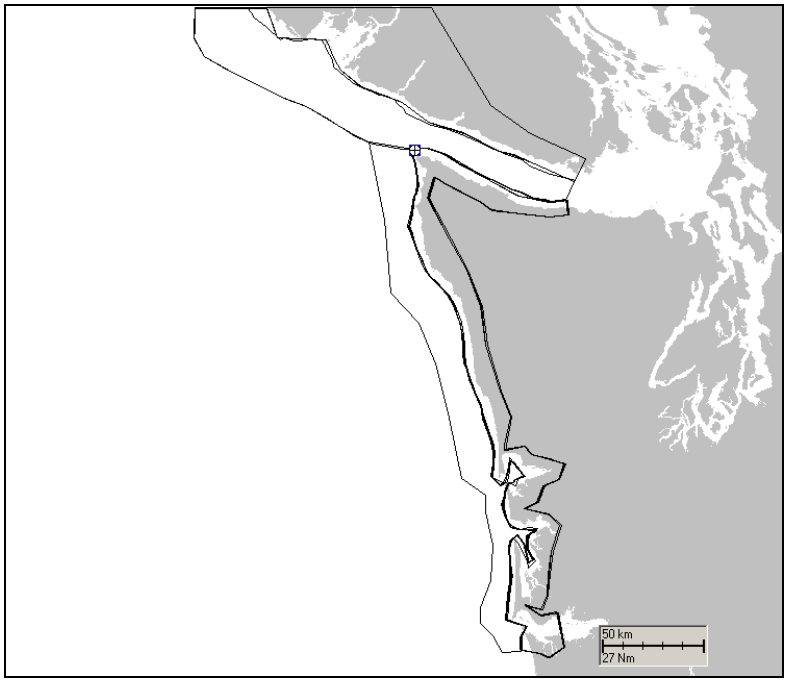


Figure XXIV.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills.

XXIV.C. CURRENT DATA

XXIV.C.1. Basis of Current Data

A 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, the 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 22200 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).

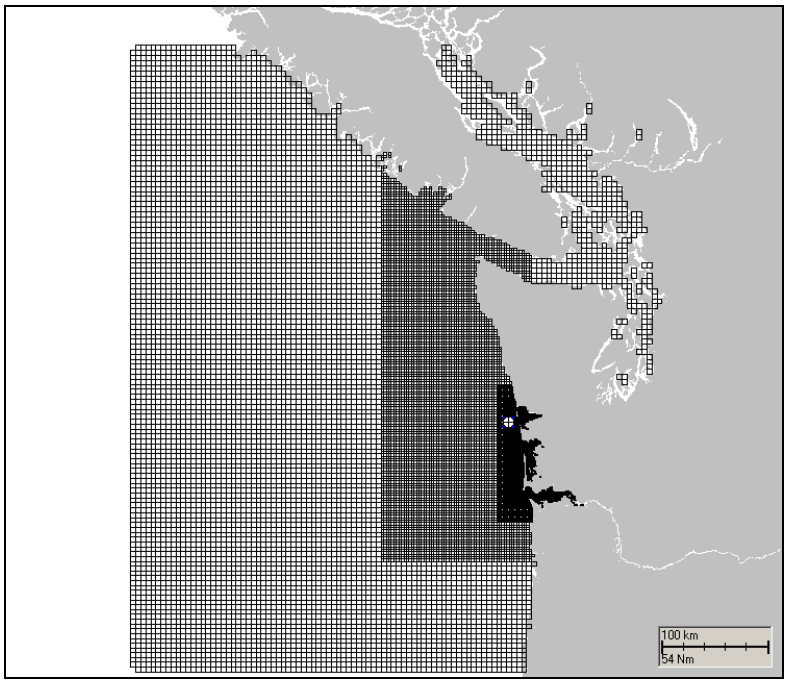


Figure XXIV.C.1-1 Grid used for the hydrodynamic model-generated current data.

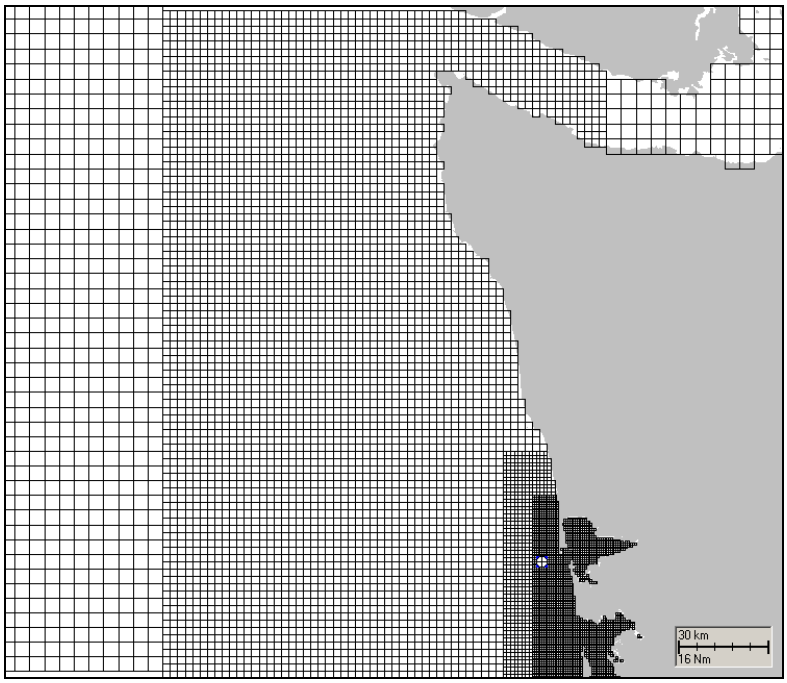


Figure XXIV.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – 3 miles off the coast of Washington – Outer Coast, Sea Lanes).

XXIV.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.

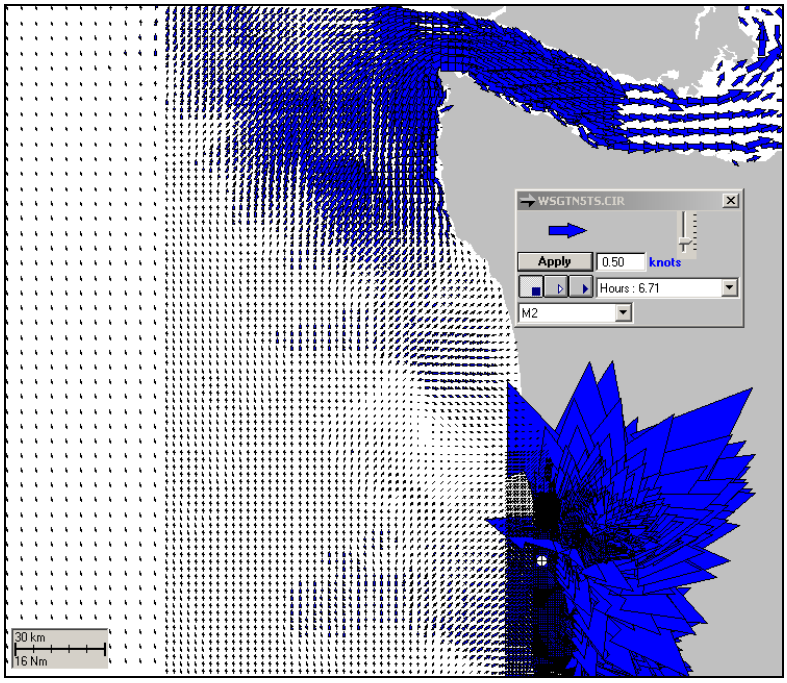


Figure XXIV.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component 3 miles off the coast of Washington – Outer Coast, Sea Lanes.

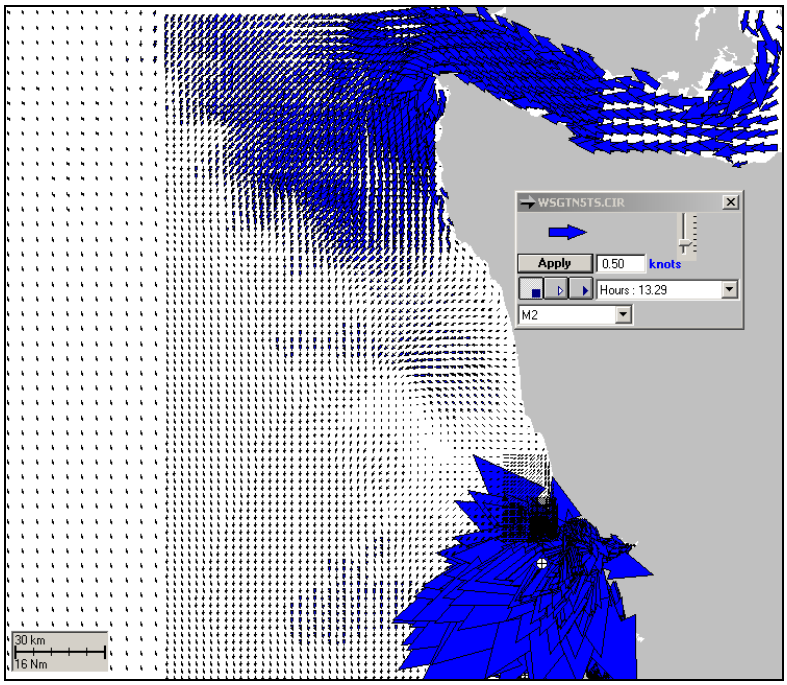


Figure XXIV.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component 3 miles off the coast of Washington – Outer Coast, Sea Lanes.

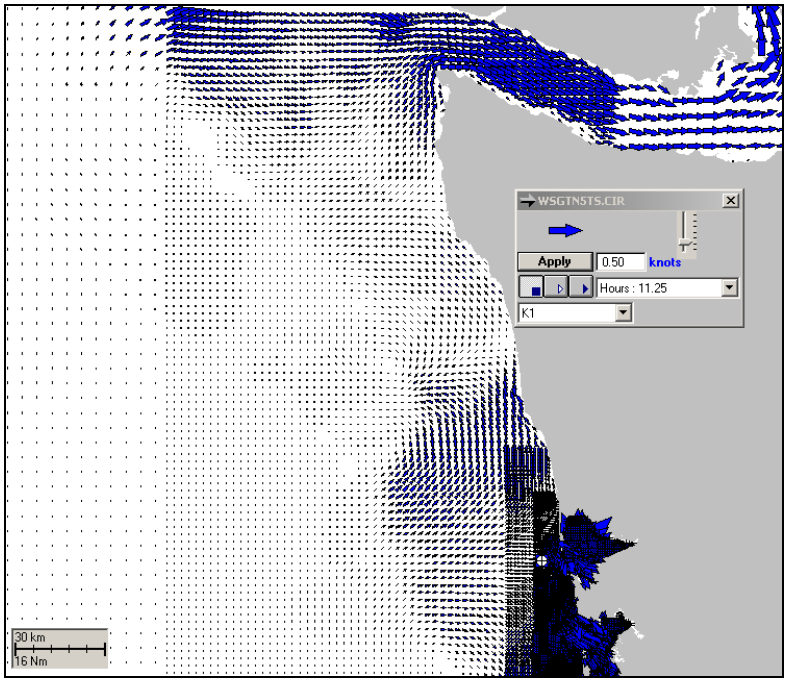


Figure XXIV.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component 3 miles off the coast of Washington – Outer Coast, Sea Lanes.

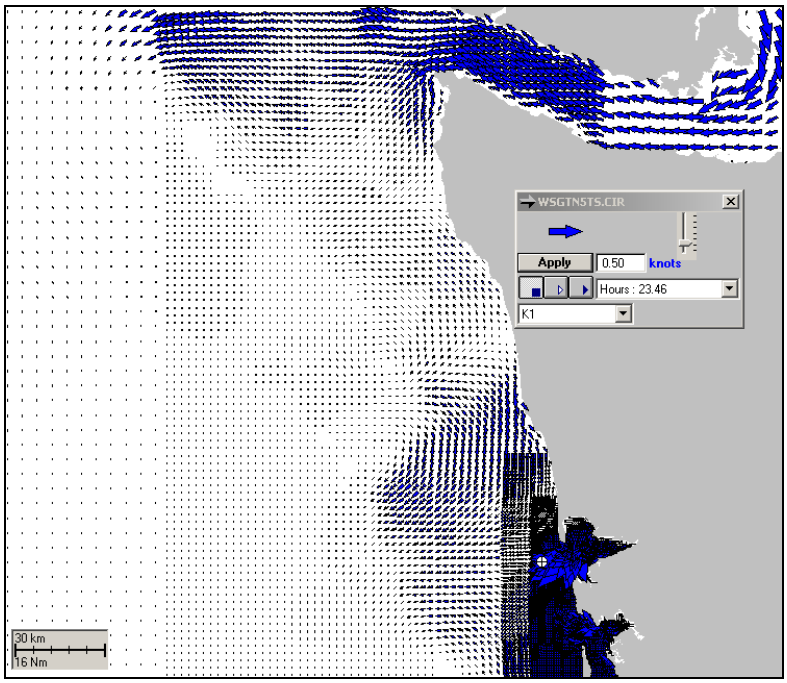


Figure XXIV.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component 3 miles off the coast of Washington – Outer Coast, Sea Lanes.

XXIV.D: OIL PROPERTIES

Table XXIV.D-1. Oil properties for Bunker C assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.9749	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	3180	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27	Jokuty et al. (1999)
Pour Point (deg. C)	7	Whiticar et al. (1994)
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)	0.00	Ostazeski et al. (1997)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.036093	Ostazeski et al. (1997)
Fraction 2-ring aromatics (included in PAHs above)	0.011987	Ostazeski et al. (1997)
Fraction 3-ring aromatics (included in PAHs above)	0.024106	Ostazeski et al. (1997)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.010000	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.037013	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.088894	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	30	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] – Jokuty 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 XXIV.D-2. Aromatic concentrations (mg/kg) for Bunker C.

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 XXIV.D-2. Aromatic concentrations (mg/kg) for Bunker C (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	346
C1-dibenzothiophene	4.86	1,072
C2-dibenzothiophene	5.50	1,489
C3-dibenzothiophene	5.73	1,176
phenanthrene	4.57	743
anthracene	4.54	88
C1-phenanthrenes/anthracenes	5.14	2,031
C2-phenanthrenes/anthracenes	5.25	2,661
C3-phenanthrenes/anthracenes	6.00	1,825
C4-phenanthrenes/anthracenes	6.51	930
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total $\log(K_{ow}) \leq 5.6$	-	32,162.3

*Estimates of $\log(K_{ow})$ are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XXIV.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 XXIV.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	3 miles off the coast of Washington – Outer Coast, Sea Lanes
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXIV.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXIV.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	150,000 bbl
Model time step	Time step used for model calculations	Hours	-	1.0
Model duration	Length of each model simulation	Days	-	56 days

Table XXIV.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XXIV.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 49	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 49	monthly means (see Table XXIV.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 49	monthly means (see Table XXIV.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

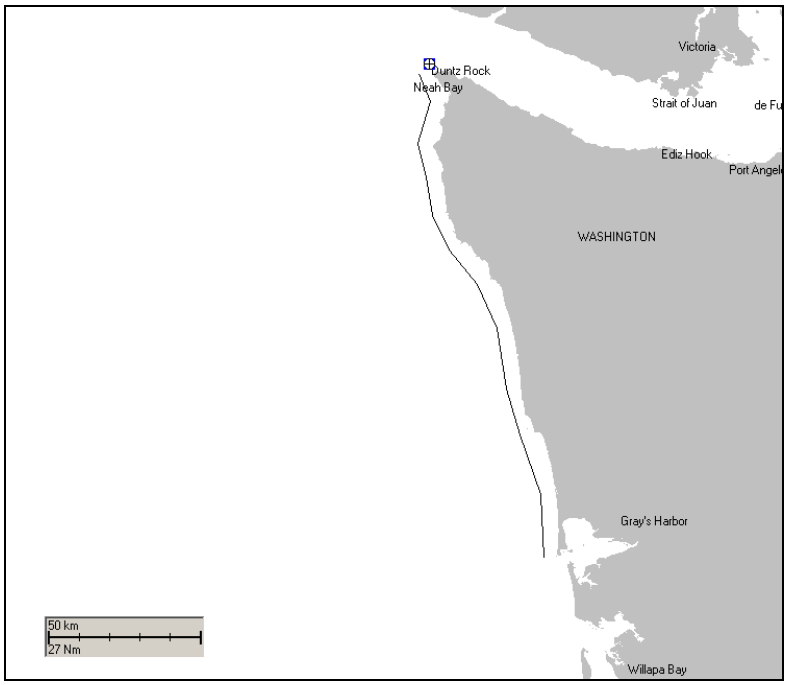


Figure XXIV.E-1. Varied spill site, along line 3 miles off the coast of Washington on-shore of the shipping lanes.

Table XXIV.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	1985	2	27	7	48.26764	124.7625
2	1988	11	19	6	47.55448	124.4316
3	2003	3	29	7	47.33396	124.3609
4	1985	3	8	7	47.34812	124.3669
5	1995	3	16	10	47.79959	124.5943
6	1993	3	15	11	48.37102	124.7894
7	1988	7	16	3	47.87662	124.6773
8	1993	9	18	0	47.9519	124.7349
9	1987	7	26	1	48.08783	124.7714
10	1989	5	9	12	47.34152	124.3641
11	1993	3	31	5	47.82314	124.6225
12	1999	5	1	20	47.74708	124.5337
13	1988	2	13	13	48.26509	124.7636
14	1985	8	31	19	47.07703	124.2474
15	1985	12	15	2	47.51303	124.4223
16	2003	12	22	17	47.2881	124.3404
17	2000	2	21	22	47.83501	124.6367
18	1995	11	21	2	47.17252	124.2796
19	2002	9	30	12	48.05666	124.7624
20	1990	11	10	15	47.88865	124.6865
21	1993	12	4	12	46.92908	124.2359
22	1991	1	12	13	47.6096	124.4441
23	1984	9	19	1	47.45824	124.4099
24	1994	6	14	5	48.21014	124.7884
25	1995	2	21	9	46.96532	124.2387
26	1994	6	21	14	47.32774	124.3582
27	1990	3	14	23	47.48236	124.4153
28	2003	8	14	7	47.0443	124.2449
29	2000	4	24	13	47.60932	124.444
30	1987	10	16	19	48.07026	124.7655
31	1993	11	22	11	48.23605	124.7767
32	2002	3	7	19	47.23131	124.3105
33	1993	8	4	2	47.57392	124.436
34	1989	4	16	0	48.14214	124.7918
35	2004	8	22	6	48.20006	124.7929
36	1989	10	12	20	48.07411	124.7663
37	1986	8	28	9	47.95103	124.7342
38	1991	4	4	1	47.38362	124.3822
39	1999	4	21	1	48.10632	124.7783
40	1995	6	22	5	48.26999	124.7614
41	2003	1	26	5	48.21381	124.7867
42	1999	12	22	12	47.07333	124.2472
43	1986	2	16	9	47.72324	124.5173
44	2002	3	1	1	48.09323	124.7734
45	2004	6	14	14	47.0099	124.2422
46	2001	4	1	0	47.10309	124.2495
47	2002	10	10	11	48.17802	124.8028
48	1984	12	21	5	47.66936	124.4804
49	1986	7	1	6	48.16811	124.8015
50	1997	8	2	17	47.07487	124.2473

51	1995	12	25	13	47.46905	124.4123
52	2004	5	11	3	47.97023	124.7427
53	1997	6	7	18	48.36236	124.7843
54	1997	8	9	10	48.22901	124.7799
55	1989	9	18	11	47.56752	124.4346
56	1985	3	23	5	47.79669	124.5908
57	1994	3	31	21	47.03373	124.2441
58	2003	7	30	18	46.97005	124.2391
59	2004	8	6	19	47.11104	124.2501
60	1990	1	18	14	48.32859	124.7643
61	1999	7	12	0	47.26842	124.33
62	1985	1	9	0	48.1488	124.7943
63	2001	4	18	4	47.691	124.4952
64	1991	3	19	0	48.11678	124.7823
65	1987	2	26	14	48.35887	124.7822
66	1998	9	27	5	48.36406	124.7853
67	1991	3	20	8	47.8356	124.6375
68	2003	4	25	17	47.9362	124.7229
69	1989	4	4	1	47.71195	124.5096
70	1989	9	14	4	47.75215	124.5375
71	1997	11	19	7	47.80594	124.6019
72	1985	2	14	11	47.17292	124.2798
73	2003	9	20	9	47.78258	124.5739
74	1986	5	8	6	48.32903	124.7645
75	2001	2	11	12	48.32827	124.7641
76	1999	8	8	20	47.86408	124.6678
77	2003	9	11	19	48.23466	124.7773
78	2004	10	4	17	47.09557	124.2489
79	1984	9	23	16	47.50797	124.4211
80	1990	10	29	12	47.17667	124.2818
81	1997	5	7	22	47.2585	124.3248
82	1994	6	28	20	47.46367	124.4111
83	1999	12	11	3	48.01942	124.7539
84	2003	2	28	14	47.89087	124.6882
85	2002	9	5	4	47.87793	124.6783
86	1994	1	23	7	48.01331	124.7525
87	2002	9	22	4	47.93674	124.7233
88	2004	7	4	0	47.72694	124.5199
89	2004	7	25	16	47.82853	124.629
90	1990	5	13	22	48.32924	124.7646
91	1999	6	23	19	47.45923	124.4101
92	1993	12	20	4	47.75146	124.5367
93	1988	12	26	20	47.6205	124.4469
94	1996	1	5	2	47.80713	124.6033
95	2002	3	17	6	47.63363	124.4559
96	1999	6	3	13	47.24513	124.3178
97	1992	6	30	18	47.41462	124.3955
98	1996	8	15	13	48.18349	124.8004
99	1990	2	17	19	47.85379	124.6592
100	2001	10	9	1	47.91696	124.7082

Table XXIV.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	OC_SL_HAB-DEPTH.HAB
Grid W edge	126° 13.98’ W
Grid S edge	46° 0.06’ N
Cell size (^{o}longitude)	0.003072^o W
Cell size (^{o}latitude)	0.003072^o N
Cell size (m) west-east	236.87
Cell size (m) south-north	340.99
# cells west-east	875
# cells south-north	993
Water cell area (m^2)	80,769.68
Shore cell length (m)	284.20
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 XXIV.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	9	8	20
February	8	8	20
March	9	8	20
April	10	8	20
May	12	8	20
June	13	8	20
July	13	7	10
August	15	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	9	7	20

Table XXIV.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
DESW1_1984-2004_PST.WNE	Station DESW1 - Destruction Is., WA	47.68 ºN 124.49 ºW	1984-2004	National Data Buoy Center

The DESW1_1984-2004_PST.WNE wind data were downloaded from the buoy Station DESW1 - Destruction Is., WA. Figure XXIV.E-2 displays where the buoy is located (about 4 miles off the Washington outer coast). DESW1_1984-2004_PST.WNE data start on 13 August 1984 and end on 31 December 2004.

Figure XXIV.E-2. Wind Station Location.

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 XXV: Model Results for Runs Assuming No Response for Outer Coast Sea Lanes – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXV.A. Introduction 1
XXV.B. Maps of Exposure Probability and Time First Exposed 1
XXV.C. Statistics for All Model Runs 5
XXV.D. Shoreline Areas Exposed by Shore Type 8
XXV.E. Exposure for Representative Individual Model Runs. 10
XXV.F. Estimated Biological Impacts: Wildlife 25
XXV.G. Estimated Biological Impacts: Fish and Invertebrates 28
XXV.H. Estimated NRDA Costs: Habitat Restoration Costs 30
XXV.I. Estimated NRDA Costs: Washington Compensation schedule 33

List of Figures

Figure XXV.B-1. Outer Coast Sea Lanes, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure XXV.B-2. Outer Coast Sea Lanes, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2. 2
Figure XXV.B-3. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-3 to OC-14. 3
Figure XXV.B-4. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-15 to OC-28. 4
Figure XXV.B-5. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the GRPs within Grays Harbor. 4
Figure XXV.C-1. Outer Coast Sea Lanes, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 7
Figure XXV.C-2. Outer Coast Sea Lanes, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill. 7
Figure XXV.E-1. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 11
Figure XXV.E-2. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 11
Figure XXV.E-3. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run based on shoreline costs. 12
Figure XXV.E-4. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary. 12
Figure XXV.E-5. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary. 13
Figure XXV.E-6. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the Olympia Coast National Marine Sanctuary. 13
Figure XXV.E-7. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island. 14
Figure XXV.E-8. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island. 14
Figure XXV.E-9. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Tatoosh Island. 15
Figure XXV.E-10. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River. 15

Figure XXV.E-11. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River. 16
Figure XXV.E-12. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Quileute River. 16
Figure XXV.E-13. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River. 17
Figure XXV.E-14. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River. 17
Figure XXV.E-15. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Hoh River. 18
Figure XXV.E-16. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay. 18
Figure XXV.E-17. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay. 19
Figure XXV.E-18. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Willapa Bay. 19
Figure XXV.E-19. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor. 20
Figure XXV.E-20. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor. 20
Figure XXV.E-21. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Grays Harbor. 21
Figure XXV.E-22. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River. 21
Figure XXV.E-23. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River. 22
Figure XXV.E-24. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Lower Columbia River. 22
Figure XXV.E-25. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs. 23
Figure XXV.E-26. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs. 23
Figure XXV.E-27. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the GRPs. 24

List of Tables

Table XXV.C-1. Outer Coast Sea Lanes, No removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 6
Table XXV.D-1. Outer Coast Sea Lanes, No removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 8
Table XXV.D-2. Outer Coast Sea Lanes, No removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 8
Table XXV.D-3. Outer Coast Sea Lanes, No removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 9
Table XXV.D-4. Outer Coast Sea Lanes, No removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 9
Table XXV.F-1. Outer Coast Sea Lanes, no removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose..... 26
Table XXV.F-2. Outer Coast Sea Lanes, no removal: Wildlife injury (as numbers lost). 27
Table XXV.G-1. Outer Coast Sea Lanes, no removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column..... 29
Table XXV.G-2. Outer Coast Sea Lanes, no removal: Fish and invertebrate injury (as biomass lost in kg). 29
Table XXV.H-1. Outer Coast Sea Lanes, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 31
Table XXV.H-2. Outer Coast Sea Lanes, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 32
Table XXV.I-1. Outer Coast Sea Lanes, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 33

XXV.A. INTRODUCTION

The results of the stochastic scenario for the Outer Coast Sea Lanes 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).

XXV.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)

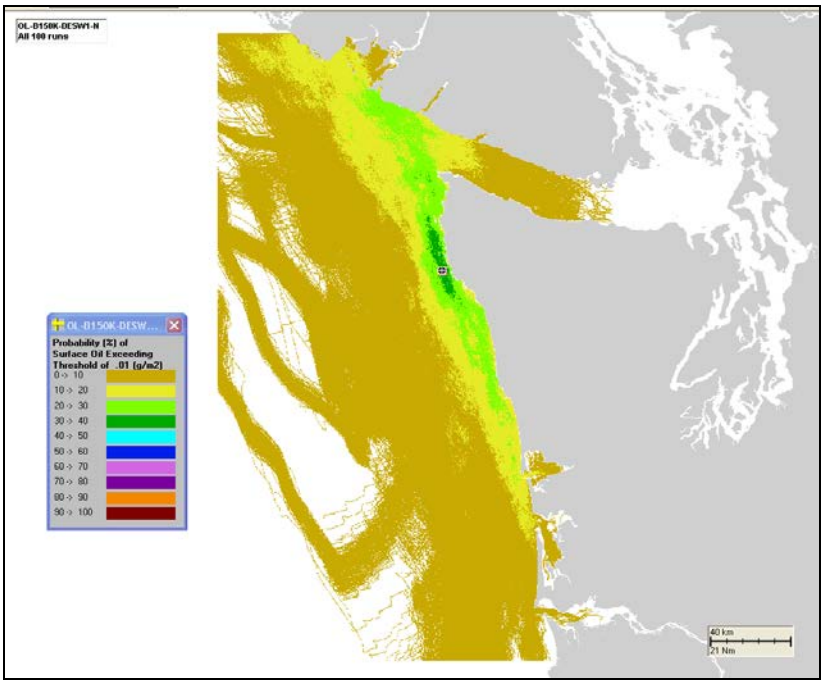


Figure XXV.B-1. Outer Coast Sea Lanes, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

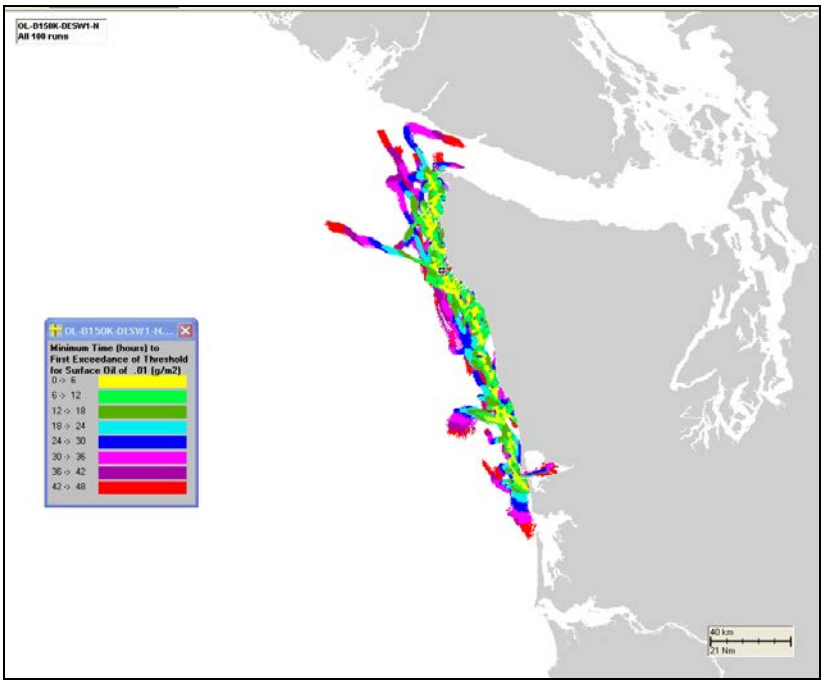


Figure XXV.B-2. Outer Coast Sea Lanes, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed for the Outer Coast Sea Lanes location, maximum water column exposure of dissolved aromatic concentration never exceeded 1 ppb averaged over a 0.08 km^2 grid cell. Consequently, maps of such exceedances are not shown here.

Primary areas of concern are the locations of the geographic response plans (GRPs). Figures XXV.B-3 to XXV.B5 are plots of the time after the spill when the surface floating hydrocarbons could first exceed the threshold of 0.01g/m^2 for the areas of the GRPs.

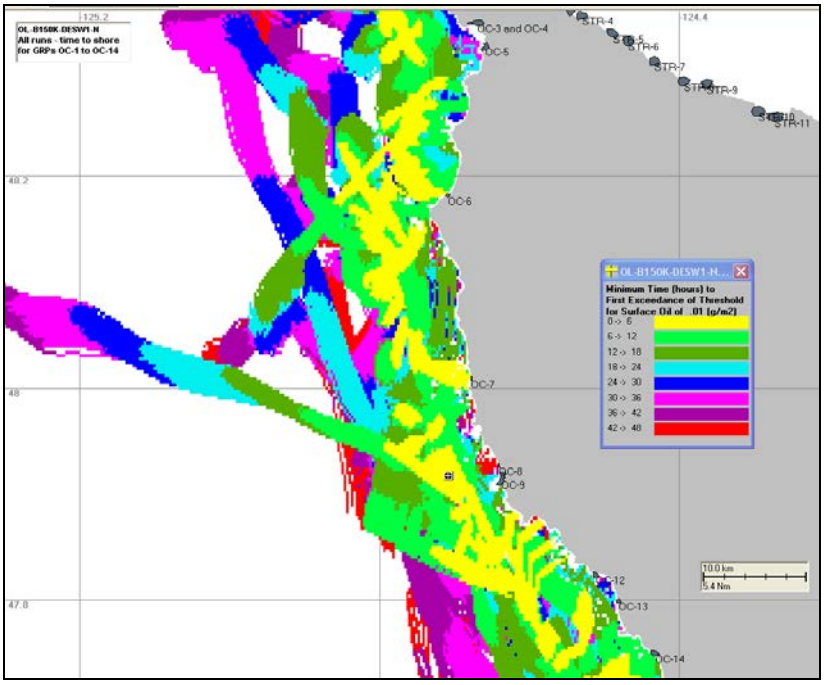


Figure XXV.B-3. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-3 to OC-14.

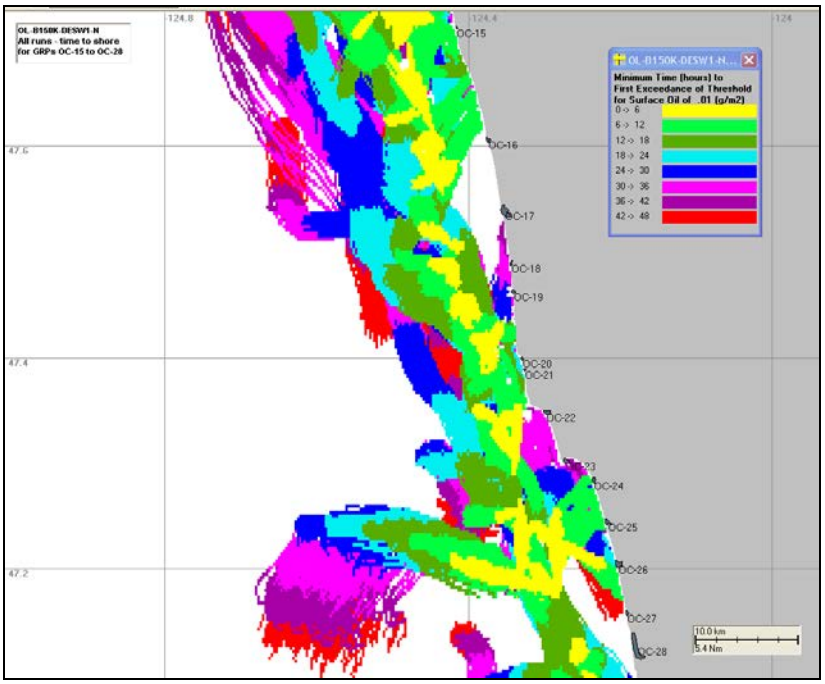


Figure XXV.B-4. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-15 to OC-28.

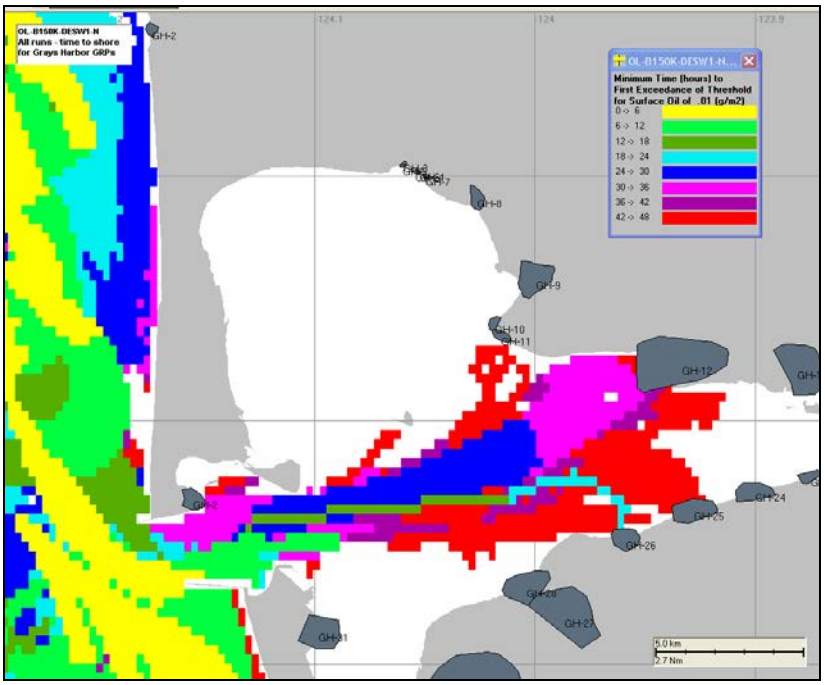


Figure XXV.B-5. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the GRPs within Grays Harbor.

XXV.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.

Since Bunker fuel is highly viscous, it does not spread to thin sheens and water areas are exposed only to thicker oil. Hence, areas exposed to >0.01 g/m^2 are the essentially the same as areas exposed to > 10 g/m^2.

Table XXV.C-1. Outer Coast Sea Lanes, No 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)	407	261	930	0	363	832	1,665
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	407	261	929	0	363	828	1,661
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	9,059	4,927	18,914	0	8,604	17,405	29,441
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	9,059	4,927	18,914	0	8,604	17,404	29,441
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	9,056	4,922	18,901	0	8,604	17,392	29,407
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	9,055	4,920	18,894	0	8,604	17,385	29,354
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	8,543	4,290	17,124	0	8,009	16,340	22,498
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	2,459	958	4,376	0	2,352	4,645	5,251
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	0.00E+00	0.00E+00	0.00E+00	100	0.00E+00	0.00E+00	0.00E+00
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 (%)	28.99	15.74	60.47	11	32.63	51.40	62.60
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	29.1886	16.3818	61.9522	8	33.6631	51.2282	55.3765
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	6.96	4.47	15.91	0	7.42	13.57	22.64

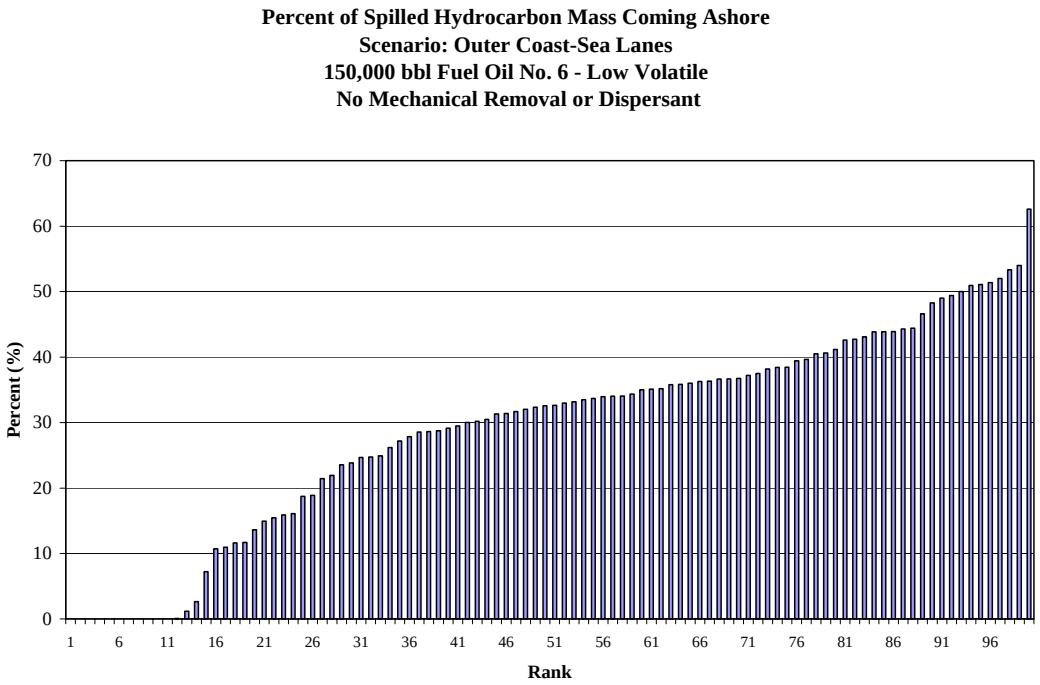


Figure XXV.C-1. Outer Coast Sea Lanes, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

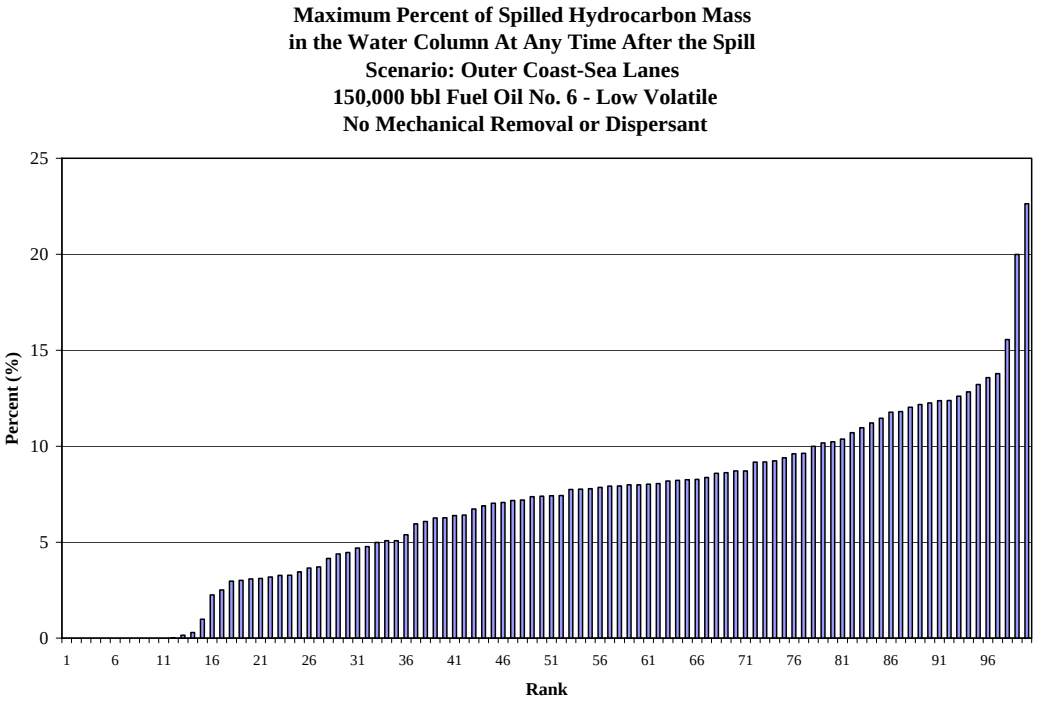


Figure XXV.C-2. Outer Coast Sea Lanes, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

XXV.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 XXV.D-1. Outer Coast Sea Lanes, No 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	1,020,846	274,536	294,432	451,878	0	0	0
95th	2,392,963	334,218	63,661	503,034	179,046	1,313,004	0
Maximum	3,397,327	476,601	322,283	1,180,851	2,029,188	1,313,004	0
Mean	1,030,060	143,987	89,404	534,069	164,125	98,475	0
Std. Dev.	725,779	132,899	96,536	318,260	427,300	202,058	0
Mean + 2 Std. Dev.	2,481,618	409,785	282,476	1,170,589	1,018,725	502,591	0

Table XXV.D-2. Outer Coast Sea Lanes, No 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	1,020,846	274,536	294,432	451,878	0	0	0
95th	2,388,700	334,218	63,661	498,771	179,046	1,313,004	0
Maximum	3337645	476601	322283	1180851	2029188	1313004	0
Mean	1024009	143944	89364	532875	161738	96088	0
Std. Dev.	718616	132841	96515	317662	419818	200363	0
Mean + 2 Std. Dev.	2,461,241	409,626	282,394	1,168,199	1,001,374	496,814	0

Table XXV.D-3. Outer Coast Sea Lanes, No 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	979,353	172,225	278,516	528,612	0	0	0
95th	2,086,312	40,072	0	613,872	1,432,368	0	0
Maximum	2,895,146	476,601	322,283	1,078,539	1,909,824	1,014,594	0
Mean	943,174	143,876	89,125	475,026	148,608	86,539	0
Std. Dev.	644,438	132,805	96,290	278,314	384,029	174,749	0
Mean + 2 Std. Dev.	2,232,050	409,486	281,705	1,031,654	916,666	436,037	0

Table XXV.D-4. Outer Coast Sea Lanes, No 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	481,719	20,462	17,905	443,352	0	0	0
95th	1,000,666	430,561	75,597	255,780	0	238,728	0
Maximum	1,140,778	430,561	264,591	647,976	954,912	358,092	0
Mean	480,301	130,789	72,971	210,294	45,358	20,889	0
Std. Dev.	298,668	120,525	79,718	148,544	152,247	65,365	0
Mean + 2 Std. Dev.	1,077,637	371,839	232,407	507,382	349,852	151,619	0

XXV.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three representative runs were selected from the 100 stochastic runs involving no response as worst cases for certain locations 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. Maps of oil exposure to the selected sites and other sensitive sites are included below. The representative runs for the alternative response scenarios are numbered 1, 2 and 9 below.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts for the Olympia Coast National Marine Sanctuary;
3. the worst case run for impacts for Tatoosh Island;
4. the worst case run for impacts for the area near Quileute River;
5. the worst case run for impacts for the area near Hoh River;
6. the worst case run for impacts for Willapa Bay;
7. the worst case run for impacts for Grays Harbor;
8. the worst case run for impacts for Lower Columbia River, and
9. the worst case run for impacts to sensitive areas as indicated in Geographic Response Plans (GRPs).

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. This section also contains plots of shoreline exposed to floating hydrocarbons (g/m^2) at any time after the spill, and the time after the spill when the surface floating hydrocarbons could first exceed the threshold of $0.01 g/m^2$. 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.

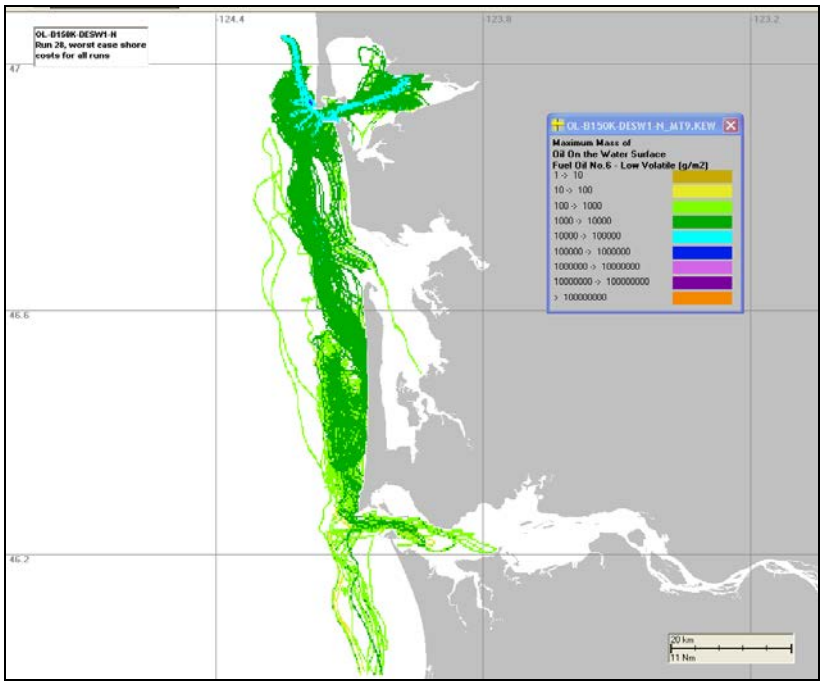


Figure XXV.E-1. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

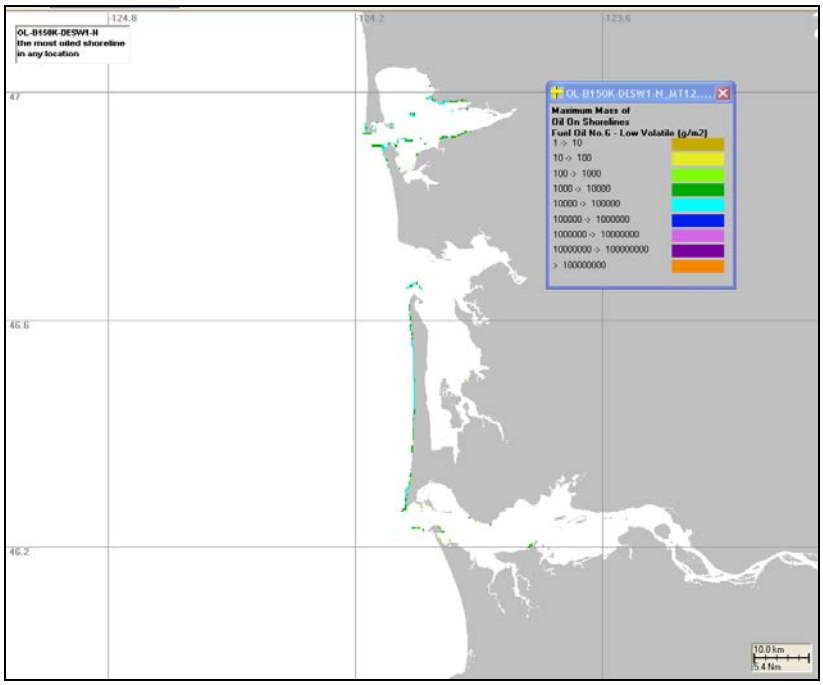


Figure XXV.E-2. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

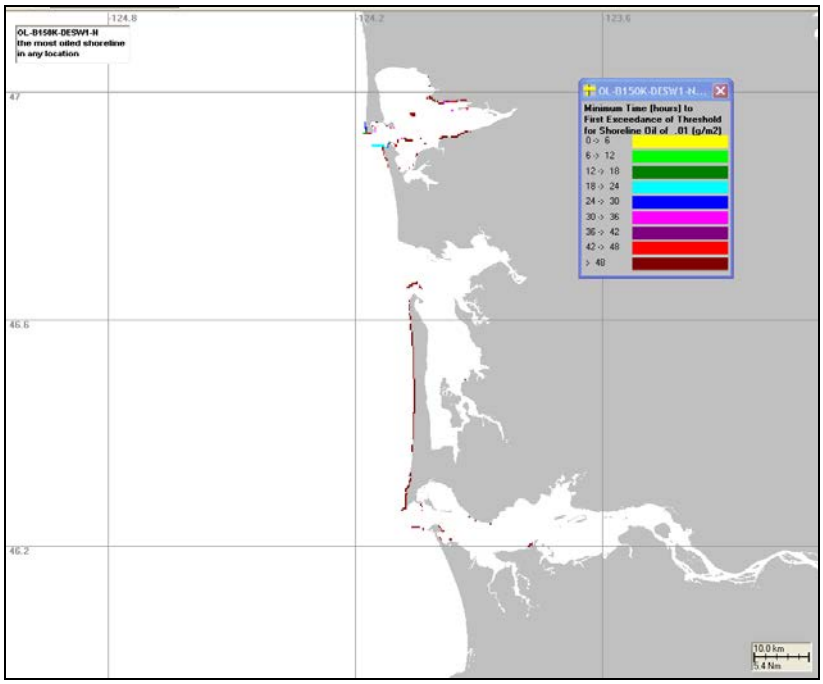


Figure XXV.E-3. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run based on shoreline costs.

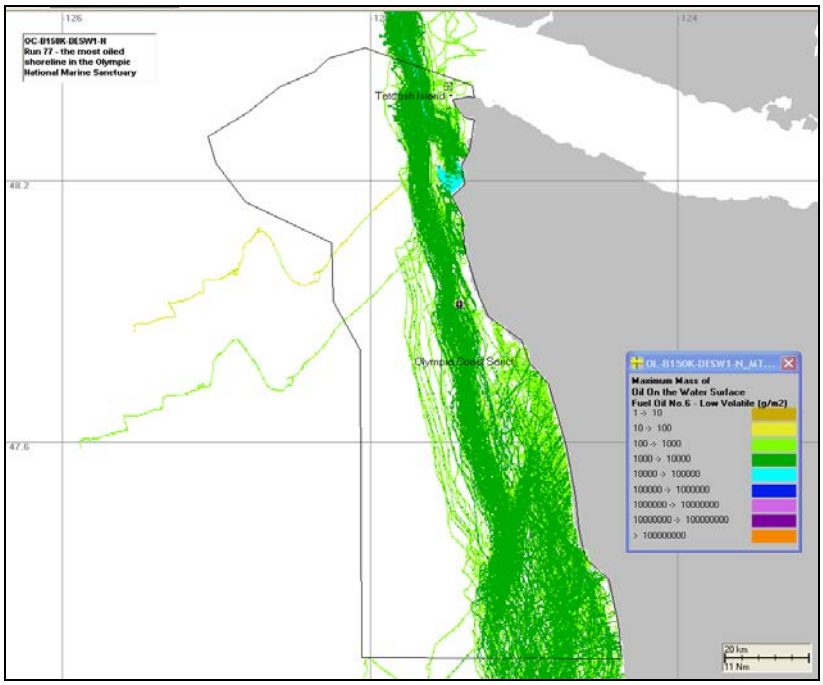


Figure XXV.E-4. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary.

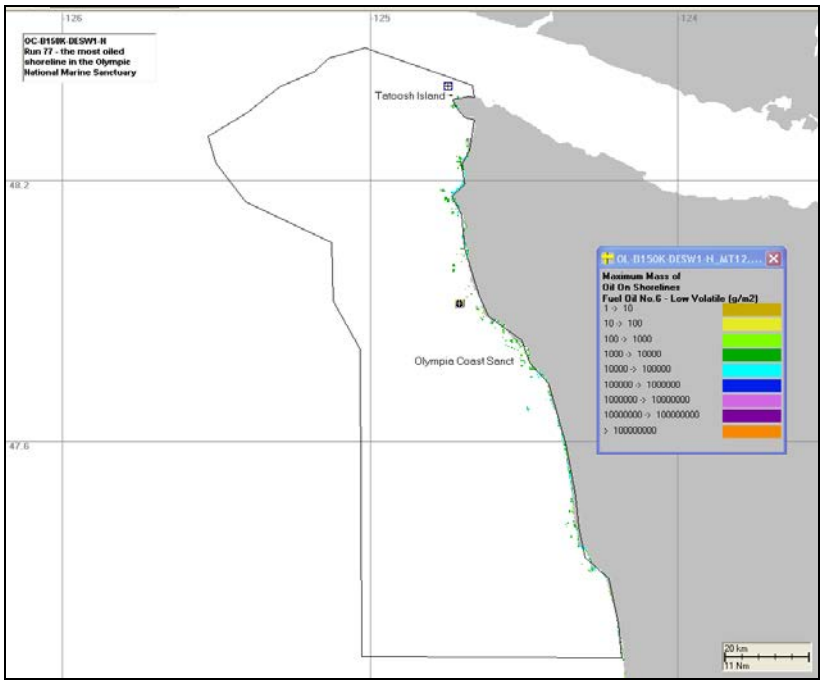


Figure XXV.E-5. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary.

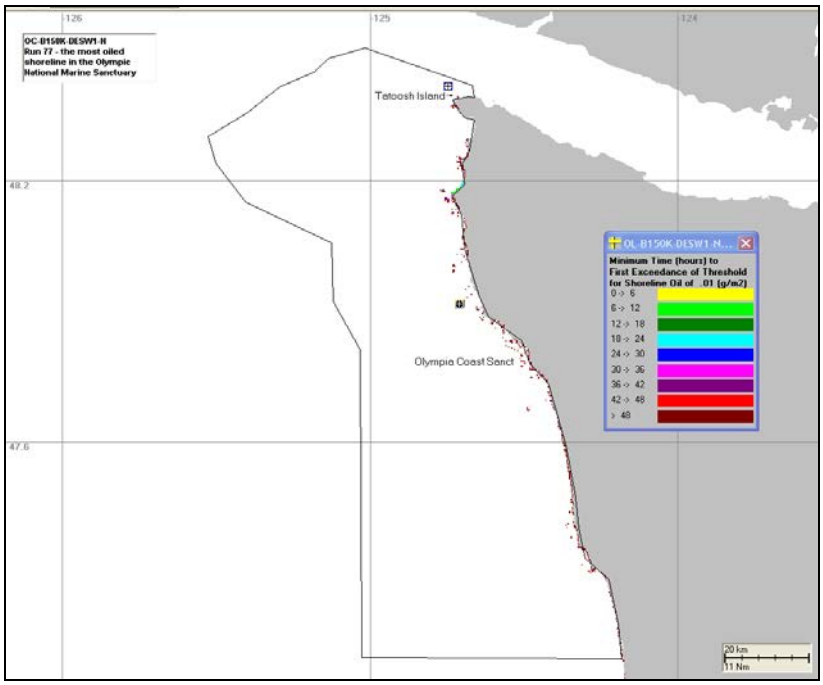


Figure XXV.E-6. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the Olympia Coast National Marine Sanctuary.

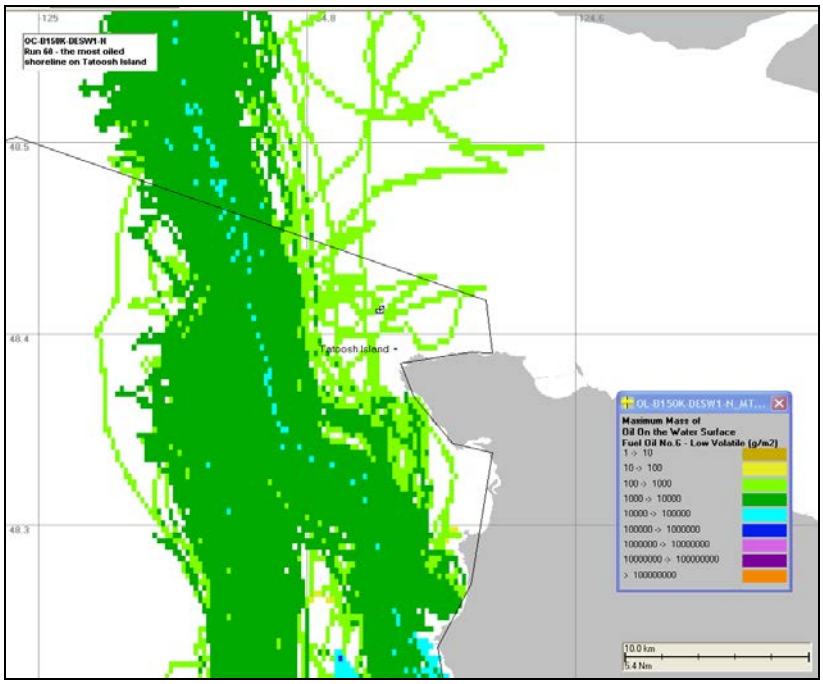


Figure XXV.E-7. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island.

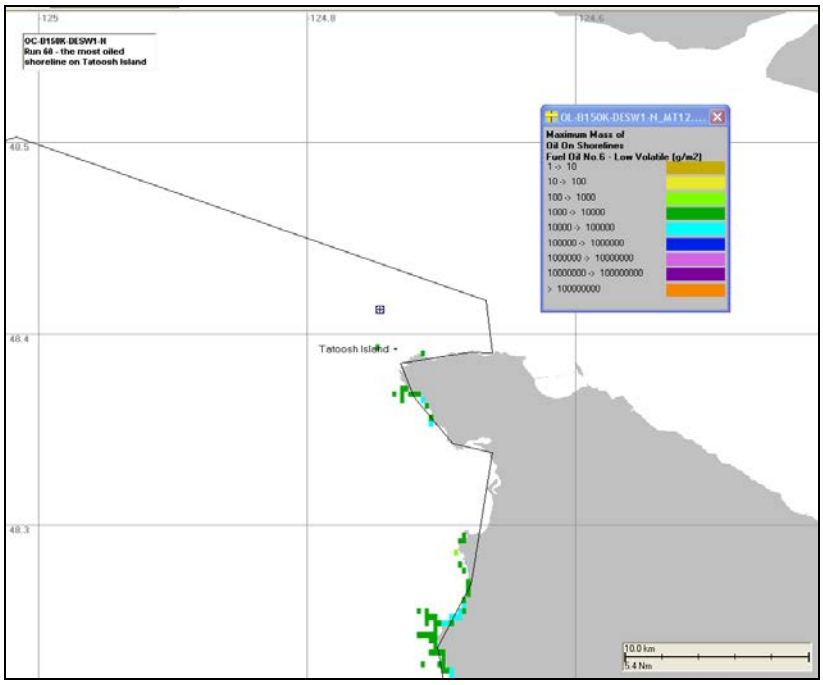


Figure XXV.E-8. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Tatoosh Island.

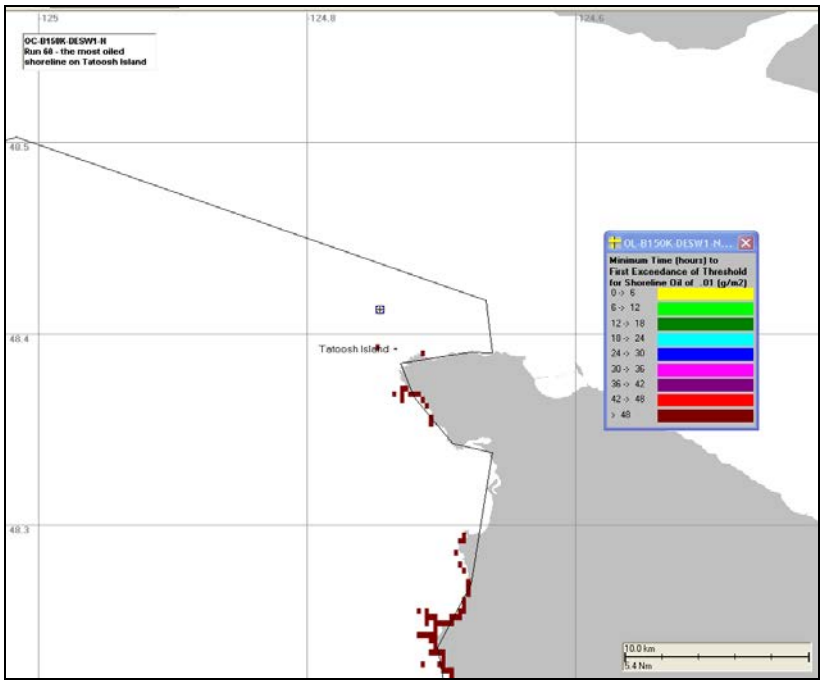


Figure XXV.E-9. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Tatoosh Island.

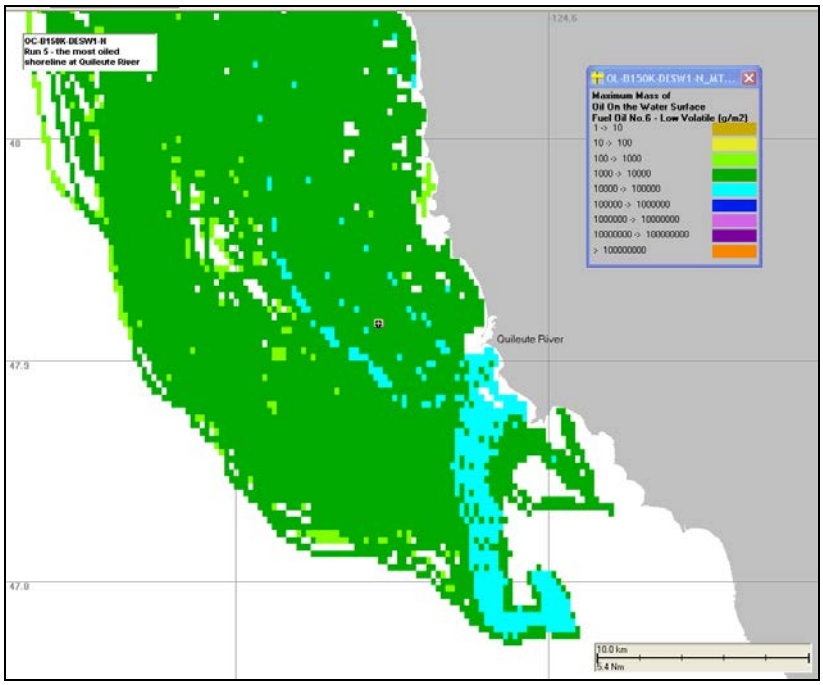


Figure XXV.E-10. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River.

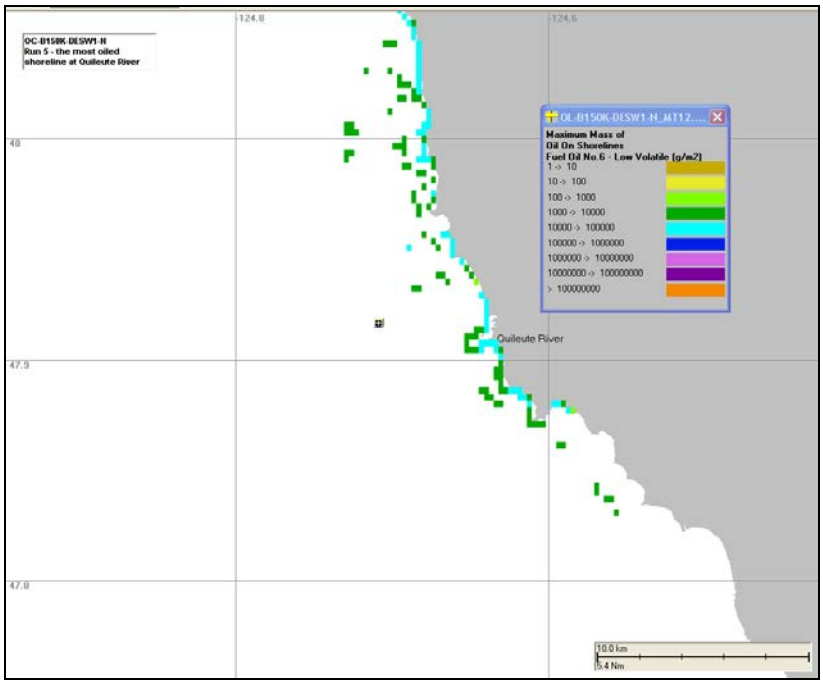


Figure XXV.E-11. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River.

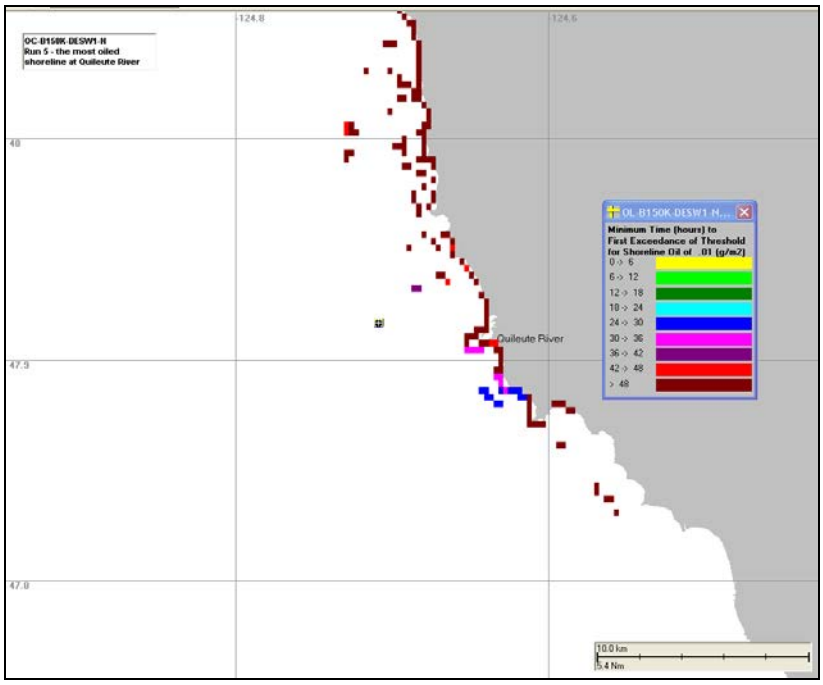


Figure XXV.E-12. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Quileute River.

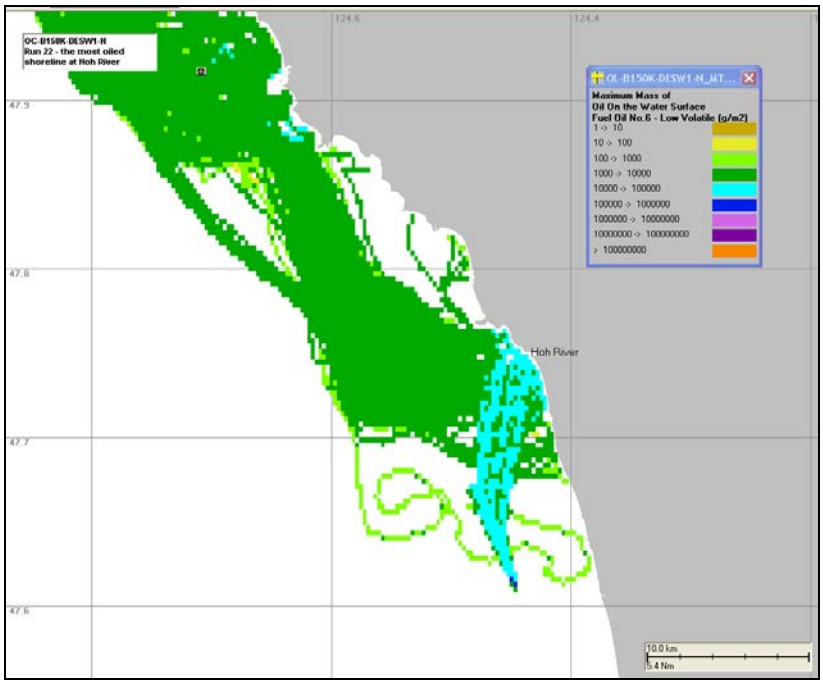


Figure XXV.E-13. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River.

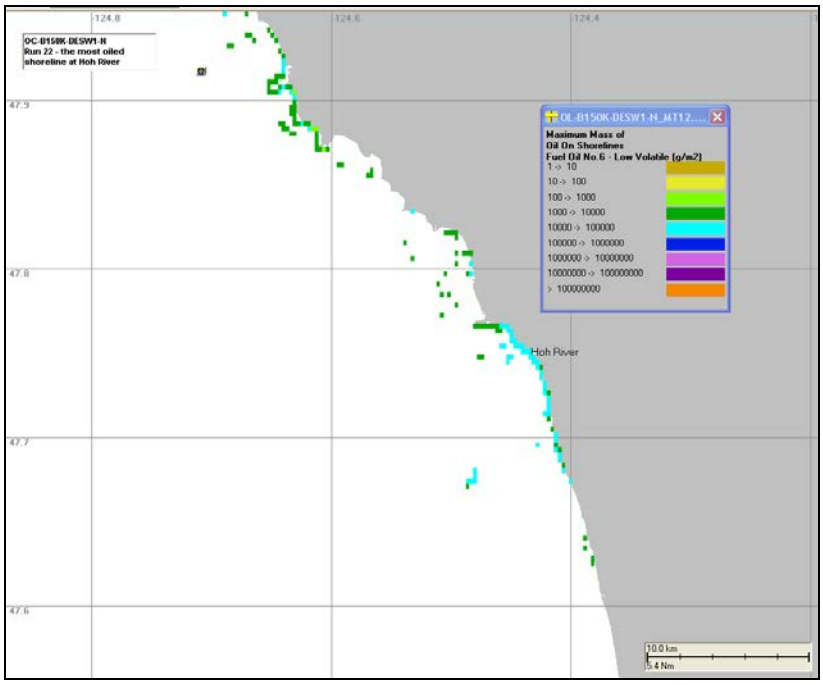


Figure XXV.E-14. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River.

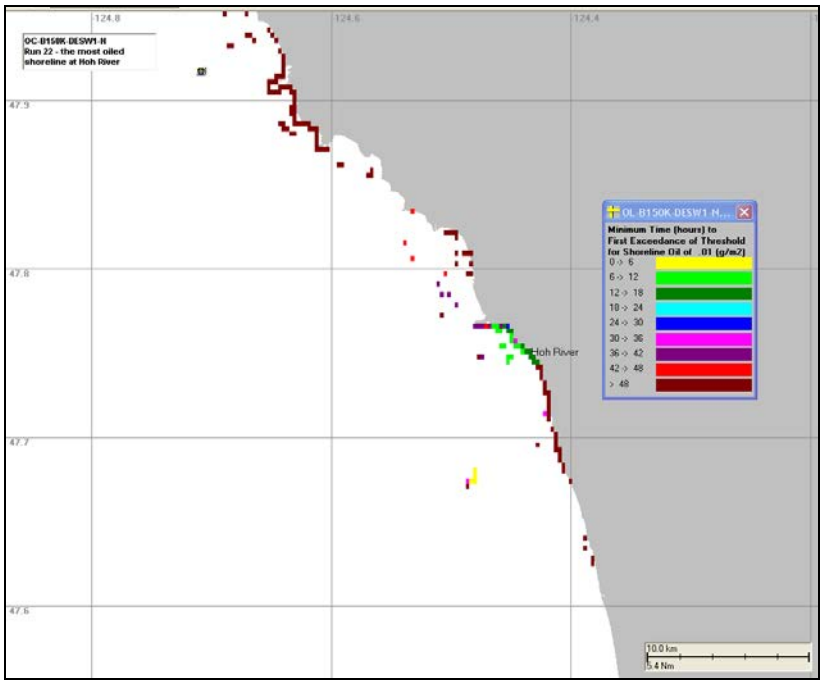


Figure XXV.E-15. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Hoh River.

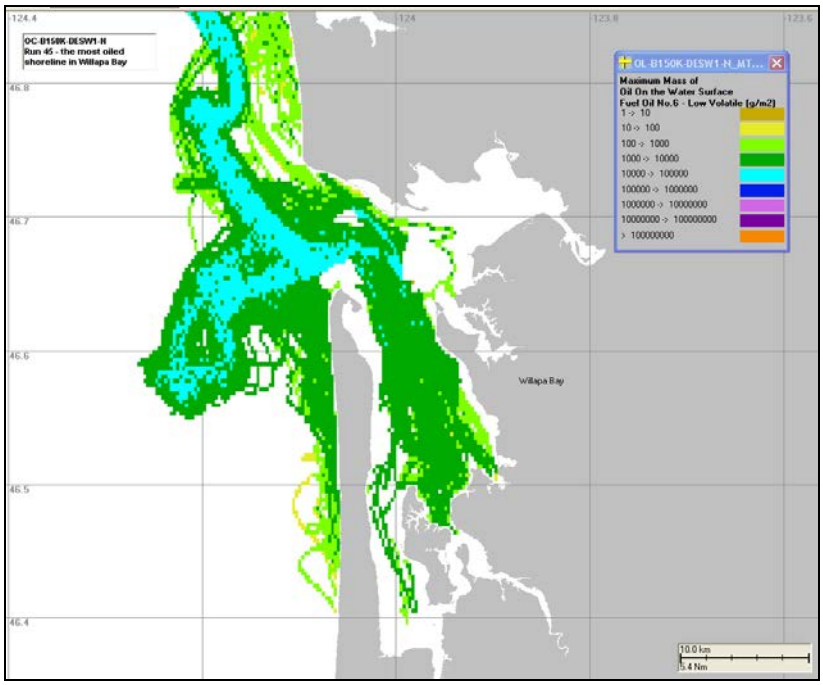


Figure XXV.E-16. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay.

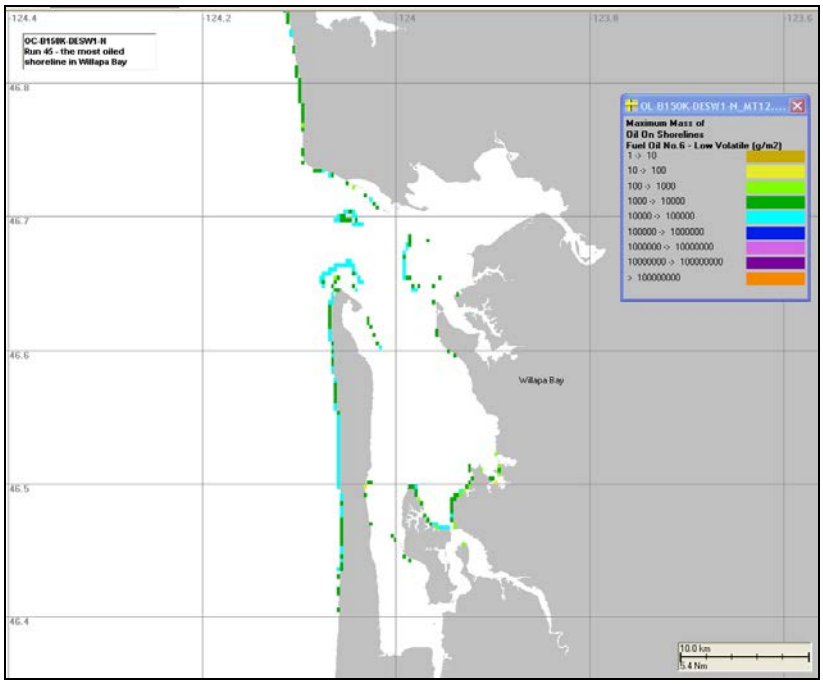


Figure XXV.E-17. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay.

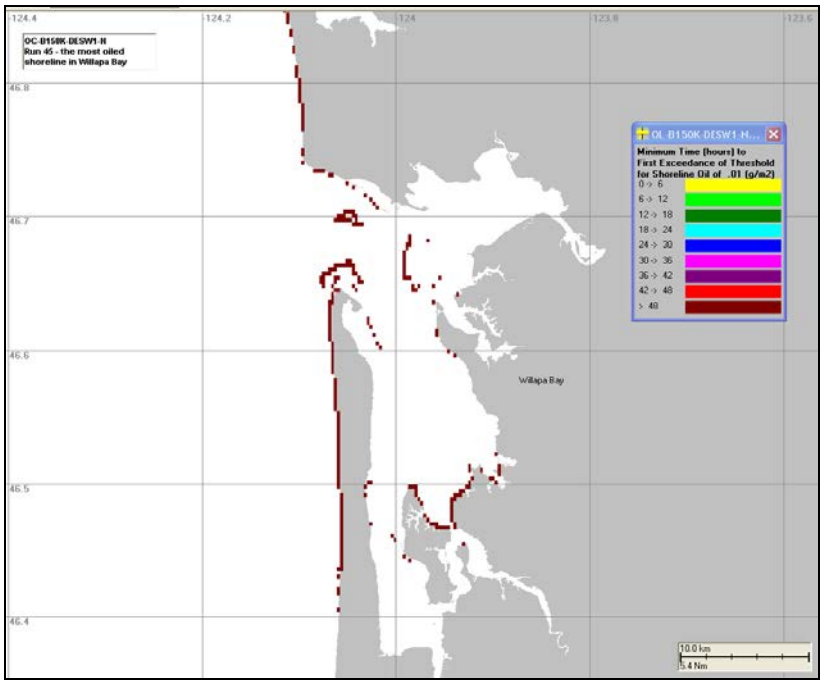


Figure XXV.E-18. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Willapa Bay.

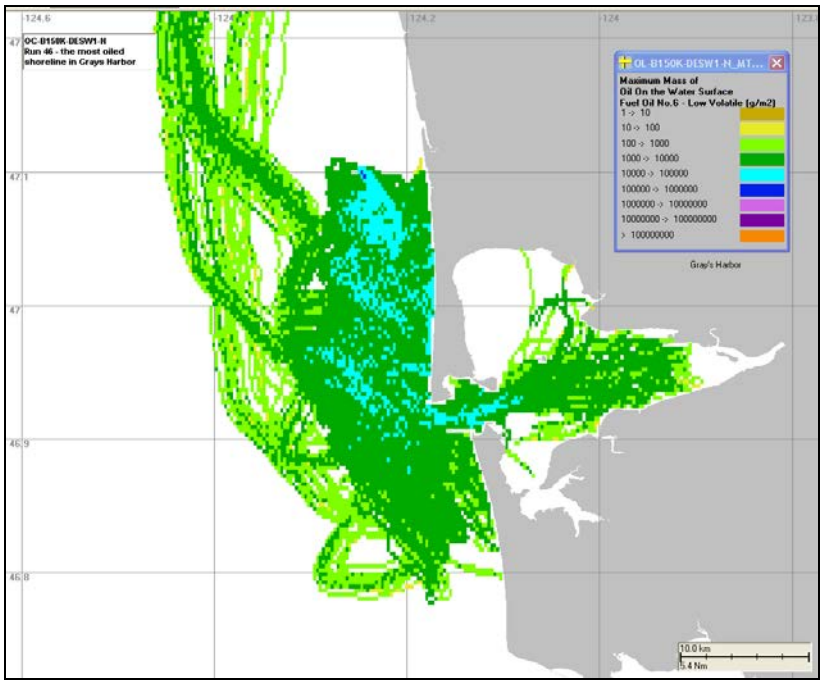


Figure XXV.E-19. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor.

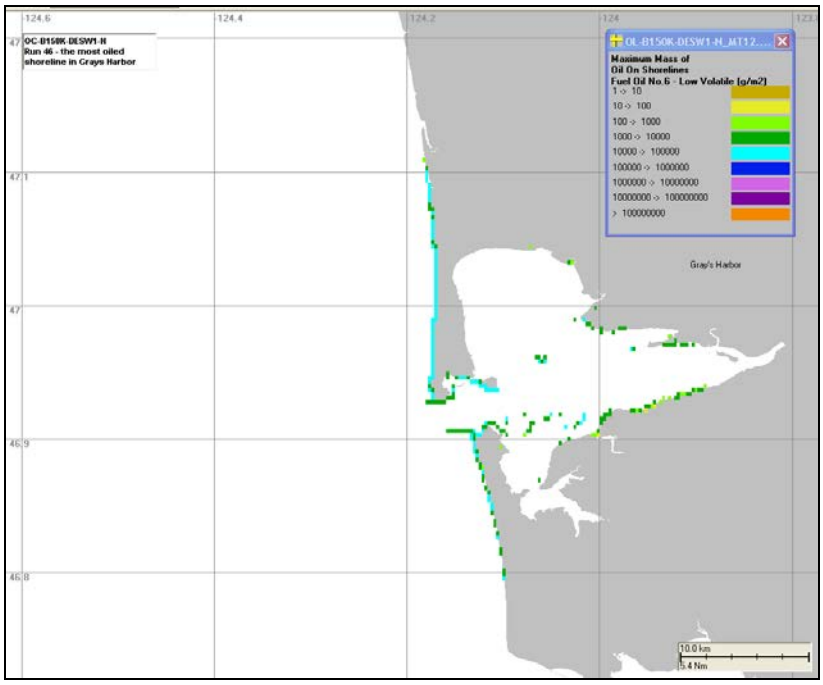


Figure XXV.E-20. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor.

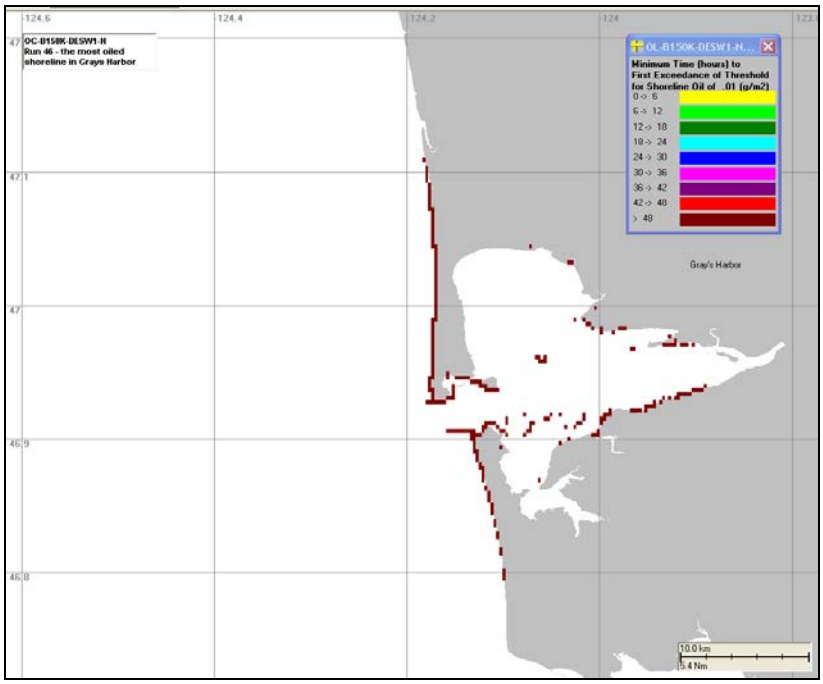


Figure XXV.E-21. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Grays Harbor.

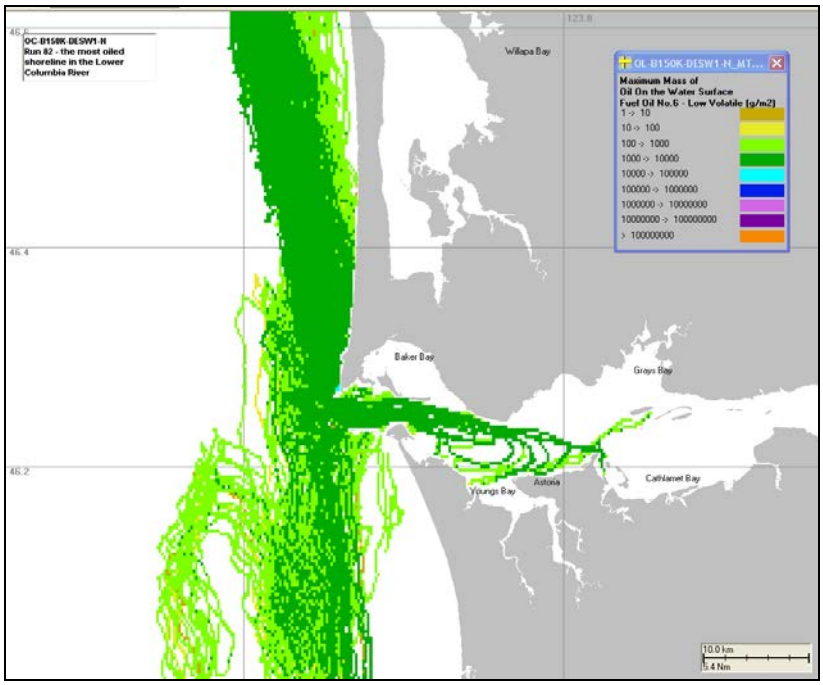


Figure XXV.E-22. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River.

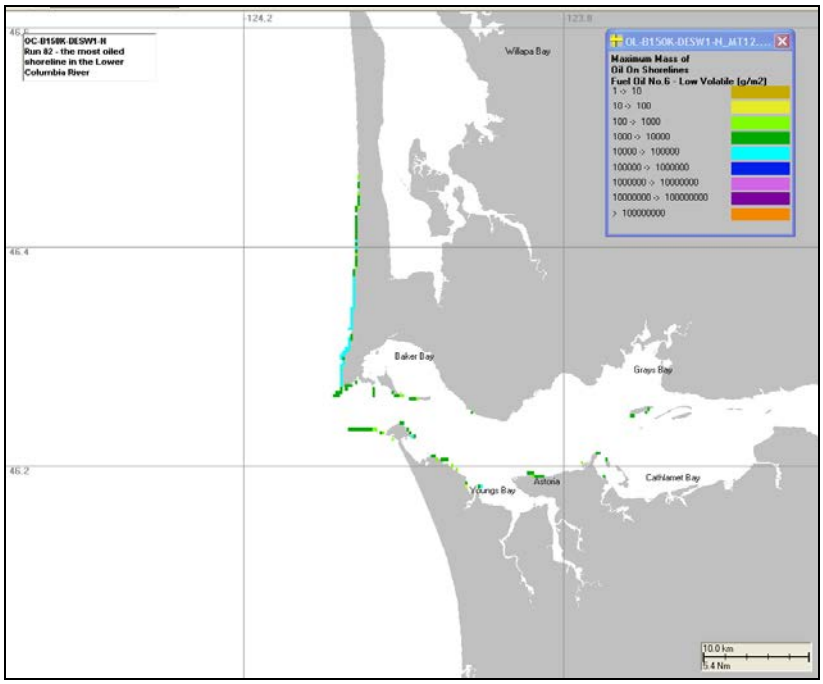


Figure XXV.E-23. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River.

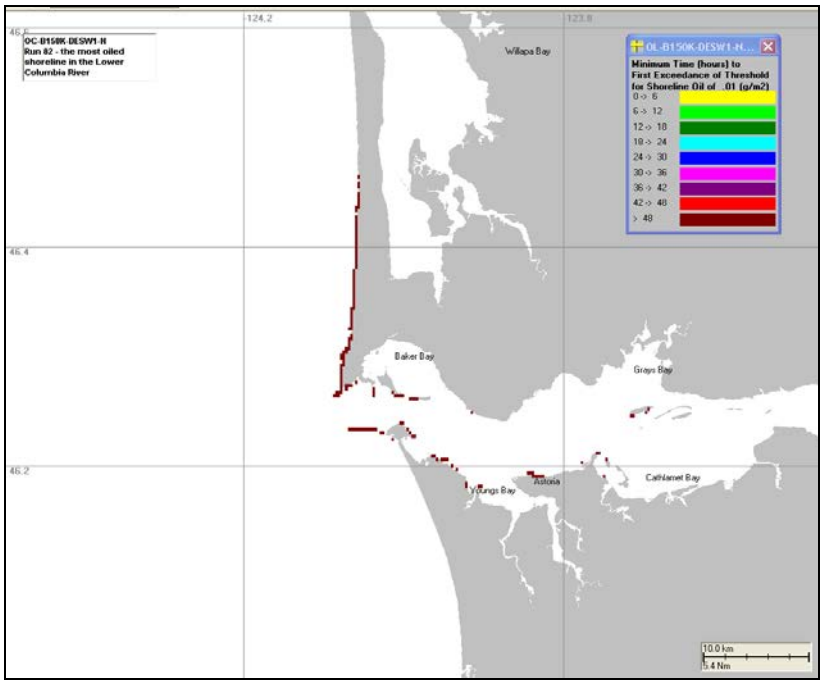


Figure XXV.E-24. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Lower Columbia River.

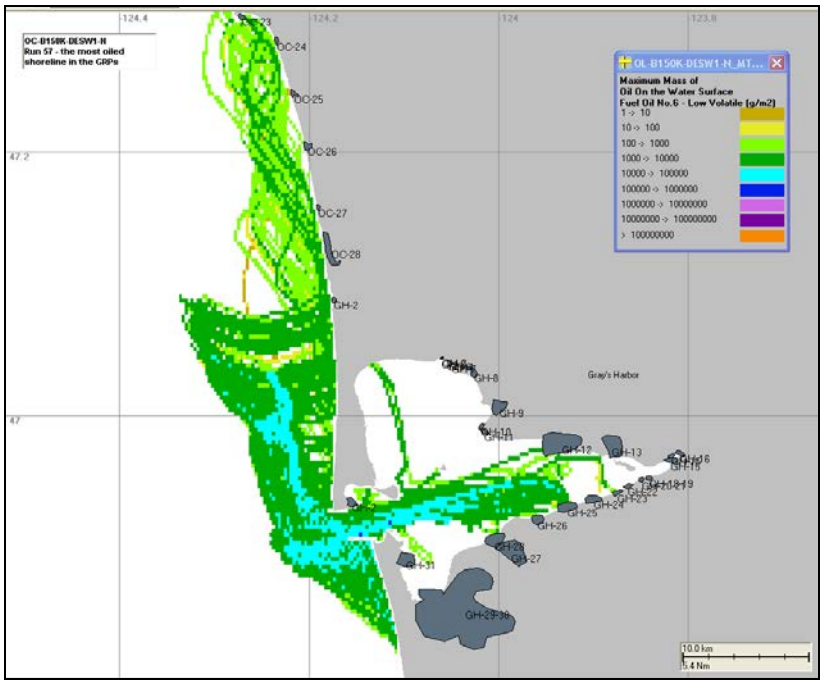


Figure XXV.E-25. Outer Coast Sea Lanes, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs.

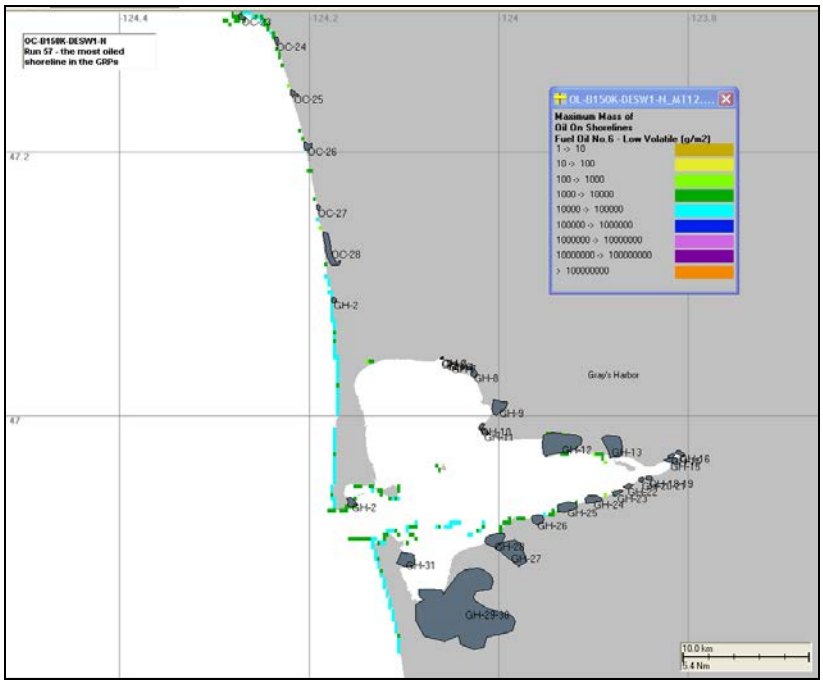


Figure XXV.E-26. Outer Coast Sea Lanes, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs.

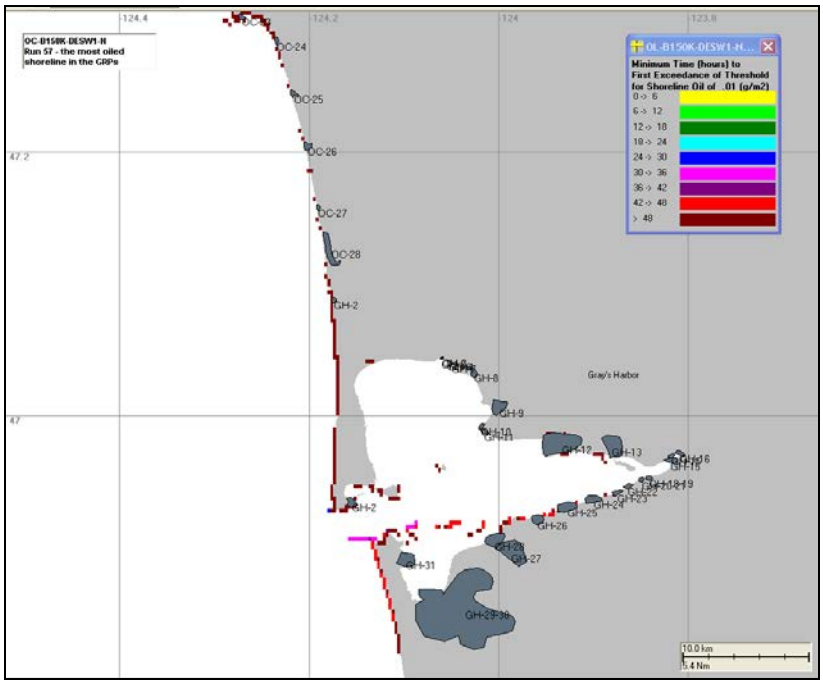


Figure XXV.E-27. Outer Coast Sea Lanes, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the GRPs.

XXV.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, 30th, 50th, 65th, 80th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions, and
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table XXV.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, 30th, 50th, 65th, 80th 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 XXV.F-1. Outer Coast Sea Lanes, no 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	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Waterfowl	3.95E-05	-2.11E+04	6.30E+04	4.79E-01	6.92E-01
Seabirds	7.26E-06	4.04E+03	1.45E+04	3.70E-01	6.08E-01
Wading birds	7.21E-05	-5.33E+01	7.84E+01	5.12E-01	7.16E-01
Shorebirds	3.96E-04	-3.53E+02	2.51E+02	7.55E-01	8.69E-01
Raptors[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kingfishers	2.39E-08	-7.88E-02	3.80E-01	9.29E-01	9.64E-01
Cetaceans	4.75E-06	7.76E+03	2.80E+04	6.52E-02	2.55E-01
Pinnipeds (seals)	8.86E-07	1.79E+03	4.10E+03	9.86E-02	3.14E-01
Other mammals	1.76E-07	1.08E+02	3.29E+02	4.02E-01	6.34E-01

[1] Results of these regressions reflect the fact that no injuries were sustained for these wildlife species.

Table XXV.F-2. Outer Coast Sea Lanes, 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	-	16,575	-	-	-	1	17	7	16,605	16,580	25.38
50th Percentile	56,327	42,106	15	1,647	-	4	29	18	100,826	100,774	51.07
95th Percentile	190,664	93,337	109	23,914	-	9	53	41	284,374	284,272	102.59
Mean	69,324	46,666	27	5,288	-	4	31	20	121,361	121,305	55.63
Std Dev (SD)	70,194	27,191	38	8,420	-	3	13	12	97,106	97,079	27.36
Mean - 2SD	-	-	-	-	-	-	6	-	-	-	0.90
Mean + 2SD	209,712	101,049	103	22,127	-	9	56	44	315,574	315,464	110.35

XXV.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th, and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XXV.G-1. Outer Coast Sea Lanes, no 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	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Total small pelagic fish[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total large pelagic fish	5.66E+00	2.70E+01	1.78E+01	6.09E-01	7.81E-01
Total demersal fish	1.36E+00	6.49E+00	4.29E+00	6.09E-01	7.81E-01
Total demersal invertebrates[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total mollusks[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[1] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table XXV.G-2. Outer Coast Sea Lanes, 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	-	27.01	6.49	-	-	-	33
50th Percentile	-	68.92	16.56	-	-	6,760	6,845
95th Percentile	-	101.88	24.47	-	-	21,538	21,665
Mean	-	66.41	15.95	-	-	7,986	8,068
Std Dev (SD)	-	25.31	6.08	-	-	6,753	6,784
Mean - 2SD	-	15.80	3.79	-	-	-	20
Mean + 2SD	-	117.02	28.11	-	-	21,492	21,637

XXV.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 XXV.H-1. Outer Coast Sea Lanes, no 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	-	-	-	-	-	-
Large pelagic fish	27.0	68.9	101.9	66.4	15.8	117.0
Demersal fish	6.5	16.6	24.5	16.0	3.8	28.1
Decapods	-	-	-	-	-	-
Molluscs	-	6,760	21,538	7,986	-	21,492
Birds:						
Waterfowl (# * kg each)	-	61,490	208,142	75,678	-	228,935
Seabirds (# * kg each)	8,550	21,720	48,147	24,072	-	52,124
Waders (# * kg each)	-	8	56	14	-	53
Shorebirds (# * kg each)	-	850	12,336	2,728	-	11,414
Raptors (# * kg each)	-	-	-	-	-	-
Other wildlife:						
Sea otters, other mammals	3.5	9.4	21.2	10.4	-	22.9
Pinnipeds	8.9	15.0	27.3	16.1	3.0	29.1
Cetaceans	0.7	2.0	4.5	2.2	-	4.9
Totals:						
Subtotal fish and invertebrates	33	6,845	21,665	8,068	20	21,637
Subtotal birds	8,550	84,067	268,681	102,492	-	292,526
Subtotal other wildlife	13	26	53	29	3	57
Total all species	8,596	90,939	290,398	110,589	23	314,220

Table XXV.H-2. Outer Coast Sea Lanes, no 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)	52.2	208.3	561.5	242.1	183.7	0.2	609.6
Saltmarsh Area (acres)	129.0	514.7	1,387.4	598.2	454.0	0.6	1,506.3
Saltmarsh Cost (2004$)	24.2	96.4	260.0	112.1	85.1	0.12	282.2
Eelgrass Area (m^2)	32.6	130.2	350.9	151.3	114.8	0.1	380.9
Eelgrass Area (acres)	80.6	321.6	867.0	373.8	283.7	0.4	941.3
Eelgrass Cost (2004$)	9.6	38.4	103.5	44.6	33.8	42.8	112.4

XXV.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XXV.I-1. Outer Coast Sea Lanes, no 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.)	17.38	28.20	31.80	27.62	3.78	20.06
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	109.5	177.7	200.4	174.0	23.8	126.4

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 XXVI: Results of Alternative Response Scenarios for Outer Coast Sea Lanes – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXVI.A. Introduction 1
XXVI.B. Oil Fate Over Time 3
XXVI.C. Estimated Biological Impacts: Wildlife 43
XXVI.D. Estimated Biological Impacts: Fish and Invertebrates 47
XXVI.E. Estimated NRDA Costs: Habitat Restoration Costs 50
XXVI.F. Estimated NRDA Costs: Washington Compensation schedule 59

List of Figures

Figure XXVI.A-1 Sensitive sites for Outer Coast – Sea Lanes scenario..... 2
Figure XXVI.B-1 Outer Coast Sea Lanes - Bunker C: 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 XXVI.B-2 Outer Coast Sea Lanes - Bunker C: 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 XXVI.B-3 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). 6
Figure XXVI.B-4 Outer Coast Sea Lanes - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 7
Figure XXVI.B-6 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 9
Figure XXVI.B-7 Outer Coast Sea Lanes - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. 10
Figure XXVI.B-8 Outer Coast Sea Lanes - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the GRPs..... 11
Figure XXVI.B-10 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the GRPs. 13
Figure XXVI.B-11 Outer Coast Sea Lanes - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the GRPs 14

List of Tables

Table XXVI.B-1 Outer Coast Sea Lanes - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 15
Table XXVI.B-2 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 17
Table XXVI.B-3 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 19
Table XXVI.B-4 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 21
Table XXVI.B-5 Outer Coast Sea Lanes - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 23
Table XXVI.B-6 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 25
Table XXVI.B-7 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 27
Table XXVI.B-8 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary. 29
Table XXVI.B-9 Outer Coast Sea Lanes - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 31
Table XXVI.B-10 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 33
Table XXVI.B-11 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 35
Table XXVI.B-12 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 37
Table XXVI.B-13 Outer Coast Sea Lanes - Bunker C, 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. ... 39
Table XXVI.B-14 Outer Coast Sea Lanes - Bunker C, 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. 40

Table XXVI.B-15 Outer Coast Sea Lanes - Bunker C, 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. 41
Table XXVI.B-16 Outer Coast Sea Lanes - Bunker C, 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. 42
Table XXVI.C-1 Outer Coast Sea Lanes - Bunker C, no removal: Wildlife injury (as numbers lost)..... 43
Table XXVI.C-2 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table XXVI.C-3 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table XXVI.C-4 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table XXVI.D-1. Outer Coast Sea Lanes - Bunker C, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XXVI.D-2. Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXVI.D-3. Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXVI.D-4. Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 49
Table XXVI.E-1. Outer Coast Sea Lanes - Bunker C, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 51
Table XXVI.E-2. Outer Coast Sea Lanes - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration..... 52
Table XXVI.E-3. Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 53
Table XXVI.E-4. Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 54
Table XXVI.E-5. Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 55
Table XXVI.E-6. Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 56
Table XXVI.E-7. Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 57
Table XXVI.E-8. Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration..... 58
Table XXVI.F-1. Outer Coast Sea Lanes - Bunker C, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 59

Table XXVI.F-2. Outer Coast Sea Lanes - Bunker C, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59
Table XXVI.F-3. Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 59
Table XXVI.F-4. Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule..... 60

XXVI.A. INTRODUCTION

The results of the alternate response scenarios for the Outer Coast Sea Lanes – Bunker C 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at the Olympia Coast National Marine Sanctuary; and
3. the worst case run for impacts to sensitive sites identified in the Geographic Response Plans (GRPs).

Locations of the sensitive sites are shown in Figure XXVI.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.

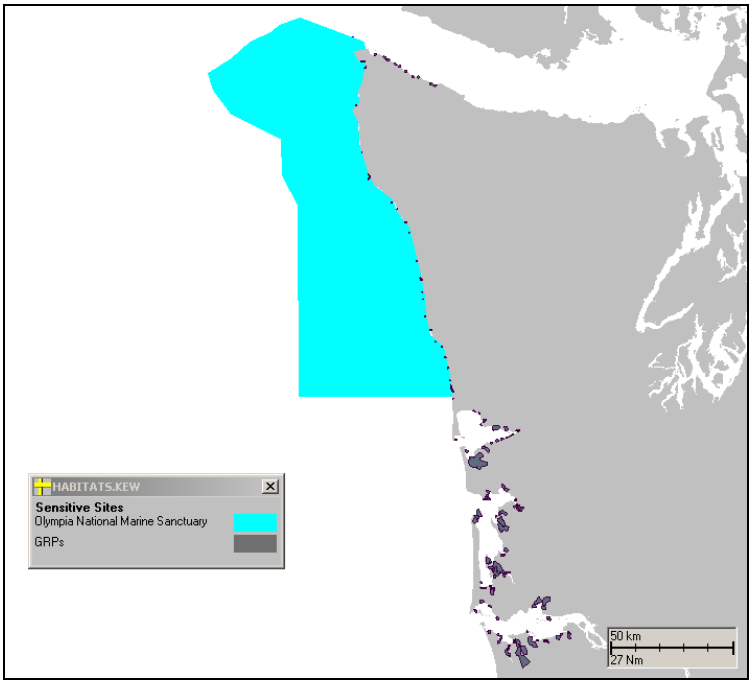
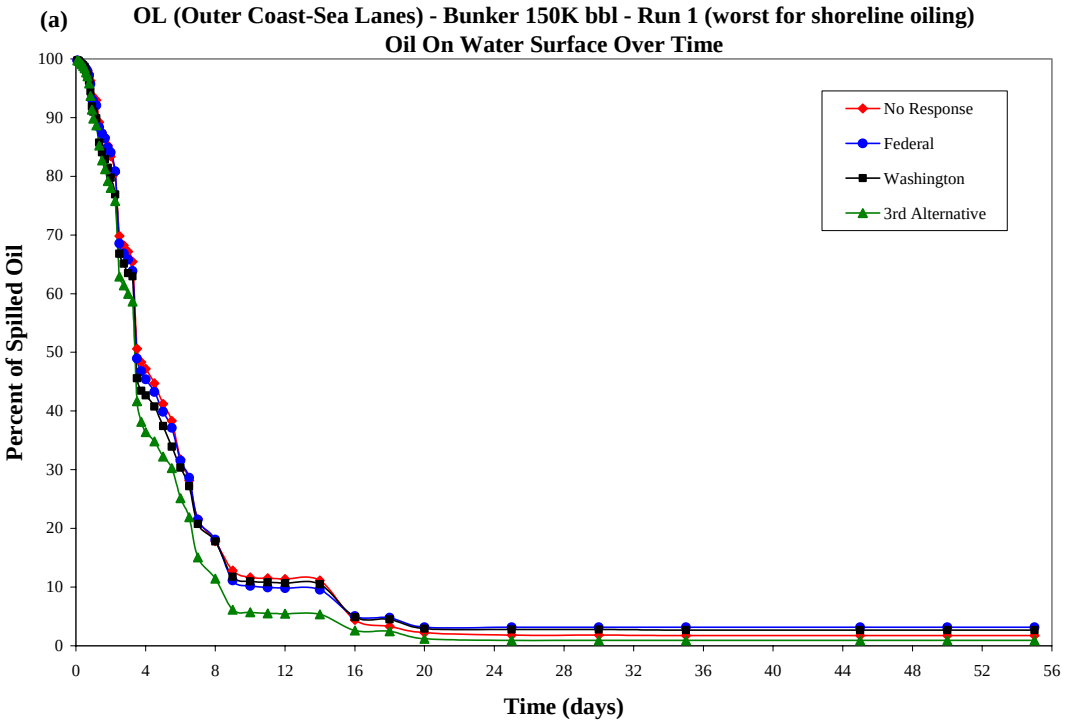


Figure XXVI.A-1 Sensitive sites for Outer Coast – Sea Lanes scenario.

XXVI.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XXVI.B-1 to XXVI.B-12 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 XXVI.B-1 to XXVI.B-11 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 XXVI.B-13 to XXVI.B-16 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 Etkin 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 some cases.



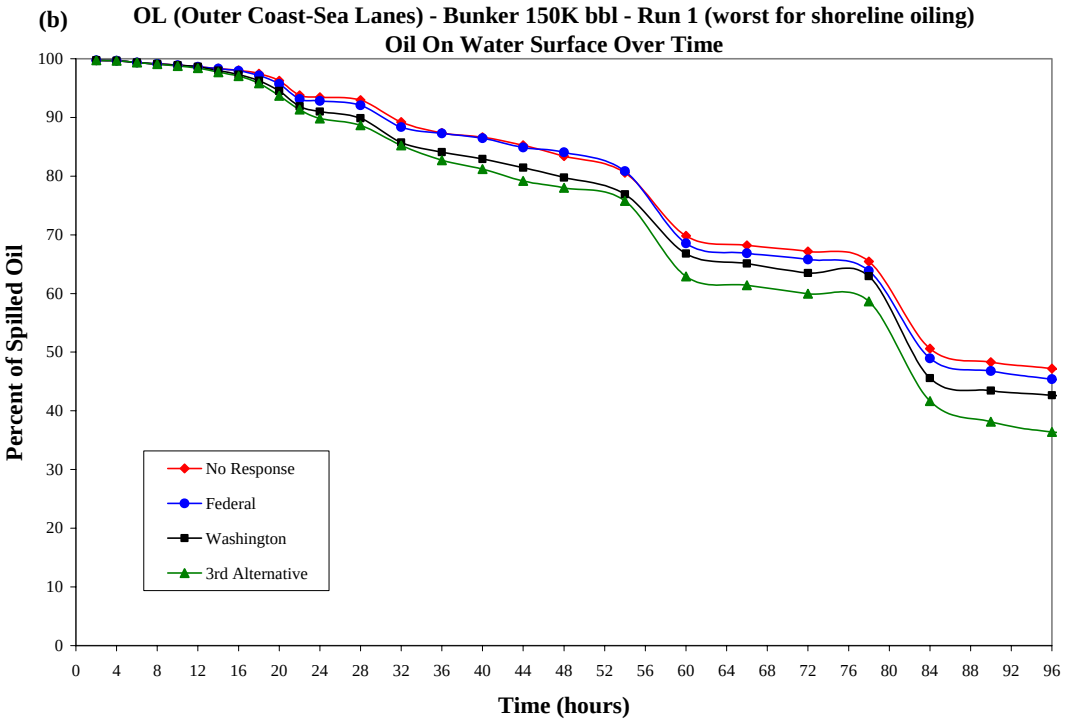
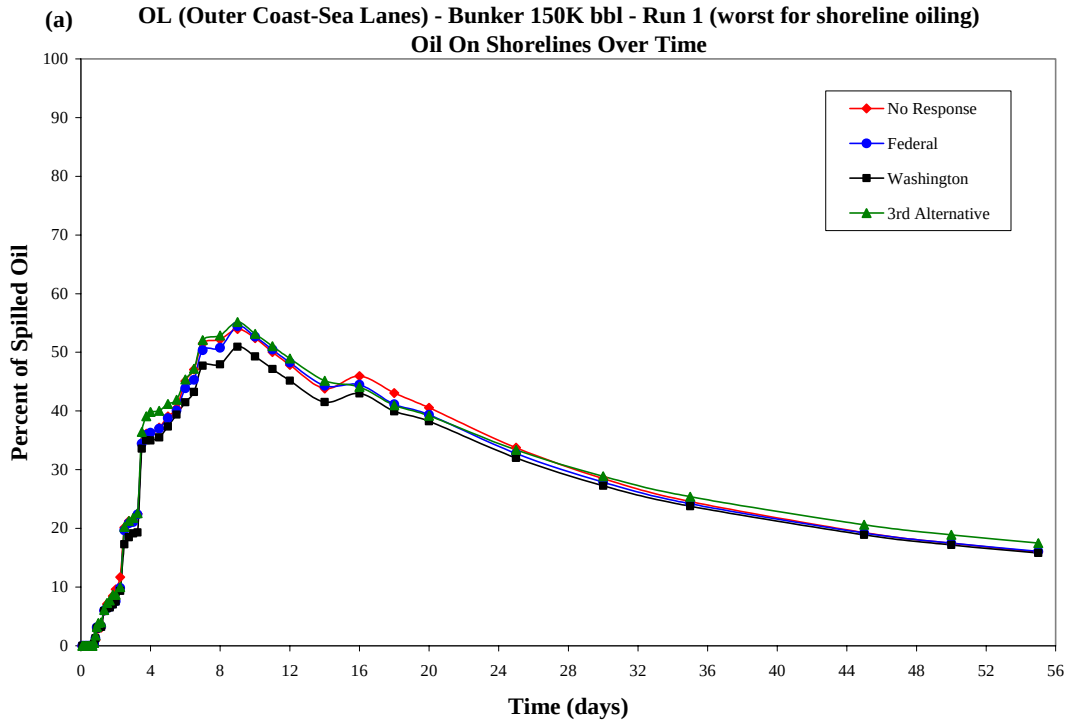


Figure XXVI.B-1 Outer Coast Sea Lanes - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a.



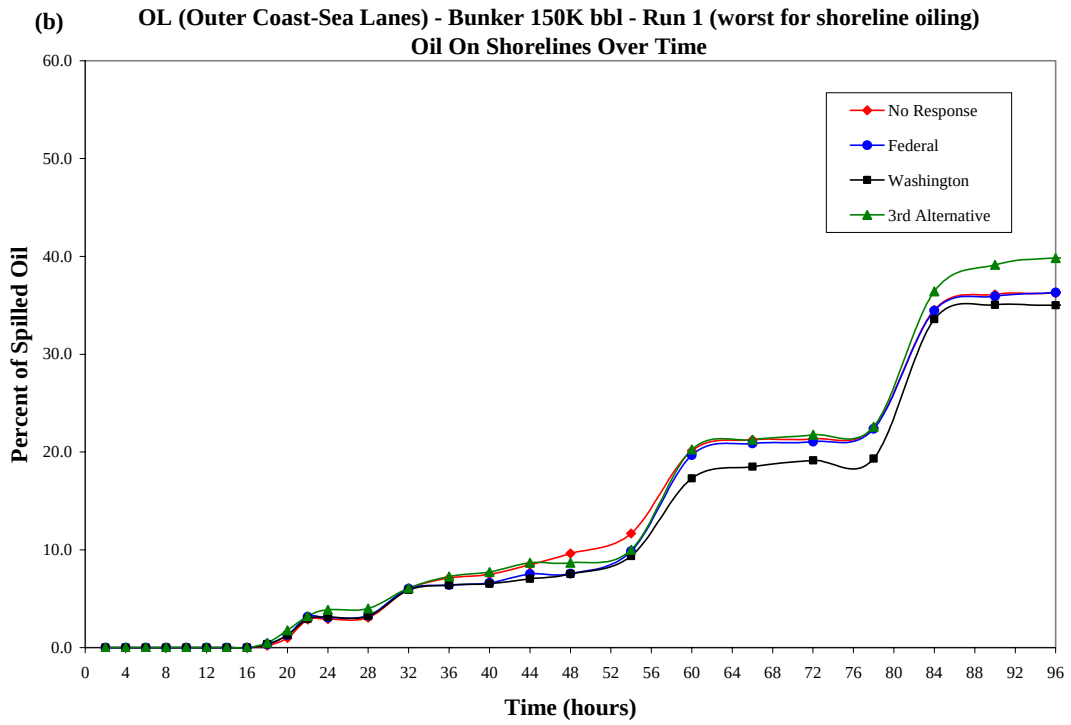
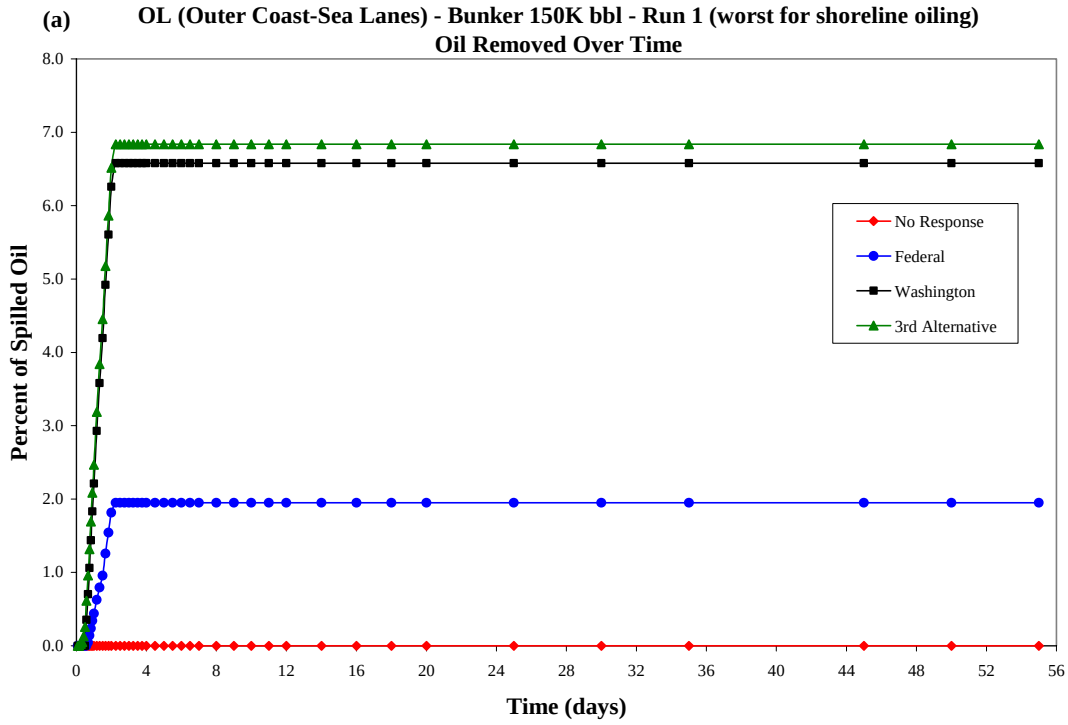


Figure XXVI.B-2 Outer Coast Sea Lanes - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



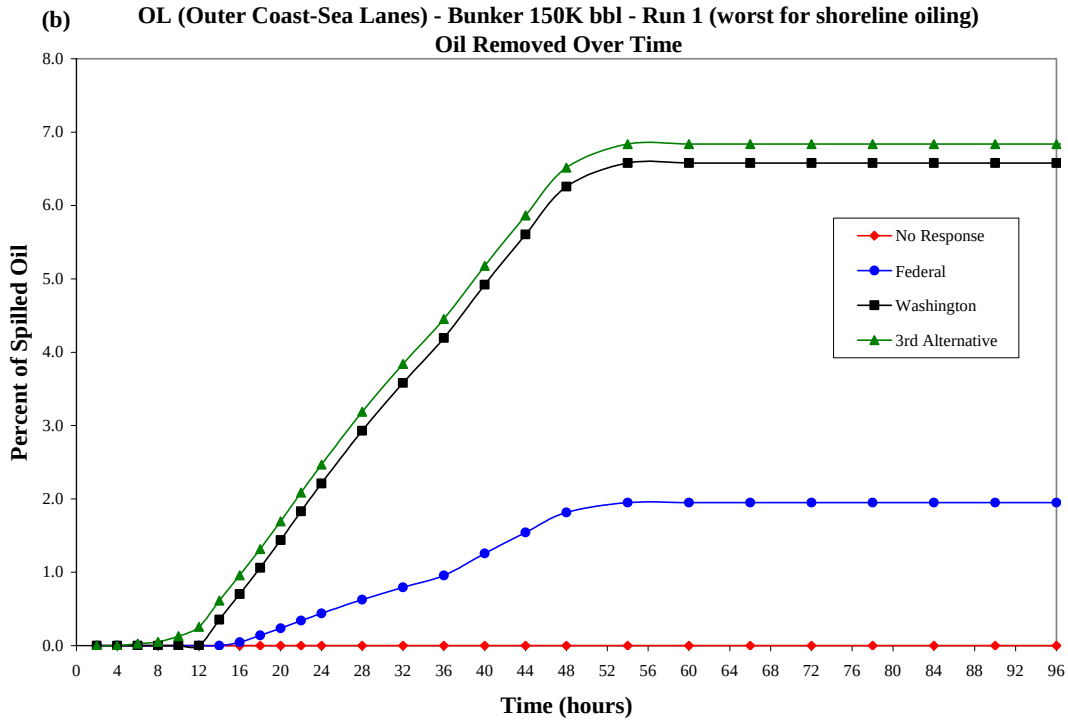
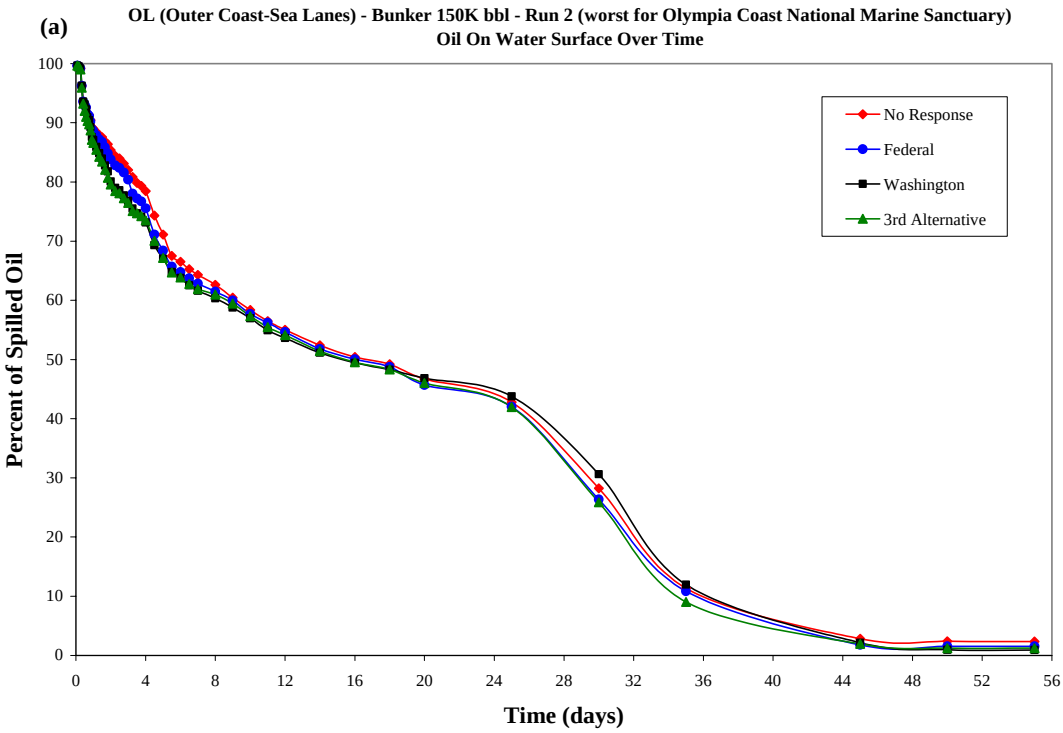


Figure XXVI.B-3 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



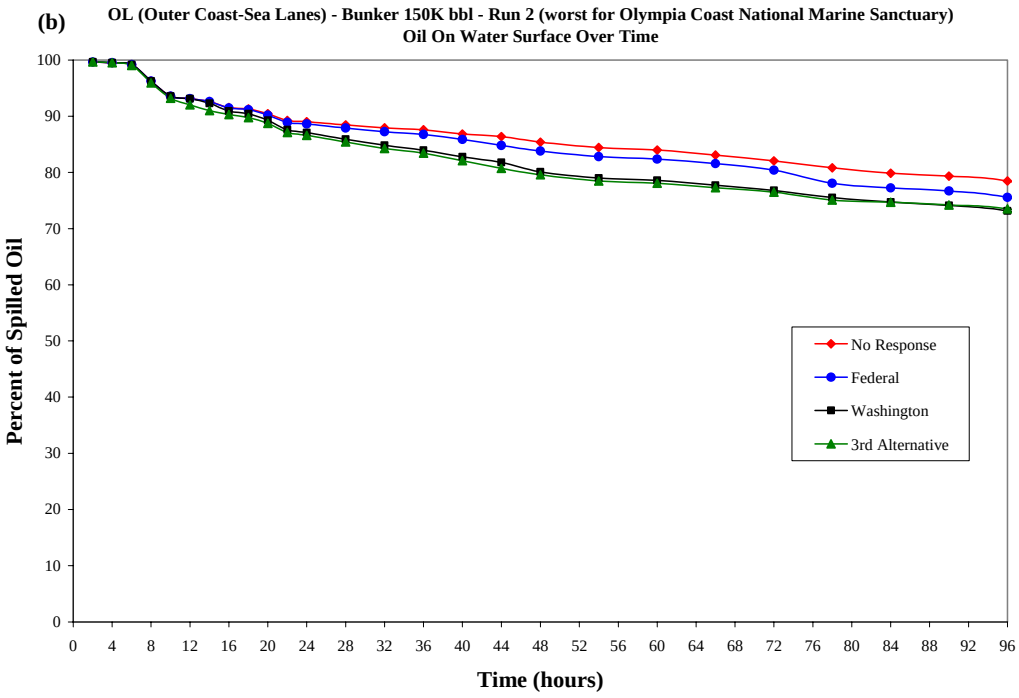
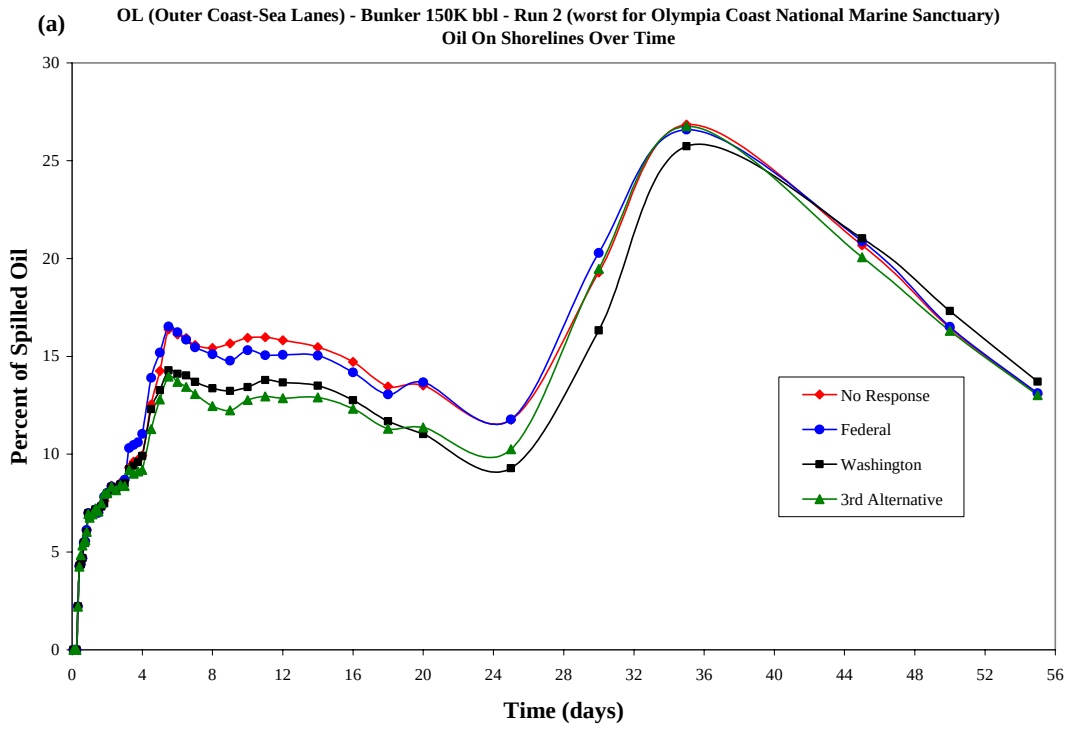


Figure XXVI.B-4 Outer Coast Sea Lanes - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between Washington and 3rd alternative runs are less than the randomized variability in the model and are not significant.)



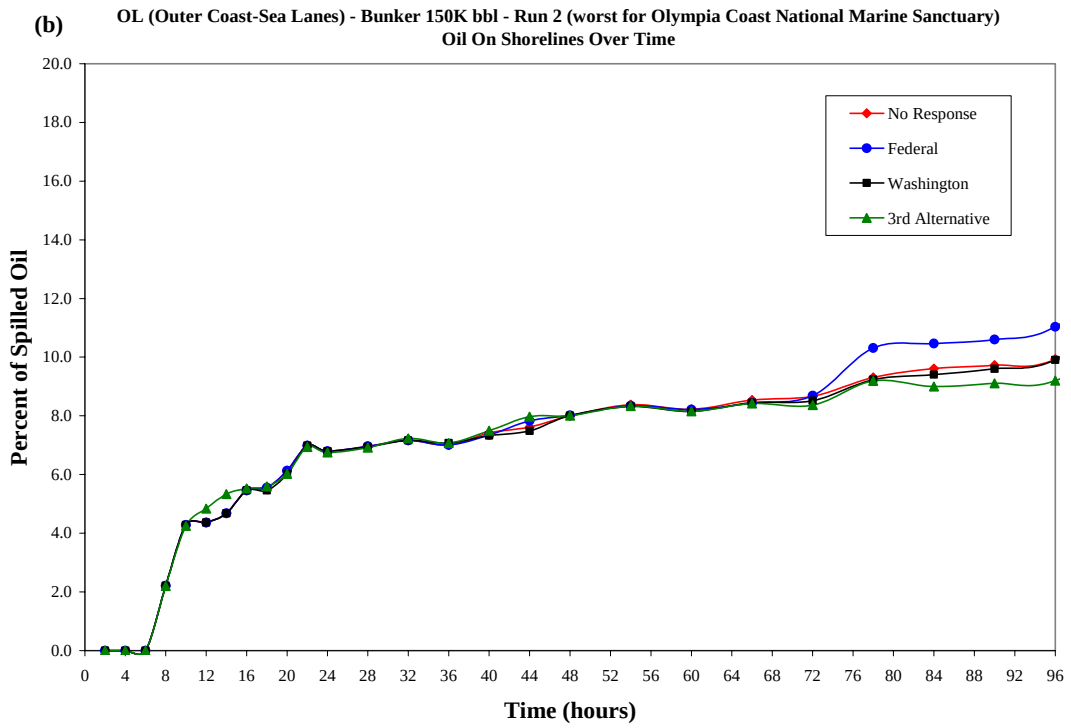
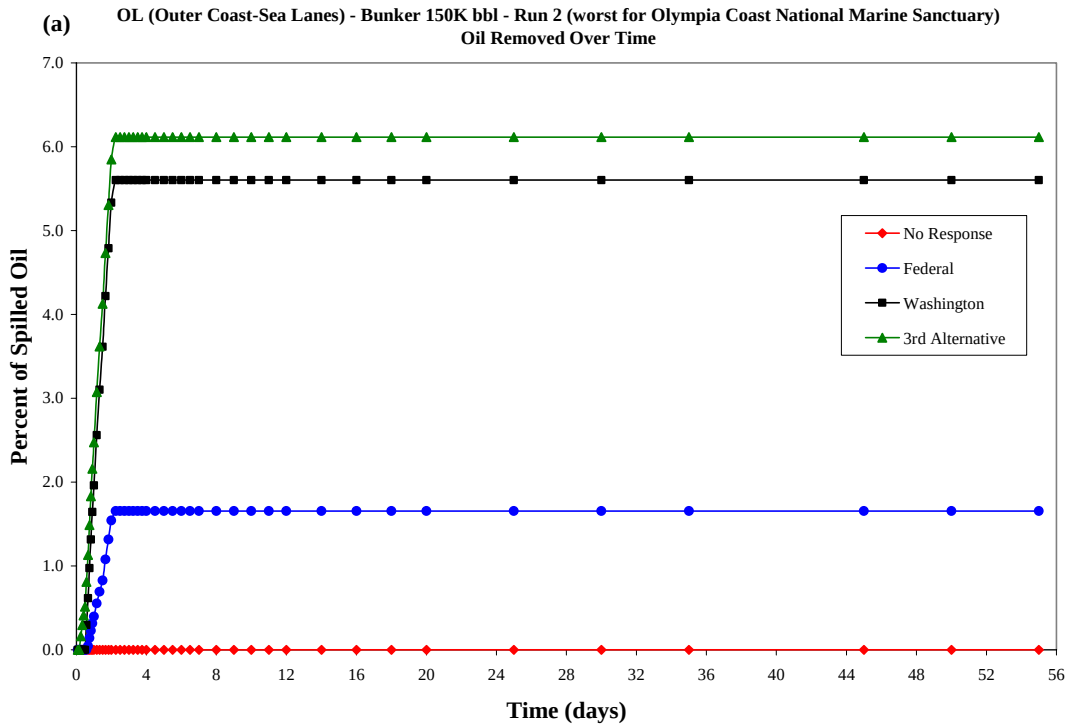


Figure XXVI.B-5 Outer Coast Sea Lanes - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.



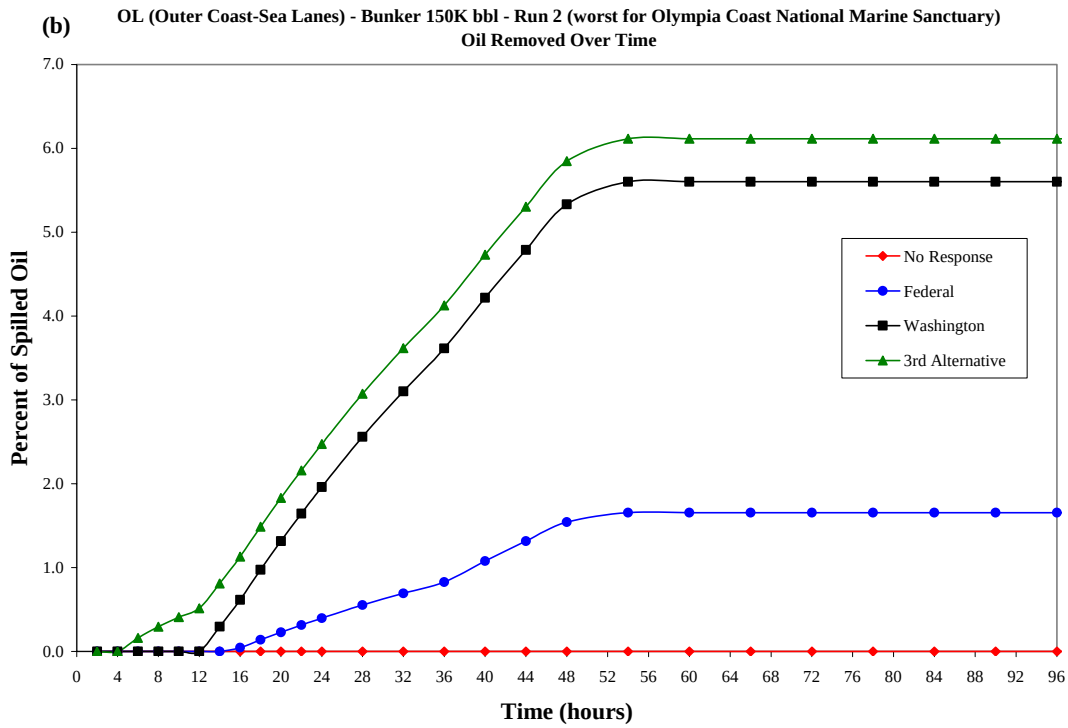
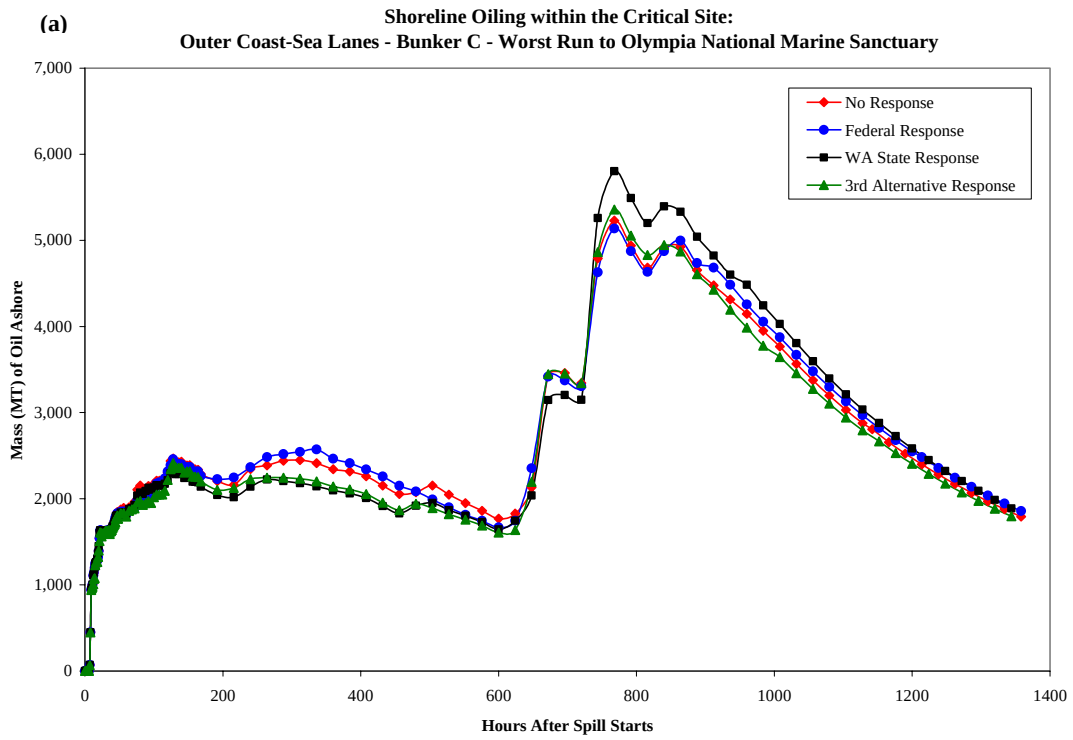


Figure XXVI.B-6 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a.



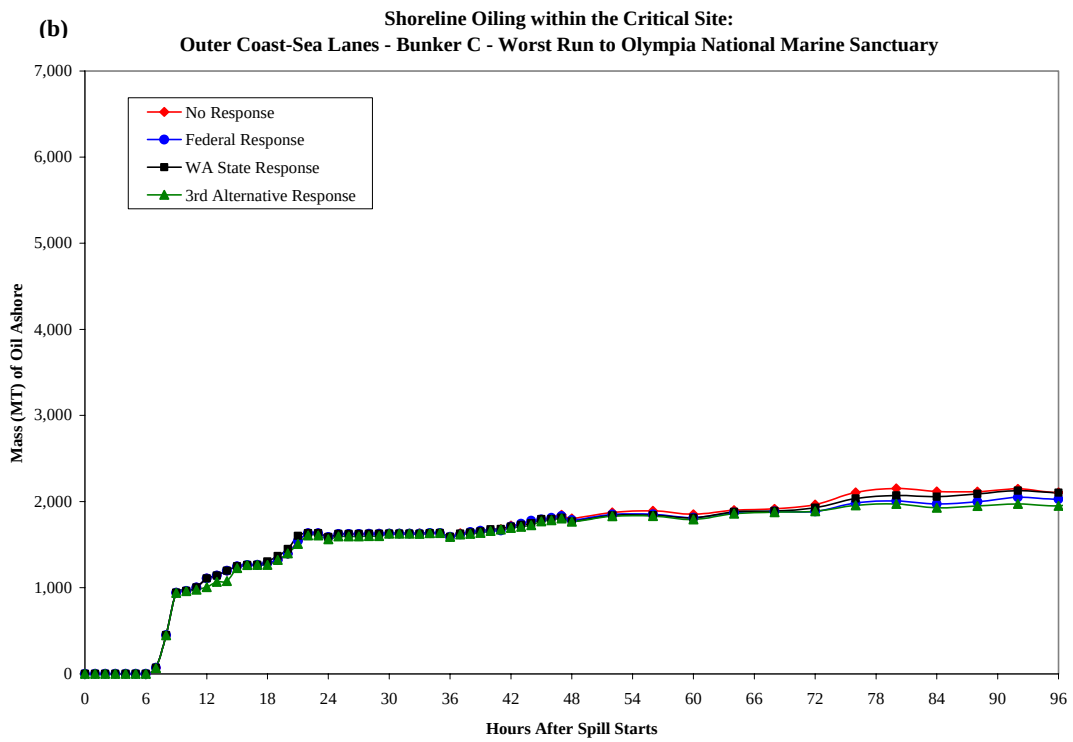
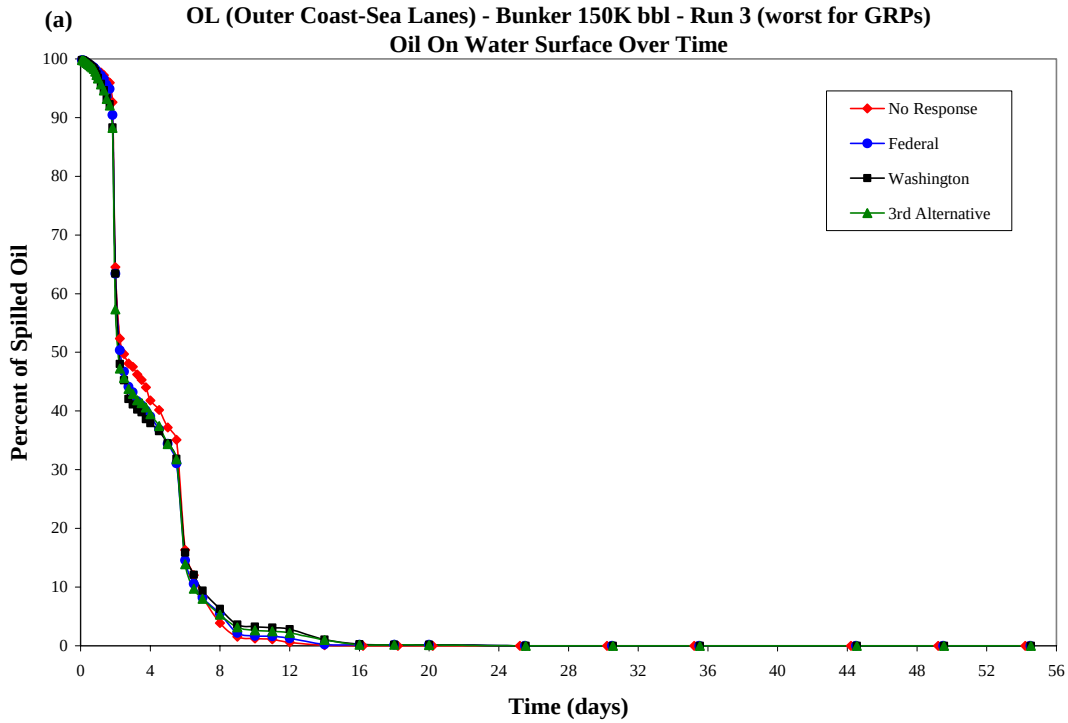


Figure XXVI.B-7 Outer Coast Sea Lanes - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the Olympia Coast National Marine Sanctuary. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



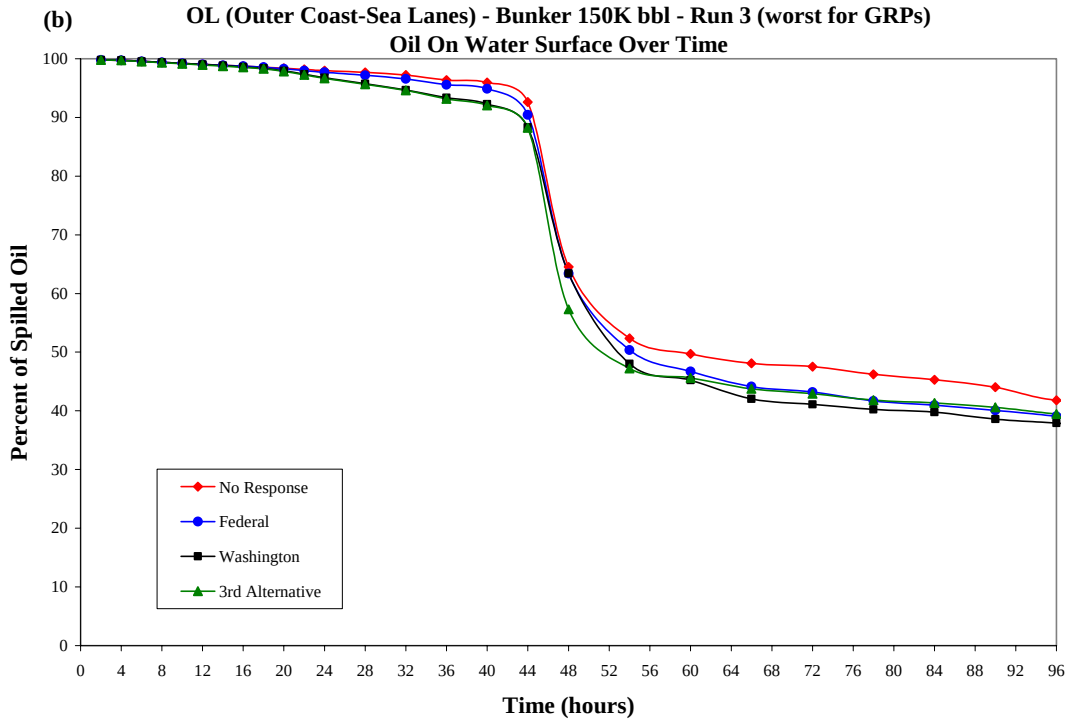
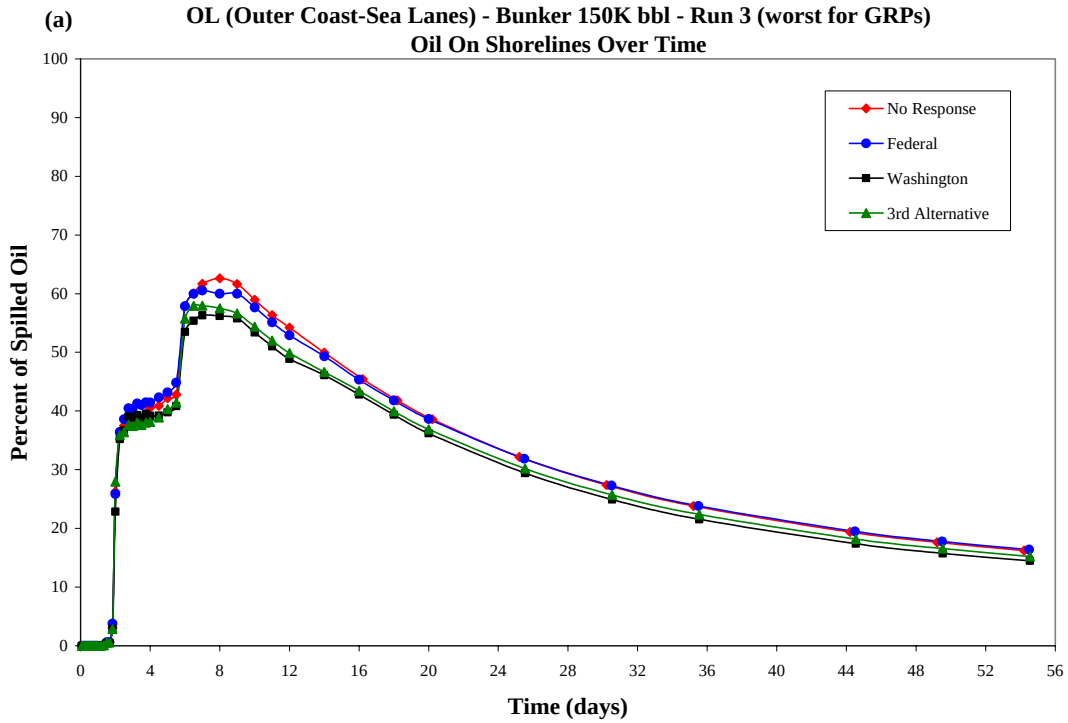


Figure XXVI.B-8 Outer Coast Sea Lanes - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the GRPs. Part b of this figure is a subset of Part a.



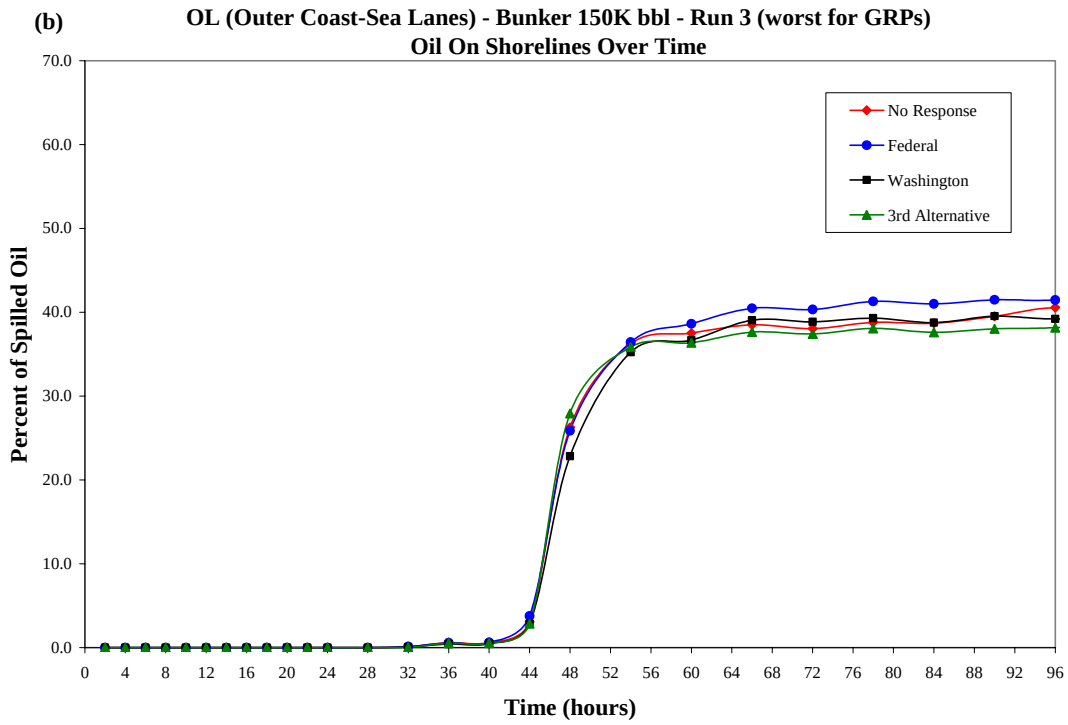


Figure XXVI.B-9 Outer Coast Sea Lanes - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the GRPs. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

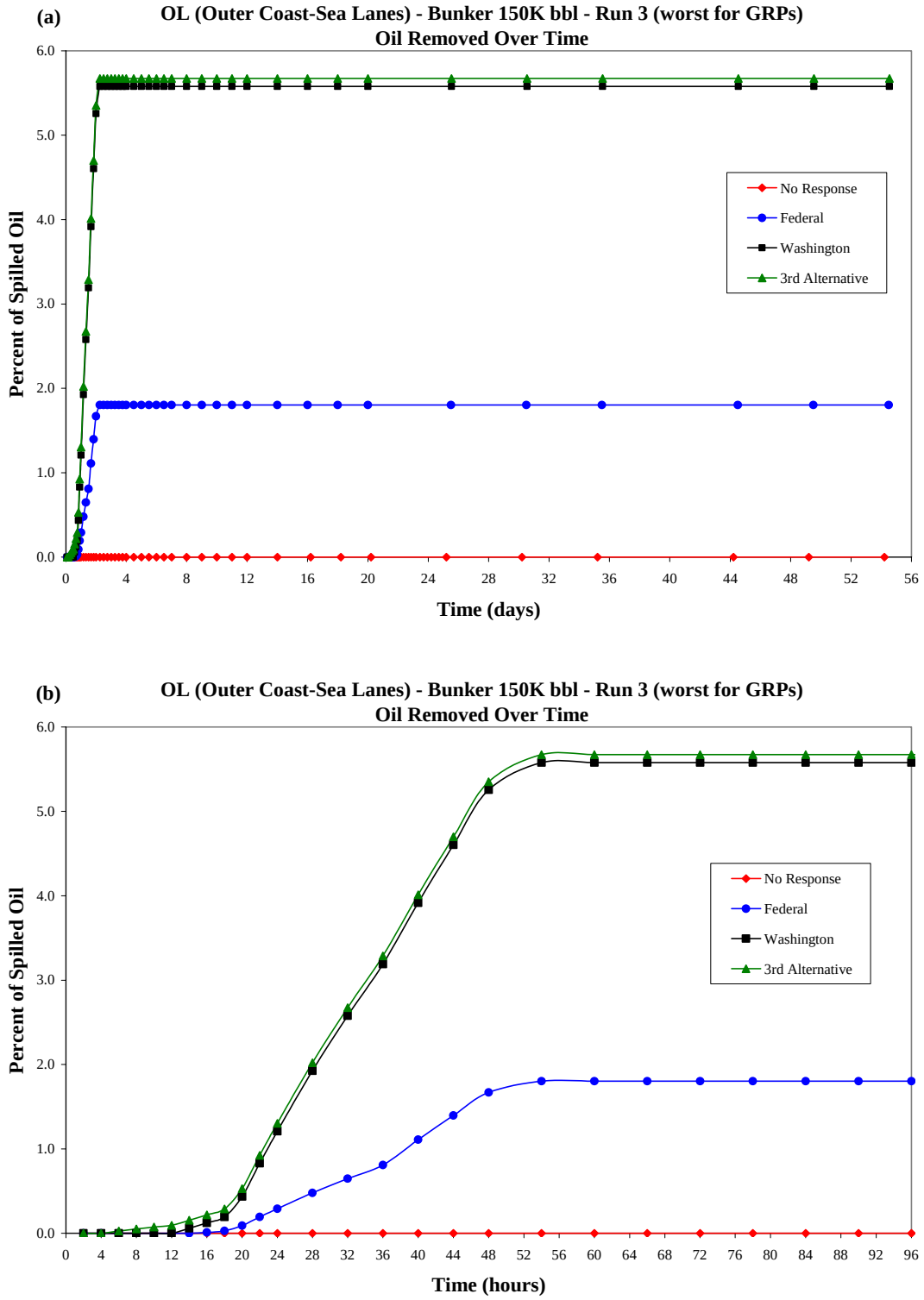
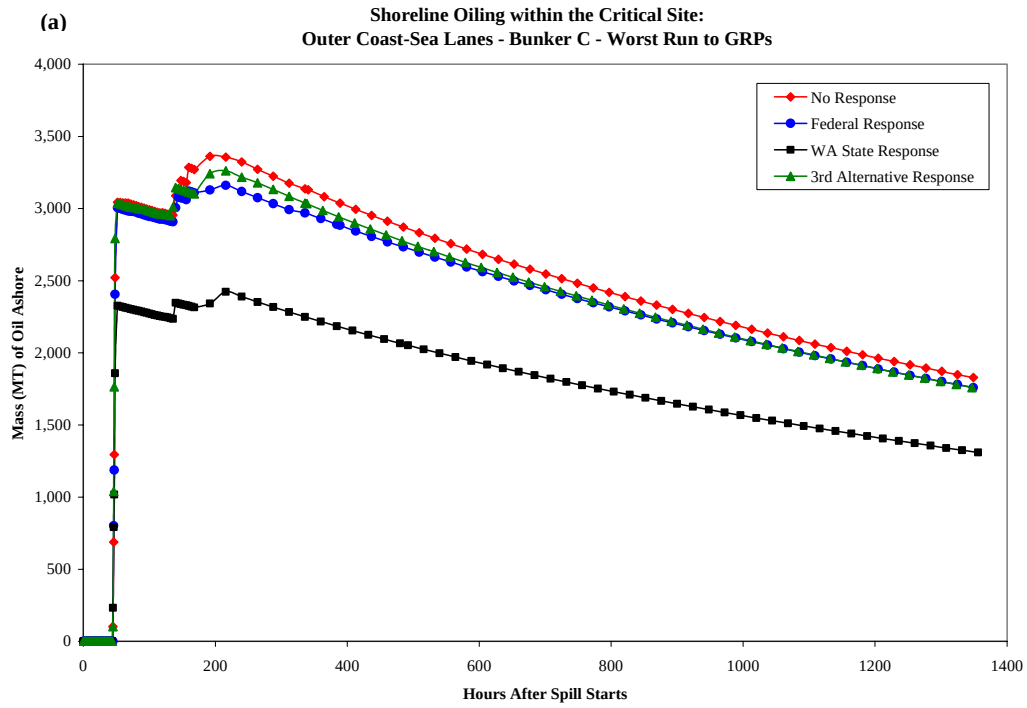


Figure XXVI.B-10 Outer Coast Sea Lanes - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the GRPs. Part b of this figure is a subset of Part a.



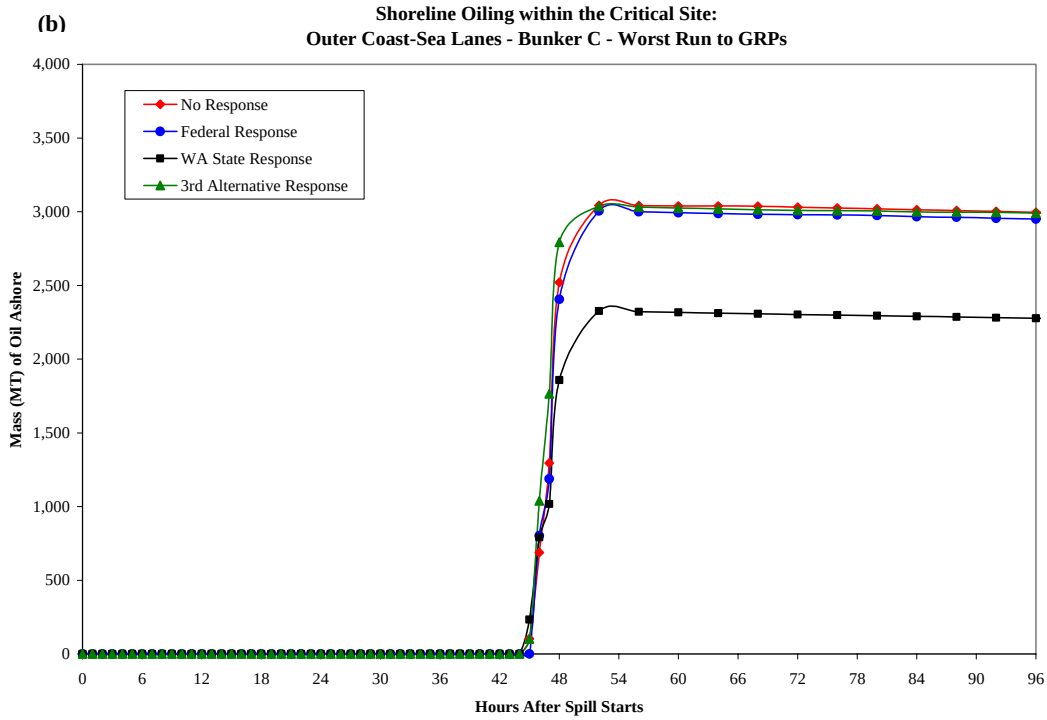


Figure XXVI.B-11 Outer Coast Sea Lanes - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the GRPs. (Differences between runs are less than the randomized variability in the model and are not significant.)

Table XXVI.B-1 Outer Coast Sea Lanes - Bunker C, 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	0.083	99.7125	0.2251	0	0	0	0.0623	0	0	99.7125
4	0.167	99.6415	0.2546	0.0001	0	0	0.1039	0	0	99.6415
6	0.25	99.361	0.4522	0	0	0	0.1867	0	0	99.361
8	0.333	99.1179	0.6126	0	0	0	0.2694	0	0	99.1179
10	0.417	98.8945	0.7536	0	0	0	0.3519	0	0	98.8945
12	0.5	98.6264	0.9394	0	0	0	0.4341	0	0	98.6264
14	0.583	98.3127	1.1711	0	0	0	0.5161	0	0	98.3127
16	0.667	97.996	1.4061	0	0	0	0.5979	0	0	97.996
18	0.75	97.4527	1.6558	0	0	0.2121	0.6794	0	0	97.4527
20	0.833	96.2684	1.9711	0	0	0.9999	0.7605	0	0	96.2684
22	0.917	93.7951	2.489	0	0	2.8747	0.8412	0	0	93.7951
24	1	93.4392	2.6339	0.0775	0	2.9277	0.9216	0	0	93.4392
28	1.167	92.938	2.8201	0.0758	0.0011	3.0825	1.0825	0	0	92.938
32	1.333	89.1988	3.5094	0.0737	0.0023	5.9732	1.2427	0	0	89.1988
36	1.5	87.3518	3.8453	0.2728	0.0023	7.1257	1.402	0	0	87.3518
40	1.667	86.6329	4.0359	0.2675	0.006	7.4969	1.5608	0	0	86.6329
44	1.833	85.2519	4.271	0.2642	0.0075	8.4863	1.7191	0	0	85.2519
48	2	83.3807	4.5945	0.5071	0.0096	9.6312	1.8769	0	0	83.3807
54	2.25	80.5748	5.1279	0.4908	0.0221	11.672	2.1124	0	0	80.5748
60	2.5	69.8109	6.8346	0.8369	0.0366	20.1356	2.3454	0	0	69.8109
66	2.75	68.1889	7.1228	0.8203	0.0459	21.2453	2.5768	0	0	68.1889
72	3	67.1819	7.4045	1.188	0.0719	21.3466	2.8071	0	0	67.1819
78	3.25	65.4577	7.7682	1.1454	0.1061	22.4867	3.0359	0	0	65.4577
84	3.5	50.6114	9.9066	1.5223	0.1625	34.5347	3.2625	0	0	50.6114

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
90	3.75	48.3087	10.4118	1.4284	0.2439	36.1204	3.4868	0	0	48.3087
96	4	47.2103	10.7064	1.8164	0.3073	36.25	3.7096	0	0	47.2103
108	4.5	44.7164	11.3707	2.0974	0.4894	37.1752	4.151	0	0	44.7164
120	5	41.2281	12.0086	2.4413	0.6672	39.0686	4.5861	0	0	41.2281
132	5.5	38.3196	12.5023	2.8275	0.8425	40.4914	5.0167	0	0	38.3196
144	6	31.7671	13.3151	3.35	1.0183	45.1075	5.4419	0	0	31.7671
156	6.5	28.1676	13.7949	3.8737	1.2523	47.0488	5.8627	0	0	28.1676
168	7	21.5847	14.5983	4.2995	1.7107	51.5293	6.2776	0	0	21.5847
192	8	17.7905	15.097	5.138	2.688	52.1968	7.0897	0	0	17.7905
216	9	12.8369	15.5502	6.2505	3.4939	53.9871	7.8814	0	0	12.8369
240	10	11.6609	15.6771	7.0029	4.5848	52.422	8.6523	0	0	11.6609
264	11	11.5298	15.6923	8.0239	5.2895	50.061	9.4036	0	0	11.5298
288	12	11.3932	15.7142	8.3845	6.5236	47.8488	10.1357	0	0	11.3932
336	14	11.1466	15.7354	8.4827	9.2746	43.8314	11.5294	0	0	11.1466
384	16	4.2522	16.2164	8.0926	12.4965	45.9517	12.8281	0	0.1625	4.4147
432	18	1.6228	16.2941	7.4245	15.9047	43.0853	13.9921	0	1.6764	3.2992
480	20	0.5575	16.3692	7.3956	18.3814	40.5534	15.0665	0	1.6764	2.2339
600	25	0.1418	16.3983	6.5683	24.0271	33.765	17.423	0	1.6764	1.8182
720	30	0.1349	16.3983	4.6936	29.2658	28.4847	19.3462	0	1.6764	1.8113
840	35	0.0925	16.4009	4.3749	31.9041	24.5749	20.9762	0	1.6764	1.7689
1080	45	0	16.4009	2.9379	36.0527	19.2714	23.5748	0	1.7622	1.7622
1200	50	0	16.4009	2.352	37.3953	17.4563	24.6333	0	1.7622	1.7622
1320	55	0	16.4009	1.5895	38.6824	15.9993	25.5657	0	1.7622	1.7622

Table XXVI.B-2 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7125	0.2251	0	0	0	0.0623	0	0	99.7125
4	0.167	99.6415	0.2546	0.0001	0	0	0.1039	0	0	99.6415
6	0.25	99.361	0.4522	0	0	0	0.1867	0	0	99.361
8	0.333	99.1179	0.6126	0	0	0	0.2694	0	0	99.1179
10	0.417	98.8945	0.7536	0	0	0	0.3519	0	0	98.8945
12	0.5	98.6264	0.9394	0	0	0	0.4341	0	0	98.6264
14	0.583	98.3127	1.1711	0	0	0	0.5161	0	0	98.3127
16	0.667	97.9494	1.4061	0.0001	0	0	0.5979	0.0466	0	97.9494
18	0.75	97.1599	1.6802	0.0001	0	0.3408	0.6793	0.1397	0	97.1599
20	0.833	95.6997	2.0225	0	0	1.2798	0.7603	0.2377	0	95.6997
22	0.917	93.1372	2.5357	0	0	3.146	0.8407	0.3403	0	93.1372
24	1	92.826	2.6598	0.082	0	3.0723	0.9208	0.4391	0	92.826
28	1.167	92.0731	2.8539	0.0802	0.0011	3.2845	1.0809	0.6263	0	92.0731
32	1.333	88.3445	3.5129	0.0779	0.0025	6.0263	1.2399	0.796	0	88.3445
36	1.5	87.2878	3.7024	0.2585	0.0026	6.395	1.3979	0.9557	0	87.2878
40	1.667	86.449	3.8667	0.2534	0.0062	6.6119	1.555	1.2577	0	86.449
44	1.833	84.8629	4.0917	0.2503	0.0077	7.5324	1.7112	1.5438	0	84.8629
48	2	84.0482	4.2226	0.462	0.01	7.5754	1.8665	1.8153	0	84.0482
54	2.25	80.8441	4.781	0.4471	0.0217	9.8591	2.0977	1.9494	0	80.8441
60	2.5	68.5588	6.6838	0.78	0.035	19.6666	2.3264	1.9494	0	68.5588
66	2.75	66.8515	6.9724	0.7646	0.0433	20.8655	2.5532	1.9494	0	66.8515
72	3	65.78	7.258	1.111	0.0672	21.0555	2.7789	1.9494	0	65.78
78	3.25	63.8711	7.6428	1.0712	0.0989	22.3633	3.0033	1.9494	0	63.8711
84	3.5	48.9486	9.8333	1.438	0.1512	34.4542	3.2254	1.9494	0	48.9486
90	3.75	46.7853	10.3257	1.3494	0.2276	35.9175	3.4451	1.9494	0	46.7853

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	45.4161	10.6501	1.7332	0.287	36.3009	3.6633	1.9494	0	45.4161
108	4.5	43.239	11.2658	2.0131	0.4598	36.9772	4.0957	1.9494	0	43.239
120	5	39.8717	11.8978	2.3513	0.6299	38.778	4.522	1.9494	0	39.8717
132	5.5	37.1184	12.3724	2.7315	0.798	40.0865	4.9438	1.9494	0	37.1184
144	6	31.5699	13.0766	3.2171	0.9678	43.8588	5.3604	1.9494	0	31.5699
156	6.5	28.6254	13.4779	3.681	1.1924	45.3012	5.7727	1.9494	0	28.6254
168	7	21.4901	14.3328	4.0755	1.6275	50.3452	6.1794	1.9494	0	21.4901
192	8	18.0942	14.8064	4.8372	2.5504	50.7866	6.9758	1.9494	0	18.0942
216	9	11.1337	15.4262	5.9763	3.3092	54.4526	7.7525	1.9494	0	11.1337
240	10	10.2128	15.5291	6.7692	4.3533	52.6771	8.5091	1.9494	0	10.2128
264	11	9.9471	15.5542	7.8025	5.0334	50.4667	9.2467	1.9494	0	9.9471
288	12	9.8294	15.573	8.1864	6.2334	48.2629	9.9655	1.9494	0	9.8294
336	14	9.5637	15.5948	8.3278	8.9228	44.3073	11.3341	1.9494	0	9.5637
384	16	4.3476	15.9149	7.89	12.082	44.4936	12.6087	1.9494	0.7138	5.0614
432	18	1.9202	15.9319	7.0815	15.3815	41.1403	13.7303	1.9494	2.865	4.7852
480	20	0.3134	16.0459	6.9579	17.7289	39.3764	14.7631	1.9494	2.865	3.1784
600	25	0	16.0459	6.0538	22.9777	32.7754	17.0243	1.9494	3.1735	3.1735
720	30	0	16.0459	4.29	27.7794	27.8855	18.8764	1.9494	3.1735	3.1735
840	35	0	16.0459	3.9862	30.1782	24.2117	20.4553	1.9494	3.1735	3.1735
1080	45	0	16.0459	2.6731	33.937	19.2236	22.9976	1.9494	3.1735	3.1735
1200	50	0	16.0459	2.1429	35.1515	17.4914	24.0454	1.9494	3.1735	3.1735
1320	55	0	16.0459	1.4516	36.3182	16.0875	24.9738	1.9494	3.1735	3.1735

Table XXVI.B-3 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7125	0.2251	0	0	0	0.0623	0	0	99.7125
4	0.167	99.6415	0.2546	0.0001	0	0	0.1039	0	0	99.6415
6	0.25	99.361	0.4522	0	0	0	0.1867	0	0	99.361
8	0.333	99.1179	0.6126	0	0	0	0.2694	0	0	99.1179
10	0.417	98.8945	0.7536	0	0	0	0.3519	0	0	98.8945
12	0.5	98.6264	0.9394	0	0	0	0.4341	0	0	98.6264
14	0.583	97.9569	1.1711	0	0	0	0.5161	0.3558	0	97.9569
16	0.667	97.2931	1.406	0.0001	0	0	0.5975	0.7034	0	97.2931
18	0.75	96.2407	1.6792	0.0001	0	0.3408	0.6783	1.0609	0	96.2407
20	0.833	94.5044	2.0203	0	0	1.2795	0.7584	1.4373	0	94.5044
22	0.917	91.8953	2.4946	0.0001	0	2.9408	0.8378	1.8315	0	91.8953
24	1	90.9779	2.6682	0.0841	0	3.1423	0.9166	2.2108	0	90.9779
28	1.167	89.8489	2.838	0.0823	0.0012	3.2266	1.0734	2.9296	0	89.8489
32	1.333	85.7223	3.4826	0.08	0.0026	5.9031	1.2283	3.5812	0	85.7223
36	1.5	84.083	3.689	0.2595	0.0028	6.3895	1.3814	4.1948	0	84.083
40	1.667	82.9074	3.8367	0.2544	0.0064	6.5426	1.533	4.9195	0	82.9074
44	1.833	81.4299	3.9829	0.2513	0.008	7.039	1.6829	5.606	0	81.4299
48	2	79.7561	4.1748	0.4476	0.0103	7.5222	1.8313	6.2578	0	79.7561
54	2.25	76.8855	4.6696	0.4331	0.0217	9.3595	2.0513	6.5795	0	76.8855
60	2.5	66.8075	6.2521	0.7521	0.0349	17.305	2.2689	6.5795	0	66.8075
66	2.75	65.0929	6.5537	0.7373	0.0434	18.5085	2.4848	6.5795	0	65.0929
72	3	63.5089	6.9106	1.0858	0.0668	19.1489	2.6995	6.5795	0	63.5089
78	3.25	62.9287	7.1024	1.0469	0.0982	19.3312	2.9131	6.5795	0	62.9287
84	3.5	45.5841	9.5931	1.3809	0.1494	33.5888	3.1242	6.5795	0	45.5841

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
90	3.75	43.4588	10.0723	1.2958	0.2225	35.0381	3.3329	6.5795	0	43.4588
96	4	42.6544	10.3193	1.6317	0.2795	34.9952	3.5404	6.5795	0	42.6544
108	4.5	40.7641	10.8913	1.8681	0.442	35.5036	3.9515	6.5795	0	40.7641
120	5	37.4399	11.5126	2.1607	0.5992	37.3515	4.3566	6.5795	0	37.4399
132	5.5	33.9165	12.0649	2.5208	0.7529	39.4077	4.7576	6.5795	0	33.9165
144	6	30.3695	12.5502	2.9393	0.9087	41.499	5.1537	6.5795	0	30.3695
156	6.5	27.1751	12.9852	3.3633	1.1133	43.2379	5.5458	6.5795	0	27.1751
168	7	20.7762	13.7714	3.7312	1.51	47.6992	5.9325	6.5795	0	20.7762
192	8	17.7563	14.2073	4.442	2.3545	47.9704	6.69	6.5795	0	17.7563
216	9	11.773	14.7454	5.4685	3.0496	50.9549	7.429	6.5795	0	11.773
240	10	10.9503	14.8404	6.1721	4.0027	49.3058	8.1494	6.5795	0	10.9503
264	11	10.8274	14.8544	7.0974	4.6212	47.1681	8.852	6.5795	0	10.8274
288	12	10.7	14.8741	7.4344	5.7109	45.1638	9.5372	6.5795	0	10.7
336	14	10.4694	14.893	7.5456	8.1484	41.5202	10.8438	6.5795	0	10.4694
384	16	4.5036	15.2912	7.1658	11.0057	43.0212	12.0644	6.5795	0.3686	4.8722
432	18	1.9603	15.314	6.4996	14.0084	39.9395	13.1447	6.5795	2.5541	4.5144
480	20	0.3766	15.4266	6.4771	16.1717	38.2709	14.1435	6.5795	2.5541	2.9307
600	25	0.0778	15.4374	5.7488	21.1017	32.0175	16.3411	6.5795	2.6962	2.774
720	30	0.074	15.4374	4.1094	25.6755	27.2772	18.1508	6.5795	2.6962	2.7702
840	35	0	15.4425	3.8367	27.9755	23.7726	19.697	6.5795	2.6962	2.6962
1080	45	0	15.4425	2.5897	31.6022	18.8974	22.1925	6.5795	2.6963	2.6963
1200	50	0	15.4425	2.078	32.7781	17.2031	23.2227	6.5795	2.6963	2.6963
1320	55	0	15.4425	1.4081	33.9084	15.8289	24.1363	6.5795	2.6963	2.6963

Table XXVI.B-4 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7125	0.2251	0	0	0	0.0623	0	0	99.7125
4	0.167	99.6415	0.2546	0.0001	0	0	0.1039	0	0	99.6415
6	0.25	99.334	0.4522	0	0	0	0.1867	0.0271	0	99.334
8	0.333	99.0665	0.6126	0	0	0	0.2694	0.0515	0	99.0665
10	0.417	98.7644	0.7535	0	0	0	0.3518	0.1303	0	98.7644
12	0.5	98.3701	0.9393	0	0	0	0.4339	0.2566	0	98.3701
14	0.583	97.701	1.1709	0	0	0	0.5156	0.6124	0	97.701
16	0.667	97.0375	1.4056	0.0001	0	0	0.5968	0.96	0	97.0375
18	0.75	95.8092	1.7074	0.0001	0	0.4884	0.6774	1.3175	0	95.8092
20	0.833	93.6636	2.1163	0	0	1.7689	0.7573	1.6939	0	93.6636
22	0.917	91.3207	2.5474	0	0	3.2073	0.8364	2.0881	0	91.3207
24	1	89.823	2.811	0.1058	0	3.8779	0.9149	2.4674	0	89.823
28	1.167	88.6483	2.9862	0.1035	0.0015	4.0032	1.0711	3.1862	0	88.6483
32	1.333	85.2258	3.5224	0.1006	0.0034	6.0846	1.2255	3.8378	0	85.2258
36	1.5	82.7161	3.8614	0.304	0.0038	7.2852	1.3781	4.4513	0	82.7161
40	1.667	81.1973	4.0607	0.298	0.0081	7.7309	1.5291	5.176	0	81.1973
44	1.833	79.1755	4.2884	0.2943	0.0099	8.691	1.6784	5.8626	0	79.1755
48	2	78.0081	4.4111	0.5371	0.0125	8.6906	1.8261	6.5144	0	78.0081
54	2.25	75.7591	4.8085	0.5198	0.0263	10.0051	2.0451	6.8361	0	75.7591
60	2.5	62.9036	6.8314	0.8766	0.0422	20.2486	2.2615	6.8361	0	62.9036
66	2.75	61.4119	7.0978	0.8592	0.0522	21.2667	2.4761	6.8361	0	61.4119
72	3	59.9555	7.431	1.2468	0.0796	21.7615	2.6895	6.8361	0	59.9555
78	3.25	58.6378	7.7215	1.2021	0.1157	22.5851	2.9017	6.8361	0	58.6378
84	3.5	41.6714	10.1847	1.596	0.1749	36.4254	3.1114	6.8361	0	41.6714

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
90	3.75	38.1427	10.8134	1.4976	0.26	39.1315	3.3187	6.8361	0	38.1427
96	4	36.4037	11.1657	1.9113	0.3261	39.8325	3.5246	6.8361	0	36.4037
108	4.5	34.8126	11.6528	2.1952	0.5169	40.054	3.9324	6.8361	0	34.8126
120	5	32.2396	12.1504	2.5136	0.7028	41.2229	4.3346	6.8361	0	32.2396
132	5.5	30.2913	12.5062	2.8597	0.883	41.8911	4.7326	6.8361	0	30.2913
144	6	25.1652	13.132	3.3021	1.0611	45.3778	5.1258	6.8361	0	25.1652
156	6.5	21.8944	13.5425	3.7356	1.2917	47.1847	5.5149	6.8361	0	21.8944
168	7	15.0464	14.3196	4.0919	1.7327	52.0745	5.8988	6.8361	0	15.0464
192	8	11.4396	14.7513	4.8019	2.6546	52.8661	6.6504	6.8361	0	11.4396
216	9	6.1586	15.2089	5.8433	3.4039	55.166	7.3833	6.8361	0	6.1586
240	10	5.7224	15.2581	6.5214	4.4187	53.1462	8.097	6.8361	0	5.7224
264	11	5.5361	15.2739	7.4476	5.0701	51.0436	8.7926	6.8361	0	5.5361
288	12	5.4729	15.2821	7.7656	6.2101	48.9628	9.4705	6.8361	0	5.4729
336	14	5.3571	15.2896	7.8352	8.7458	45.1752	10.761	6.8361	0	5.3571
384	16	2.4703	15.4846	7.3078	11.6977	44.1055	11.9633	6.8361	0.1348	2.6051
432	18	1.6295	15.4927	6.4542	14.7302	40.9729	13.054	6.8361	0.8304	2.4599
480	20	0.3759	15.5817	6.2802	16.8538	39.1749	14.067	6.8361	0.8304	1.2063
600	25	0	15.6026	5.4022	21.5437	33.3945	16.3096	6.8361	0.9113	0.9113
720	30	0	15.6026	3.8117	25.8001	28.8601	18.178	6.8361	0.9113	0.9113
840	35	0	15.6026	3.5385	27.9109	25.4089	19.7917	6.8361	0.9113	0.9113
1080	45	0	15.6026	2.377	31.2136	20.6202	22.4392	6.8361	0.9114	0.9114
1200	50	0	15.6026	1.909	32.2782	18.9137	23.549	6.8361	0.9114	0.9114
1320	55	0	15.6026	1.2964	33.3036	17.507	24.543	6.8361	0.9114	0.9114

Table XXVI.B-5 Outer Coast Sea Lanes - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	0.083	99.6703	0.2673	0	0	0	0.0623	0	0	99.6703
4	0.167	99.5202	0.376	0.0001	0	0	0.1037	0	0	99.5202
6	0.25	99.1857	0.6278	0	0	0	0.1865	0	0	99.1857
8	0.333	96.2398	1.2765	0.0001	0	2.2149	0.2688	0	0	96.2398
10	0.417	93.5744	1.7933	0	0	4.2819	0.3504	0	0	93.5744
12	0.5	93.1114	1.9563	0.1326	0	4.3679	0.4318	0	0	93.1114
14	0.583	92.5997	2.0703	0.1319	0.0002	4.6844	0.5134	0	0	92.5997
16	0.667	91.5381	2.274	0.1309	0.0007	5.4615	0.5949	0	0	91.5381
18	0.75	91.3024	2.3373	0.1298	0.0012	5.5531	0.6762	0	0	91.3024
20	0.833	90.4456	2.5369	0.1282	0.0023	6.1297	0.7574	0	0	90.4456
22	0.917	89.2265	2.8181	0.1261	0.0036	6.9873	0.8383	0	0	89.2265
24	1	89.0239	2.9395	0.3146	0.005	6.7979	0.9191	0	0	89.0239
28	1.167	88.4364	3.2036	0.3049	0.0131	6.962	1.08	0	0	88.4364
32	1.333	87.9212	3.3553	0.2991	0.0172	7.1667	1.2404	0	0	87.9212
36	1.5	87.6016	3.4833	0.4859	0.0224	7.0065	1.4003	0	0	87.6016
40	1.667	86.8477	3.6672	0.4764	0.0299	7.4192	1.5596	0	0	86.8477
44	1.833	86.3721	3.7845	0.4677	0.0366	7.6206	1.7185	0	0	86.3721
48	2	85.374	4.0381	0.6673	0.0472	7.9966	1.8768	0	0	85.374
54	2.25	84.4193	4.3741	0.6379	0.0728	8.3827	2.1131	0	0	84.4193
60	2.5	83.9859	4.5203	0.8329	0.087	8.2256	2.3482	0	0	83.9859
66	2.75	83.0883	4.8778	0.7934	0.1223	8.5361	2.582	0	0	83.0883
72	3	82.0418	5.3421	0.9627	0.1664	8.6727	2.8142	0	0	82.0418
78	3.25	80.8264	5.6968	0.9181	0.2065	9.3075	3.0447	0	0	80.8264
84	3.5	79.8528	5.9106	1.1243	0.229	9.6093	3.274	0	0	79.8528
90	3.75	79.3334	6.0901	1.0859	0.2622	9.7262	3.5023	0	0	79.3334
96	4	78.4675	6.2959	1.284	0.2909	9.9322	3.7294	0	0	78.4675

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	4.5	74.3394	7.1045	1.462	0.3784	12.5358	4.1798	0	0	74.3394
120	5	71.1331	7.8437	1.6503	0.496	14.252	4.6248	0	0	71.1331
132	5.5	67.4936	8.5522	1.8927	0.618	16.3796	5.064	0	0	67.4936
144	6	66.5174	9	2.0812	0.7824	16.1209	5.4982	0	0	66.5174
156	6.5	65.2435	9.6915	2.1521	1.0532	15.9338	5.926	0	0	65.2435
168	7	64.2859	10.2637	2.1886	1.3473	15.568	6.3466	0	0	64.2859
192	8	62.6316	10.5912	2.6061	1.5687	15.4277	7.1747	0	0	62.6316
216	9	60.453	11.0816	2.7839	2.0383	15.6561	7.9871	0	0	60.453
240	10	58.3644	11.434	2.9954	2.4822	15.9417	8.7823	0	0	58.3644
264	11	56.5034	11.8162	2.9711	3.1788	15.97	9.5605	0	0	56.5034
288	12	55.0365	12.016	3.0525	3.7515	15.8219	10.3215	0	0	55.0365
336	14	52.4169	12.2356	3.421	4.6547	15.4692	11.8026	0	0	52.4169
384	16	50.4393	12.3568	3.7248	5.5341	14.716	13.229	0	0	50.4393
432	18	49.1928	12.4096	3.6376	6.6965	13.4602	14.6033	0	0	49.1928
480	20	46.7154	12.5308	3.6656	7.6469	13.5148	15.9264	0	0	46.7154
600	25	40.9718	12.6698	3.2348	10.5906	11.7552	18.9671	0	1.8107	42.7825
720	30	26.4153	13.5952	3.2833	13.9584	19.2864	21.6507	0	1.8107	28.226
840	35	9.5262	14.7515	5.2829	17.7605	26.8451	24.023	0	1.8107	11.3369
1080	45	1.0101	15.341	7.1976	26.3192	20.682	27.6394	0	1.8107	2.8208
1200	50	0.5789	15.3692	5.5464	31.2674	16.4539	28.9735	0	1.8107	2.3896
1320	55	0.5507	15.3692	4.8435	34.3507	13.0584	30.0169	0	1.8107	2.3614

Table XXVI.B-6 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	0.083	99.6703	0.2673	0	0	0	0.0623	0	0	99.6703
4	0.167	99.5202	0.376	0.0001	0	0	0.1037	0	0	99.5202
6	0.25	99.1857	0.6278	0	0	0	0.1865	0	0	99.1857
8	0.333	96.2398	1.2765	0.0001	0	2.2149	0.2688	0	0	96.2398
10	0.417	93.5744	1.7933	0	0	4.2819	0.3504	0	0	93.5744
12	0.5	93.1114	1.9563	0.1326	0	4.3679	0.4318	0	0	93.1114
14	0.583	92.5997	2.0703	0.1319	0.0002	4.6844	0.5134	0	0	92.5997
16	0.667	91.4915	2.274	0.1309	0.0007	5.4615	0.5949	0.0466	0	91.4915
18	0.75	91.1628	2.3373	0.1298	0.0012	5.5531	0.6762	0.1397	0	91.1628
20	0.833	90.217	2.5369	0.1282	0.0023	6.1297	0.7572	0.2288	0	90.217
22	0.917	88.9127	2.818	0.1261	0.0036	6.9873	0.8379	0.3143	0	88.9127
24	1	88.6283	2.9391	0.3146	0.005	6.7979	0.9184	0.3966	0	88.6283
28	1.167	87.8869	3.2019	0.3049	0.0131	6.962	1.0786	0.5526	0	87.8869
32	1.333	87.2313	3.3535	0.2991	0.0172	7.1669	1.2379	0.694	0	87.2313
36	1.5	86.7814	3.4804	0.4859	0.0224	7.0061	1.3966	0.8272	0	86.7814
40	1.667	85.8598	3.6509	0.4764	0.0299	7.3498	1.5544	1.0788	0	85.8598
44	1.833	84.8188	3.8169	0.4677	0.0366	7.8315	1.7114	1.3172	0	84.8188
48	2	83.8163	4.0386	0.668	0.0472	8.0191	1.8674	1.5435	0	83.8163
54	2.25	82.8261	4.3611	0.6386	0.0728	8.3465	2.0996	1.6552	0	82.8261
60	2.5	82.3692	4.5101	0.8339	0.087	8.2139	2.3306	1.6552	0	82.3692
66	2.75	81.5834	4.8484	0.7944	0.1224	8.4358	2.5604	1.6552	0	81.5834
72	3	80.4077	5.3262	0.9642	0.1666	8.6915	2.7886	1.6552	0	80.4077
78	3.25	78.0595	5.8332	0.9195	0.2065	10.3111	3.0149	1.6552	0	78.0595
84	3.5	77.2391	6.023	1.1485	0.2289	10.4652	3.2401	1.6552	0	77.2391
90	3.75	76.705	6.2003	1.1094	0.2625	10.6033	3.4643	1.6552	0	76.705
96	4	75.5604	6.4383	1.3325	0.2917	11.0346	3.6873	1.6552	0	75.5604

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	4.5	71.1125	7.2754	1.5414	0.3819	13.9042	4.1294	1.6552	0	71.1125
120	5	68.4001	7.9423	1.7423	0.5055	15.1883	4.5663	1.6552	0	68.4001
132	5.5	65.6873	8.5328	1.9702	0.6345	16.5225	4.9975	1.6552	0	65.6873
144	6	64.7686	8.9686	2.1441	0.8061	16.2335	5.4239	1.6552	0	64.7686
156	6.5	63.74	9.6247	2.1986	1.0854	15.8522	5.8439	1.6552	0	63.74
168	7	62.8434	10.1833	2.2211	1.3861	15.4542	6.2568	1.6552	0	62.8434
192	8	61.4608	10.4836	2.6157	1.6107	15.1044	7.0696	1.6552	0	61.4608
216	9	59.9642	10.9123	2.7378	2.0804	14.7833	7.8669	1.6552	0	59.9642
240	10	57.6776	11.2782	2.9071	2.5159	15.3188	8.6473	1.6552	0	57.6776
264	11	56.2133	11.6248	2.8465	3.1901	15.0591	9.4111	1.6552	0	56.2133
288	12	54.6443	11.8306	2.9016	3.7378	15.0722	10.1582	1.6552	0	54.6443
336	14	51.8036	12.0651	3.2343	4.5923	15.0367	11.6128	1.6552	0	51.8036
384	16	50.0453	12.1698	3.5163	5.4228	14.176	13.0146	1.6552	0	50.0453
432	18	48.7441	12.2264	3.4352	6.5196	13.0533	14.3661	1.6552	0	48.7441
480	20	45.7024	12.389	3.4936	7.4173	13.6743	15.6683	1.6552	0	45.7024
600	25	40.5321	12.5094	3.1051	10.2313	11.7771	18.671	1.6552	1.5189	42.051
720	30	24.8357	13.521	3.3262	13.5309	20.2807	21.3313	1.6552	1.5189	26.3546
840	35	9.3272	14.5812	5.2802	17.3688	26.5885	23.68	1.6552	1.5189	10.8461
1080	45	0.2514	15.2174	7.2445	25.9771	20.8866	27.249	1.6552	1.5189	1.7703
1200	50	0	15.2351	5.568	30.9524	16.5122	28.5582	1.6552	1.5189	1.5189
1320	55	0	15.2351	4.8553	34.0453	13.1133	29.577	1.6552	1.5189	1.5189

Table XXVI.B-7 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	0.083	99.6703	0.2673	0	0	0	0.0623	0	0	99.6703
4	0.167	99.5202	0.376	0.0001	0	0	0.1037	0	0	99.5202
6	0.25	99.1857	0.6278	0	0	0	0.1865	0	0	99.1857
8	0.333	96.2398	1.2765	0.0001	0	2.2149	0.2688	0	0	96.2398
10	0.417	93.5744	1.7933	0	0	4.2819	0.3504	0	0	93.5744
12	0.5	93.1114	1.9563	0.1326	0	4.3679	0.4318	0	0	93.1114
14	0.583	92.3033	2.0703	0.1319	0.0002	4.6844	0.5134	0.2965	0	92.3033
16	0.667	90.9226	2.2738	0.1309	0.0007	5.4615	0.5945	0.616	0	90.9226
18	0.75	90.4433	2.3183	0.1298	0.0012	5.4586	0.6753	0.9735	0	90.4433
20	0.833	89.2656	2.5136	0.1282	0.0023	6.0191	0.7556	1.3157	0	89.2656
22	0.917	87.5938	2.8146	0.1261	0.0036	6.9823	0.8353	1.6441	0	87.5938
24	1	87.0728	2.9348	0.3146	0.005	6.7979	0.9147	1.9602	0	87.0728
28	1.167	85.9167	3.1902	0.3049	0.0131	6.9438	1.072	2.5592	0	85.9167
32	1.333	84.8452	3.3419	0.2991	0.0172	7.1666	1.2278	3.1022	0	84.8452
36	1.5	83.9458	3.4775	0.4869	0.0224	7.0717	1.3822	3.6135	0	83.9458
40	1.667	82.7852	3.6286	0.4773	0.03	7.3263	1.5352	4.2174	0	82.7852
44	1.833	81.7945	3.7365	0.4686	0.0366	7.4873	1.6868	4.7896	0	81.7945
48	2	80.0953	4.0111	0.6699	0.0473	8.0067	1.837	5.3327	0	80.0953
54	2.25	78.9907	4.3174	0.6404	0.073	8.318	2.0596	5.6008	0	78.9907
60	2.5	78.5854	4.4552	0.8362	0.0872	8.1541	2.281	5.6008	0	78.5854
66	2.75	77.7344	4.7931	0.7966	0.1228	8.4511	2.5012	5.6008	0	77.7344
72	3	76.8102	5.2208	0.9644	0.1671	8.5168	2.7198	5.6008	0	76.8102
78	3.25	75.5168	5.5842	0.9197	0.2072	9.2345	2.9367	5.6008	0	75.5168
84	3.5	74.7179	5.7712	1.123	0.2299	9.4045	3.1527	5.6008	0	74.7179
90	3.75	74.1269	5.9545	1.0846	0.2631	9.6025	3.3675	5.6008	0	74.1269

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	73.1655	6.1693	1.2841	0.2918	9.9071	3.5814	5.6008	0	73.1655
108	4.5	69.3163	6.9323	1.4616	0.3793	12.3045	4.0052	5.6008	0	69.3163
120	5	67.0344	7.5441	1.6236	0.4971	13.276	4.424	5.6008	0	67.0344
132	5.5	64.7715	8.0788	1.8062	0.618	14.2873	4.8374	5.6008	0	64.7715
144	6	63.8039	8.5194	1.9434	0.7758	14.1104	5.2462	5.6008	0	63.8039
156	6.5	62.5167	9.1997	1.9767	1.0293	14.028	5.6488	5.6008	0	62.5167
168	7	61.6254	9.7516	1.9838	1.2997	13.694	6.0447	5.6008	0	61.6254
192	8	60.3533	10.0392	2.316	1.5	13.3666	6.824	5.6008	0	60.3533
216	9	58.7679	10.4714	2.4235	1.9158	13.2319	7.5887	5.6008	0	58.7679
240	10	56.9739	10.792	2.5627	2.3011	13.4319	8.3375	5.6008	0	56.9739
264	11	54.9433	11.1793	2.5226	2.8957	13.7874	9.0709	5.6008	0	54.9433
288	12	53.6205	11.3625	2.5795	3.3811	13.6668	9.7887	5.6008	0	53.6205
336	14	51.1285	11.5683	2.8767	4.1414	13.4969	11.1874	5.6008	0	51.1285
384	16	49.4412	11.6665	3.1152	4.8788	12.7607	12.5368	5.6008	0	49.4412
432	18	48.2808	11.712	3.0295	5.8485	11.6889	13.8395	5.6008	0	48.2808
480	20	46.8527	11.7576	3.0248	6.6384	11.0294	15.0963	5.6008	0	46.8527
600	25	43.2569	11.8277	2.4871	8.9834	9.2802	18.0325	5.6008	0.5314	43.7883
720	30	30.0844	12.6426	2.5773	11.5526	16.3292	20.6816	5.6008	0.5314	30.6158
840	35	11.4339	13.918	4.8612	14.8517	25.7441	23.0589	5.6008	0.5314	11.9653
1080	45	1.613	14.5896	7.0028	22.8913	21.0271	26.7441	5.6008	0.5314	2.1444
1200	50	0.4267	14.6713	5.5723	27.7613	17.3133	28.1229	5.6008	0.5314	0.9581
1320	55	0.4059	14.6713	4.9819	30.8901	13.7102	29.2083	5.6008	0.5314	0.9373

Table XXVI.B-8 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the Olympia Coast National Marine Sanctuary.

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	0.083	99.6703	0.2673	0	0	0	0.0623	0	0	99.6703
4	0.167	99.5202	0.376	0.0001	0	0	0.1037	0	0	99.5202
6	0.25	99.0234	0.6277	0	0	0	0.1865	0.1623	0	99.0234
8	0.333	95.9592	1.2739	0.0001	0	2.2018	0.2686	0.2965	0	95.9592
10	0.417	93.2019	1.7874	0	0	4.2516	0.3499	0.4091	0	93.2019
12	0.5	92.0179	2.0504	0.147	0	4.8394	0.4309	0.5144	0	92.0179
14	0.583	90.9959	2.1997	0.1463	0.0002	5.335	0.512	0.8109	0	90.9959
16	0.667	90.3134	2.2906	0.1451	0.0008	5.527	0.5927	1.1304	0	90.3134
18	0.75	89.7472	2.3493	0.1439	0.0014	5.5973	0.673	1.4879	0	89.7472
20	0.833	88.7276	2.5189	0.1421	0.0026	6.026	0.7529	1.8301	0	88.7276
22	0.917	87.1207	2.8059	0.1398	0.0042	6.9387	0.8322	2.1585	0	87.1207
24	1	86.6013	2.9254	0.3274	0.0058	6.7543	0.9111	2.4746	0	86.6013
28	1.167	85.4265	3.1826	0.3173	0.0143	6.9181	1.0676	3.0736	0	85.4265
32	1.333	84.245	3.3516	0.3113	0.0186	7.2344	1.2226	3.6166	0	84.245
36	1.5	83.4266	3.4739	0.4988	0.0241	7.0726	1.3762	4.1279	0	83.4266
40	1.667	82.0745	3.6537	0.4889	0.0319	7.4909	1.5283	4.7318	0	82.0745
44	1.833	80.7004	3.8193	0.48	0.0387	7.9786	1.679	5.3039	0	80.7004
48	2	79.5822	4.0061	0.6805	0.0496	8.0062	1.8283	5.8471	0	79.5822
54	2.25	78.4664	4.3128	0.6506	0.0758	8.3295	2.0497	6.1152	0	78.4664
60	2.5	78.0771	4.4473	0.8456	0.0903	8.1547	2.2698	6.1152	0	78.0771
66	2.75	77.2659	4.7782	0.8055	0.1262	8.4201	2.4888	6.1152	0	77.2659
72	3	76.481	5.1847	0.9721	0.1711	8.3697	2.7062	6.1152	0	76.481
78	3.25	75.0749	5.5558	0.927	0.2116	9.1936	2.9219	6.1152	0	75.0749
84	3.5	74.7033	5.6842	1.1277	0.2345	8.9984	3.1367	6.1152	0	74.7033
90	3.75	74.211	5.8543	1.0892	0.2681	9.1119	3.3504	6.1152	0	74.211

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	73.5148	6.0323	1.28	0.297	9.1976	3.5631	6.1152	0	73.5148
108	4.5	70.0581	6.7352	1.4375	0.3848	11.2843	3.9849	6.1152	0	70.0581
120	5	67.1648	7.4182	1.5987	0.501	12.8003	4.4017	6.1152	0	67.1648
132	5.5	64.7222	7.9797	1.787	0.6201	13.9629	4.813	6.1152	0	64.7222
144	6	63.8492	8.4111	1.9286	0.7763	13.6998	5.2197	6.1152	0	63.8492
156	6.5	62.7609	9.074	1.966	1.028	13.4356	5.6202	6.1152	0	62.7609
168	7	61.8922	9.6297	1.9763	1.2973	13.0754	6.0139	6.1152	0	61.8922
192	8	60.9458	9.8895	2.3065	1.4976	12.4563	6.7891	6.1152	0	60.9458
216	9	59.4709	10.3179	2.394	1.9117	12.2407	7.5497	6.1152	0	59.4709
240	10	57.3284	10.6734	2.5297	2.2927	12.7663	8.2944	6.1152	0	57.3284
264	11	55.4866	11.0497	2.4882	2.88	12.9567	9.0237	6.1152	0	55.4866
288	12	54.1517	11.2363	2.5442	3.3594	12.8555	9.7376	6.1152	0	54.1517
336	14	51.4164	11.4624	2.8609	4.1128	12.9035	11.1287	6.1152	0	51.4164
384	16	49.5458	11.5748	3.1245	4.8489	12.32	12.4708	6.1152	0	49.5458
432	18	48.299	11.627	3.0625	5.8253	11.3047	13.7663	6.1152	0	48.299
480	20	46.0432	11.7327	3.098	6.6265	11.3684	15.0159	6.1152	0	46.0432
600	25	41.1791	11.8806	2.7402	9.1135	10.247	17.9264	6.1152	0.7979	41.977
720	30	25.0759	12.9181	3.0488	12.0424	19.4706	20.5311	6.1152	0.7979	25.8738
840	35	8.2508	14.0776	5.3494	15.8053	26.762	22.8418	6.1152	0.7979	9.0487
1080	45	1.131	14.567	6.8167	24.1562	20.0673	26.3486	6.1152	0.7979	1.9289
1200	50	0.4405	14.6139	5.2545	28.8308	16.2998	27.6475	6.1152	0.7979	1.2384
1320	55	0.419	14.6139	4.6111	31.7547	13.0188	28.6694	6.1152	0.7979	1.2169

Table XXVI.B-9 Outer Coast Sea Lanes - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7989	0.1387	0	0	0	0.0624	0	0	99.7989
4	0.167	99.7306	0.1655	0.0001	0	0	0.1039	0	0	99.7306
6	0.25	99.5497	0.2633	0	0	0	0.187	0	0	99.5497
8	0.333	99.3726	0.3576	0	0	0	0.2698	0	0	99.3726
10	0.417	99.2148	0.4326	0	0	0	0.3525	0	0	99.2148
12	0.5	99.0408	0.524	0	0	0	0.4351	0	0	99.0408
14	0.583	98.8808	0.6016	0	0	0	0.5176	0	0	98.8808
16	0.667	98.7293	0.6708	0	0	0	0.5999	0	0	98.7293
18	0.75	98.5716	0.7463	0	0	0	0.6821	0	0	98.5716
20	0.833	98.3677	0.8681	0	0	0	0.7641	0	0	98.3677
22	0.917	98.1645	0.9895	0	0	0	0.846	0	0	98.1645
24	1	97.9745	1.0978	0	0	0	0.9277	0	0	97.9745
28	1.167	97.6469	1.2624	0	0	0	1.0907	0	0	97.6469
32	1.333	97.2079	1.4276	0	0	0.1114	1.2531	0	0	97.2079
36	1.5	96.3507	1.6196	0.0105	0	0.6042	1.415	0	0	96.3507
40	1.667	95.9534	1.8351	0.0103	0.0001	0.6248	1.5763	0	0	95.9534
44	1.833	92.6109	2.5459	0.0099	0.0002	3.0963	1.7368	0	0	92.6109
48	2	64.5221	7.0159	0.2927	0	26.2771	1.8922	0	0	64.5221
54	2.25	52.338	9.0381	0.2786	0.0051	36.2159	2.1243	0	0	52.338
60	2.5	49.7045	9.5934	0.8199	0.013	37.5148	2.3545	0	0	49.7045
66	2.75	48.103	9.9823	0.7731	0.0481	38.5103	2.5831	0	0	48.103
72	3	47.5285	10.233	1.2962	0.0907	38.0412	2.8104	0	0	47.5285
78	3.25	46.2511	10.5457	1.2222	0.1519	38.7929	3.0363	0	0	46.2511
84	3.5	45.2914	10.7817	1.7533	0.2072	38.7057	3.2608	0	0	45.2914
90	3.75	44.0251	11.0229	1.6781	0.2683	39.5215	3.4841	0	0	44.0251
96	4	41.8018	11.3601	2.2346	0.3282	40.5691	3.7062	0	0	41.8018

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	4.5	40.1727	11.6421	2.7356	0.4359	40.8665	4.1472	0	0	40.1727
120	5	37.198	12.249	3.0525	0.7373	42.1801	4.583	0	0	37.198
132	5.5	35.0966	12.6791	3.3662	1.0533	42.7921	5.0127	0	0	35.0966
144	6	16.3152	14.9312	4.0291	1.4684	57.8205	5.4356	0	0	16.3152
156	6.5	12.0225	15.4594	4.7118	1.9145	60.0405	5.8514	0	0	12.0225
168	7	8.4086	15.8603	5.3991	2.3904	61.68	6.2616	0	0	8.4086
192	8	3.894	16.3251	6.3345	3.7836	62.6001	7.0628	0	0	3.894
216	9	1.5507	16.5328	7.538	4.914	61.6257	7.8388	0	0	1.5507
240	10	1.2431	16.5605	8.5105	6.1315	58.9621	8.5924	0	0	1.2431
264	11	1.1048	16.5731	8.9653	7.7099	56.3256	9.3213	0	0	1.1048
288	12	0.5901	16.6127	9.0433	9.5248	54.2075	10.0216	0	0	0.5901
336	14	0.098	16.6486	8.9115	13.0574	49.9436	11.3409	0	0	0.098
389	16.208	0	16.6557	11.1149	14.0871	45.442	12.7003	0	0	0
437	18.208	0	16.6557	13.1228	14.5277	41.8105	13.8832	0	0	0
485	20.208	0	16.6557	14.1466	15.5671	38.6133	15.0173	0	0	0
605	25.208	0	16.6557	15.497	18.0361	32.1675	17.6437	0	0	0
725	30.208	0	16.6557	15.3847	20.5815	27.4052	19.973	0	0	0
845	35.208	0	16.6557	14.2243	23.2476	23.8364	22.036	0	0	0
1061	44.208	0	16.6557	11.1957	27.6232	19.3886	25.1368	0	0	0
1181	49.208	0	16.6557	9.7897	29.3299	17.6386	26.5861	0	0	0
1301	54.208	0	16.6557	8.1533	31.0956	16.2273	27.868	0	0	0

Table XXVI.B-10 Outer Coast Sea Lanes - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7989	0.1387	0	0	0	0.0624	0	0	99.7989
4	0.167	99.7306	0.1655	0.0001	0	0	0.1039	0	0	99.7306
6	0.25	99.5497	0.2633	0	0	0	0.187	0	0	99.5497
8	0.333	99.3726	0.3576	0	0	0	0.2698	0	0	99.3726
10	0.417	99.2148	0.4326	0	0	0	0.3525	0	0	99.2148
12	0.5	99.0408	0.524	0	0	0	0.4351	0	0	99.0408
14	0.583	98.8808	0.6016	0	0	0	0.5176	0	0	98.8808
16	0.667	98.72	0.6708	0	0	0	0.5999	0.0093	0	98.72
18	0.75	98.5437	0.7463	0	0	0	0.6821	0.0279	0	98.5437
20	0.833	98.2775	0.8681	0	0	0	0.7641	0.0903	0	98.2775
22	0.917	97.9717	0.9895	0	0	0	0.8459	0.193	0	97.9717
24	1	97.6831	1.0977	0	0	0	0.9274	0.2917	0	97.6831
28	1.167	97.1691	1.2622	0	0	0	1.0898	0.4789	0	97.1691
32	1.333	96.5614	1.4273	0	0	0.1114	1.2513	0.6486	0	96.5614
36	1.5	95.566	1.616	0.01	0	0.5877	1.412	0.8084	0	95.566
40	1.667	94.8621	1.8311	0.0098	0.0001	0.6147	1.5718	1.1103	0	94.8621
44	1.833	90.4342	2.6615	0.0094	0.0001	3.768	1.7303	1.3964	0	90.4342
48	2	63.4036	6.9174	0.2653	0	25.8628	1.8829	1.668	0	63.4036
54	2.25	50.3541	9.0424	0.2525	0.0039	36.4346	2.1105	1.802	0	50.3541
60	2.5	46.7197	9.7275	0.7899	0.01	38.6147	2.3363	1.802	0	46.7197
66	2.75	44.1426	10.233	0.7451	0.043	40.474	2.5604	1.802	0	44.1426
72	3	43.1977	10.5206	1.2832	0.083	40.3304	2.7831	1.802	0	43.1977
78	3.25	41.6963	10.853	1.2102	0.1427	41.2914	3.0043	1.802	0	41.6963
84	3.5	40.9619	11.0471	1.7559	0.1967	41.012	3.2244	1.802	0	40.9619
90	3.75	40.0952	11.2334	1.6808	0.2572	41.4882	3.4432	1.802	0	40.0952
96	4	39.099	11.4266	2.2283	0.3168	41.4663	3.661	1.802	0	39.099

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	4.5	36.8698	11.7783	2.7283	0.4237	42.3047	4.0933	1.802	0	36.8698
120	5	34.3942	12.3263	3.0581	0.7235	43.1753	4.5206	1.802	0	34.3942
132	5.5	31.076	12.9047	3.4201	1.0392	44.8164	4.9416	1.802	0	31.076
144	6	14.5867	14.8855	4.0456	1.4604	57.8638	5.3559	1.802	0	14.5867
156	6.5	10.5465	15.3563	4.6878	1.909	59.9349	5.7635	1.802	0	10.5465
168	7	8.1781	15.6279	5.3205	2.3833	60.5226	6.1657	1.802	0	8.1781
192	8	5.4659	15.9408	6.1178	3.7514	59.9709	6.9512	1.802	0	5.4659
216	9	2.2142	16.2284	7.2188	4.8418	59.9826	7.7122	1.802	0	2.2142
240	10	1.6929	16.2747	8.124	6.006	57.6488	8.4515	1.802	0	1.6929
264	11	1.6007	16.2845	8.5399	7.5108	55.095	9.1671	1.802	0	1.6007
288	12	1.2785	16.3101	8.6016	9.2377	52.915	9.8551	1.802	0	1.2785
336	14	0.2401	16.3857	8.4796	12.5931	49.3462	11.1532	1.802	0	0.2401
384	16	0.186	16.3894	8.5088	15.4218	45.3385	12.3534	1.802	0	0.186
432	18	0.1691	16.3904	8.5308	17.8539	41.7844	13.4694	1.802	0	0.1691
480	20	0.1657	16.3905	8.1628	20.334	38.6423	14.5028	1.802	0	0.1657
612	25.5	0	16.4023	10.3781	22.4862	31.8704	17.0609	1.802	0	0
732	30.5	0	16.4023	11.3082	24.0433	27.2794	19.1647	1.802	0	0
852	35.5	0	16.4023	10.9489	25.9716	23.8264	21.0487	1.802	0	0
1068	44.5	0	16.4023	9.9094	28.4179	19.4976	23.9708	1.802	0	0
1188	49.5	0	16.4023	8.9217	29.715	17.7822	25.3767	1.802	0	0
1308	54.5	0	16.4023	7.617	31.1538	16.3918	26.6331	1.802	0	0

Table XXVI.B-11 Outer Coast Sea Lanes - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7989	0.1387	0	0	0	0.0624	0	0	99.7989
4	0.167	99.7306	0.1655	0.0001	0	0	0.1039	0	0	99.7306
6	0.25	99.5497	0.2633	0	0	0	0.187	0	0	99.5497
8	0.333	99.3726	0.3576	0	0	0	0.2698	0	0	99.3726
10	0.417	99.2148	0.4326	0	0	0	0.3525	0	0	99.2148
12	0.5	99.0408	0.524	0	0	0	0.4351	0	0	99.0408
14	0.583	98.8215	0.6016	0	0	0	0.5176	0.0593	0	98.8215
16	0.667	98.6062	0.6708	0	0	0	0.5998	0.1232	0	98.6062
18	0.75	98.3771	0.7463	0	0	0	0.6819	0.1947	0	98.3771
20	0.833	97.9339	0.8681	0	0	0	0.7638	0.4342	0	97.9339
22	0.917	97.3371	0.9893	0	0	0	0.8452	0.8284	0	97.3371
24	1	96.769	1.0972	0	0	0	0.9261	1.2077	0	96.769
28	1.167	95.7269	1.2599	0	0	0	1.0866	1.9265	0	95.7269
32	1.333	94.6802	1.4162	0	0	0.0801	1.2455	2.578	0	94.6802
36	1.5	93.3748	1.5839	0.0035	0	0.4435	1.4027	3.1916	0	93.3748
40	1.667	92.2565	1.7943	0.0034	0	0.4711	1.5583	3.9163	0	92.2565
44	1.833	88.3281	2.4857	0.0033	0	2.8682	1.7118	4.6029	0	88.3281
48	2	63.4141	6.3597	0.2654	0	22.8466	1.8595	5.2547	0	63.4141
54	2.25	48.0379	8.8231	0.2527	0.0042	35.2272	2.0784	5.5764	0	48.0379
60	2.5	45.235	9.3781	0.8387	0.0108	36.6659	2.2952	5.5764	0	45.235
66	2.75	42.0406	9.9742	0.7913	0.0467	39.0605	2.5103	5.5764	0	42.0406
72	3	41.1205	10.2521	1.3812	0.0902	38.8556	2.724	5.5764	0	41.1205
78	3.25	40.2476	10.49	1.3027	0.1555	39.2914	2.9364	5.5764	0	40.2476
84	3.5	39.7774	10.6473	1.8751	0.215	38.7612	3.1476	5.5764	0	39.7774
90	3.75	38.5872	10.875	1.7947	0.281	39.5281	3.3575	5.5764	0	38.5872

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	37.9252	11.0219	2.3759	0.3458	39.1884	3.5664	5.5764	0	37.9252
108	4.5	36.586	11.2631	2.892	0.4626	39.2387	3.9812	5.5764	0	36.586
120	5	34.5055	11.7561	3.2039	0.7835	39.7834	4.3911	5.5764	0	34.5055
132	5.5	31.8805	12.2518	3.5333	1.1176	40.8454	4.7949	5.5764	0	31.8805
144	6	15.8888	14.1826	4.1149	1.5563	53.489	5.1921	5.5764	0	15.8888
156	6.5	12.0978	14.6396	4.7152	2.016	55.3725	5.5825	5.5764	0	12.0978
168	7	9.3888	14.9502	5.3066	2.4959	56.3145	5.9675	5.5764	0	9.3888
192	8	6.2986	15.3022	6.0465	3.8601	56.1971	6.7191	5.5764	0	6.2986
216	9	3.5998	15.5482	7.0907	4.9401	55.7982	7.4467	5.5764	0	3.5998
240	10	3.2718	15.5815	7.9364	6.0857	53.3952	8.1531	5.5764	0	3.2718
264	11	3.0829	15.6015	8.3157	7.5575	51.0295	8.8365	5.5764	0	3.0829
288	12	2.83	15.6237	8.3616	9.2412	48.8739	9.4931	5.5764	0	2.83
336	14	1.073	15.7525	8.2509	12.5062	46.1098	10.7312	5.5764	0	1.073
384	16	0.2796	15.8097	8.38	15.2723	42.8072	11.8748	5.5764	0	0.2796
432	18	0.1618	15.8179	8.4812	17.6795	39.3468	12.9364	5.5764	0	0.1618
480	20	0.1586	15.818	8.1665	20.1541	36.2096	13.9169	5.5764	0	0.1586
613	25.542	0	15.8293	10.1467	22.6687	29.4313	16.3477	5.5764	0	0
733	30.542	0	15.8293	11.2725	24.0896	24.9152	18.317	5.5764	0	0
853	35.542	0	15.8293	10.9377	26.0317	21.5476	20.0772	5.5764	0	0
1069	44.542	0	15.8293	9.9243	28.4927	17.3837	22.7936	5.5764	0	0
1189	49.542	0	15.8293	8.9526	29.785	15.7611	24.0956	5.5764	0	0
1309	54.542	0	15.8293	7.5979	31.2839	14.4617	25.2508	5.5764	0	0

Table XXVI.B-12 Outer Coast Sea Lanes - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7989	0.1387	0	0	0	0.0624	0	0	99.7989
4	0.167	99.7306	0.1655	0.0001	0	0	0.1039	0	0	99.7306
6	0.25	99.5227	0.2633	0	0	0	0.1869	0.0271	0	99.5227
8	0.333	99.3212	0.3576	0	0	0	0.2698	0.0515	0	99.3212
10	0.417	99.1409	0.4326	0	0	0	0.3525	0.074	0	99.1409
12	0.5	98.946	0.524	0	0	0	0.435	0.095	0	98.946
14	0.583	98.7267	0.6016	0	0	0	0.5174	0.1543	0	98.7267
16	0.667	98.5115	0.6707	0	0	0	0.5995	0.2182	0	98.5115
18	0.75	98.2826	0.7461	0	0	0	0.6815	0.2897	0	98.2826
20	0.833	97.8396	0.8679	0	0	0	0.7633	0.5293	0	97.8396
22	0.917	97.2429	0.989	0	0	0	0.8447	0.9234	0	97.2429
24	1	96.6751	1.0967	0	0	0	0.9255	1.3027	0	96.6751
28	1.167	95.6335	1.2591	0	0	0	1.0859	2.0215	0	95.6335
32	1.333	94.6195	1.4103	0	0	0.0526	1.2446	2.6731	0	94.6195
36	1.5	93.1763	1.5969	0.0086	0	0.5299	1.4016	3.2867	0	93.1763
40	1.667	92.0717	1.8048	0.0084	0.0001	0.5466	1.5571	4.0114	0	92.0717
44	1.833	88.2297	2.4845	0.0081	0.0001	2.8692	1.7106	4.6979	0	88.2297
48	2	57.3105	7.2593	0.2774	0	27.9454	1.8577	5.3497	0	57.3105
54	2.25	47.2245	8.8977	0.264	0.0044	35.862	2.076	5.6714	0	47.2245
60	2.5	45.6263	9.2775	0.7523	0.0117	36.3682	2.2926	5.6714	0	45.6263
66	2.75	43.7453	9.6899	0.7093	0.0435	37.6327	2.5078	5.6714	0	43.7453
72	3	42.9492	9.9554	1.1998	0.082	37.4206	2.7217	5.6714	0	42.9492
78	3.25	41.8248	10.2323	1.1314	0.138	38.0679	2.9341	5.6714	0	41.8248
84	3.5	41.3638	10.3928	1.6175	0.1887	37.6203	3.1455	5.6714	0	41.3638
90	3.75	40.59	10.5686	1.5481	0.2447	38.0215	3.3557	5.6714	0	40.59

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	39.4688	10.7798	2.0485	0.2996	38.167	3.5648	5.6714	0	39.4688
108	4.5	37.4511	11.1116	2.5137	0.398	38.8742	3.9801	5.6714	0	37.4511
120	5	34.3827	11.7264	2.8304	0.674	40.3247	4.3904	5.6714	0	34.3827
132	5.5	31.7472	12.2205	3.1627	0.966	41.4373	4.7948	5.6714	0	31.7472
144	6	13.8845	14.3695	3.8031	1.355	55.7239	5.1927	5.6714	0	13.8845
156	6.5	9.7298	14.8615	4.4624	1.7754	57.9156	5.5839	5.6714	0	9.7298
168	7	8.0093	15.0709	5.0922	2.2258	57.9604	5.9699	5.6714	0	8.0093
192	8	5.2982	15.3768	5.8898	3.5368	57.503	6.724	5.6714	0	5.2982
216	9	3.176	15.569	6.9392	4.5871	56.6028	7.4544	5.6714	0	3.176
240	10	2.6515	15.6164	7.7968	5.707	54.3929	8.1641	5.6714	0	2.6515
264	11	2.4801	15.6337	8.189	7.1517	52.0231	8.8509	5.6714	0	2.4801
288	12	2.206	15.6567	8.2496	8.8086	49.8964	9.5113	5.6714	0	2.206
336	14	0.9985	15.745	8.1464	12.0297	46.6517	10.7573	5.6714	0	0.9985
384	16	0.1708	15.8044	8.2314	14.7525	43.46	11.9094	5.6714	0	0.1708
432	18	0.1573	15.8052	8.3126	17.1125	39.9606	12.9803	5.6714	0	0.1573
480	20	0.1542	15.8052	7.9913	19.5341	36.8727	13.9711	5.6714	0	0.1542
613	25.542	0	15.8163	9.9093	21.9852	30.1846	16.4332	5.6714	0	0
733	30.542	0	15.8163	11.0021	23.3656	25.7131	18.4315	5.6714	0	0
853	35.542	0	15.8163	10.6722	25.2544	22.3641	20.2216	5.6714	0	0
1069	44.542	0	15.8163	9.6812	27.6444	18.1935	22.9932	5.6714	0	0
1189	49.542	0	15.8163	8.733	28.8993	16.554	24.326	5.6714	0	0
1309	54.542	0	15.8163	7.4116	30.3561	15.2325	25.5121	5.6714	0	0

Table XXVI.B-13 Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	917	5,563	392
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	916	5,563	390
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	3,134	1,312	2,355
Shoreline length (km) oiled by > 100 g/m^2	3,014	1,293	2,295
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	727,270	172,790	371,730
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,406,600	1,138,800	1,983,100
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	363.6	104.6	273.2

Table XXVI.B-14 Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	902	5,222	369
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	887	5,091	368
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	3,071	1,432	1,932
Shoreline length (km) oiled by > 100 g/m^2	2,882	1,425	1,872
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	659,060	207,180	270,270
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,411,700	1,224,900	1,661,700
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	361.1	113.8	216.9

Table XXVI.B-15 Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	876	5,654	376
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	863	5,615	376
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	2,457	1,484	2,270
Shoreline length (km) oiled by > 100 g/m^2	2,390	1,480	2,270
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	456,140	241,290	213,150
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,000,800	1,242,500	2,057,300
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	288.4	116.9	271.6

Table XXVI.B-16 Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	818	5,315	355
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	808	5,222	354
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	3,112	1,434	2,311
Shoreline length (km) oiled by > 100 g/m^2	3,084	1,414	2,252
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	721,300	324,560	507,300
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	2,391,000	1,109,800	1,804,100
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	370.1	107.0	259.3

XXVI.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 XXVI.C-1 Outer Coast Sea Lanes - Bunker C, 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)	12,645	25,448	153	34,325	-	2	21	11	72,605	72,571	34
Worst run for the Olympia Coast National Marine Sanctuary	205,840	99,125	31	5,256	-	9	56	44	310,360	310,252	108
Worst run for the GRPs	-	17,102	109	23,783	-	1	17	7	41,020	40,994	26

Table XXVI.C-2 Outer Coast Sea Lanes - Bunker C, 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)	11,457	24,994	132	29,392	-	2	21	11	66,009	65,976	34
Worst run for the Olympia Coast National Marine Sanctuary	186,197	91,634	38	7,002	-	9	52	40	284,972	284,872	101
Worst run for the GRPs	-	16,740	81	17,148	-	1	17	7	33,995	33,969	25

Table XXVI.C-3 Outer Coast Sea Lanes - Bunker C, 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)	10,429	24,602	105	22,910	-	2	21	10	58,079	58,046	33
Worst run for the Olympia Coast National Marine Sanctuary	208,011	99,953	41	7,728	-	9	56	44	315,842	315,733	109
Worst run for the GRPs	-	16,868	98	21,330	-	1	17	7	38,322	38,297	26

Table XXVI.C-4 Outer Coast Sea Lanes - Bunker C, 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)	8,147	23,732	139	30,986	-	2	21	10	63,037	63,004	32
Worst run for the Olympia Coast National Marine Sanctuary	191,671	93,721	37	6,856	-	9	53	41	292,388	292,285	103
Worst run for the GRPs	-	16,516	93	20,019	-	1	17	7	36,653	36,628	25

XXVI.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 XXVI.D-1. Outer Coast Sea Lanes - Bunker C, 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)	-	76.30	18.33	-	-	30,341	30,435
Worst run for the Olympia Coast National Marine Sanctuary	-	67.73	16.27	-	-	9,556	9,640
Worst run for the GRPs	-	115.04	27.64	-	-	23,296	23,438

Table XXVI.D-2. Outer Coast Sea Lanes - Bunker C, 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)	-	75.28	18.08	-	-	28,844	28,938
Worst run for the Olympia Coast National Marine Sanctuary	-	67.99	16.33	-	-	10,481	10,565
Worst run for the GRPs	-	91.65	22.02	-	-	18,936	19,050

Table XXVI.D-3. Outer Coast Sea Lanes - Bunker C, 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)	-	70.79	17.01	-	-	23,868	23,955
Worst run for the Olympia Coast National Marine Sanctuary	-	66.70	16.02	-	-	11,538	11,620
Worst run for the GRPs	-	91.51	21.98	-	-	23,119	23,233

Table XXVI.D-4. Outer Coast Sea Lanes - Bunker C, 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)	-	72.59	17.44	-	-	31,046	31,136
Worst run for the Olympia Coast National Marine Sanctuary	-	65.57	15.75	-	-	10,833	10,914
Worst run for the GRPs	-	89.95	21.61	-	-	22,988	23,099

XXVI.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 XXVI.E-1. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	76	68	115
Demersal fish	18	16	28
Decapods	-	-	-
Molluscs	30,341	9,556	23,296
Birds:			
Waterfowl (# * kg each)	13,804	224,708	-
Seabirds (# * kg each)	13,127	51,132	8,822
Waders (# * kg each)	79	16	56
Shorebirds (# * kg each)	17,706	2,711	12,268
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	6	22	4
Pinnipeds	11	29	9
Cetaceans	1	5	1
Totals:			
Subtotal fish and invertebrates	30,435	9,640	23,438
Subtotal birds	44,716	278,568	21,146
Subtotal other wildlife	18	56	13
Total all species	75,169	288,263	44,598

Table XXVI.E-2. Outer Coast Sea Lanes - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Saltmarsh Area (ha)	122	586	72
Saltmarsh Area (acres)	302	1,448	178
Saltmarsh Cost (millions of 2004$)	56.6	271.4	33.4
Eelgrass Area (m2)	76	366	45
Eelgrass Area (acres)	189	905	111
Eelgrass Cost (millions of 2004$)	22.5	108.1	13.3

Table XXVI.E-3. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	75	68	92
Demersal fish	18	16	22
Decapods	-	-	-
Molluscs	28,844	10,481	18,936
Birds:			
Waterfowl (# * kg each)	12,507	203,266	-
Seabirds (# * kg each)	12,893	47,268	8,635
Waders (# * kg each)	68	20	42
Shorebirds (# * kg each)	15,161	3,612	8,846
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	5	21	4
Pinnipeds	11	27	9
Cetaceans	1	4	1
Totals:			
Subtotal fish and invertebrates	28,938	10,565	19,050
Subtotal birds	40,630	254,165	17,522
Subtotal other wildlife	17	52	13
Total all species	69,585	264,782	36,585

Table XXVI.E-4. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Saltmarsh Area (ha)	116	538	66
Saltmarsh Area (acres)	287	1,330	163
Saltmarsh Cost (millions of 2004$)	53.7	249.1	30.6
Eelgrass Area (m2)	72	336	41
Eelgrass Area (acres)	179	831	102
Eelgrass Cost (millions of 2004$)	21.4	99.2	12.2

Table XXVI.E-5. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	71	67	92
Demersal fish	17	16	22
Decapods	-	-	-
Molluscs	23,868	11,538	23,119
Birds:			
Waterfowl (# * kg each)	11,385	227,078	-
Seabirds (# * kg each)	12,691	51,559	8,701
Waders (# * kg each)	54	21	51
Shorebirds (# * kg each)	11,818	3,986	11,003
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	5	23	4
Pinnipeds	11	29	9
Cetaceans	1	5	1
Totals:			
Subtotal fish and invertebrates	23,955	11,620	23,233
Subtotal birds	35,947	282,645	19,755
Subtotal other wildlife	17	56	13
Total all species	59,920	294,322	43,001

Table XXVI.E-6. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Saltmarsh Area (ha)	109	593	70
Saltmarsh Area (acres)	268	1,466	172
Saltmarsh Cost (millions of 2004$)	50.3	274.7	32.3
Eelgrass Area (m2)	68	371	44
Eelgrass Area (acres)	168	916	108
Eelgrass Cost (millions of 2004$)	20.0	109.4	12.8

Table XXVI.E-7. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	73	66	90
Demersal fish	17	16	22
Decapods	-	-	-
Molluscs	31,046	10,833	22,988
Birds:			
Waterfowl (# * kg each)	8,894	209,240	-
Seabirds (# * kg each)	12,242	48,345	8,519
Waders (# * kg each)	72	19	48
Shorebirds (# * kg each)	15,984	3,536	10,327
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	5	21	4
Pinnipeds	11	27	9
Cetaceans	1	4	1
Totals:			
Subtotal fish and invertebrates	31,136	10,914	23,099
Subtotal birds	37,191	261,141	18,894
Subtotal other wildlife	17	53	13
Total all species	68,344	272,108	42,006

Table XXVI.E-8. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Saltmarsh Area (ha)	109	552	68
Saltmarsh Area (acres)	269	1,363	167
Saltmarsh Cost (millions of 2004$)	50.4	255.5	31.4
Eelgrass Area (m2)	68	345	42
Eelgrass Area (acres)	168	852	105
Eelgrass Cost (millions of 2004$)	20.1	101.7	12.5

XXVI.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 XXVI.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XXVI.F-1. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Vulnerability Score ($/gal.)	31.16	28.07	30.44
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	196.3	176.8	191.8

Table XXVI.F-2. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Vulnerability Score ($/gal.)	31.01	28.05	30.42
% Removed by 24 hours	0.4	0.4	0.3
Compensation (millions $)	194.5	176.0	191.1

Table XXVI.F-3. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Vulnerability Score ($/gal.)	31.13	28.05	30.46
% Removed by 24 hours	2.2	2.0	1.2
Compensation (millions $)	191.8	173.3	189.6

Table XXVI.F-4. Outer Coast Sea Lanes - Bunker C, 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 the Olympia Coast National Marine Sanctuary	Worst run for the GRPs
Vulnerability Score ($/gal.)	30.98	28.06	30.45
% Removed by 24 hours	2.5	2.5	1.3
Compensation (millions $)	190.3	172.4	189.3

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 XXVII: Model Inputs for Grays Harbor – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXVII.A. Introduction 1
XXVII.B. Geographical Data 2
XXVII.B.1. Maps of the Vicinity of the Modeled Spill Locations 2
XXVII.B.2. Gridded Habitat Mapping 3
XXVII.B-3. Gridded Depth Data 4
XXVII.B-4. Areas Where Response Actions Assumed 5
XXVII.C. Current Data 7
XXVII.C.1. Basis of Current Data 7
XXVII.C.2. Current Vector Plots for Current Data Used in the Oil Spill Simulations 9
XXVII.D: Oil Properties 12
XXVII.E: Inputs to the SIMAP Physical Fates Model 15

List of Figures

Figure XXVII.B.1-1 Map of the vicinity of the potential spill locations. 2
Figure XXVII.B.2-1 Habitat grid used for modeling the potential spills. 3
Figure XXVII.B.2-2 Habitat grid used for modeling the potential spills (closer view). 3
Figure XXVII.B.3-1 Depth grid used for modeling the potential spills. 4
Figure XXVII.B.3-2 Depth grid used for modeling the potential spills (closer view). 4
Figure XXVII.B.4-1 Jurisdictions in the area of the potential spills. 5
Figure XXVII.B.4-2 Areas where protection booming was assumed to occur in modeling the potential spills. 5
Figure XXVII.B.4-3 Areas where protection booming was assumed to occur in modeling the potential spills (closer view). 6
Figure XXVII.B.4-4 Areas where mechanical removal was assumed to occur in modeling the potential spills. 6
Figure XXVII.C.1-1 Grid used for the hydrodynamic model-generated current data..... 8
Figure XXVII.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – Grays Harbor)..... 8
Figure XXVII.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 Grays Harbor. 9
Figure XXVII.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 Grays Harbor. 10
Figure XXVII.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 Grays Harbor. 10
Figure XXVII.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 Grays Harbor. 11
Figure XXIV.E-1. Varied range of spill site, from 3 miles outside entrance of Gray's Harbor to entrance of Gray's Harbor. 18
Figure XXVII.E-1. Wind Station Locations. 22

List of Tables

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

XXVII.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.

XXVII.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.

XXVII.B.1. Maps of the Vicinity of the Modeled Spill Locations

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

XXVII.B.2. Gridded Habitat Mapping

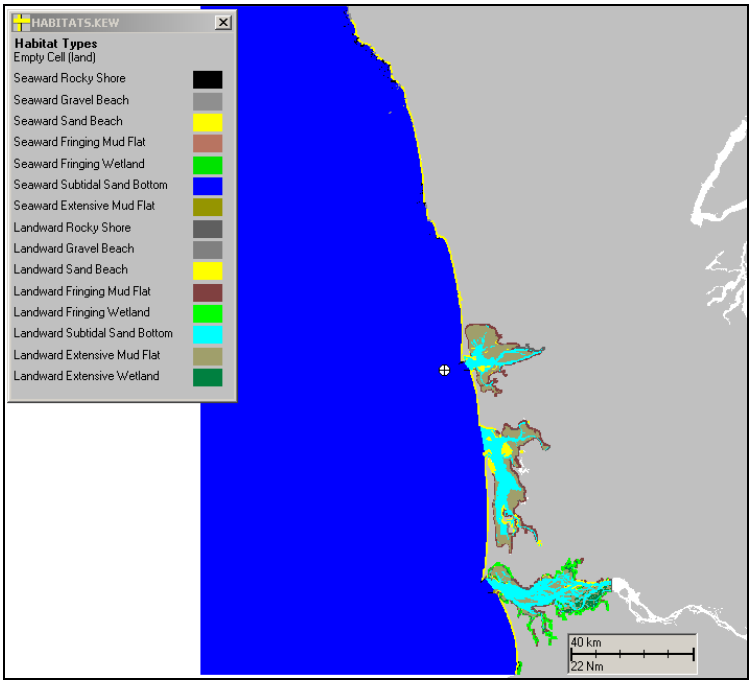


Figure XXVII.B.2-1 Habitat grid used for modeling the potential spills.

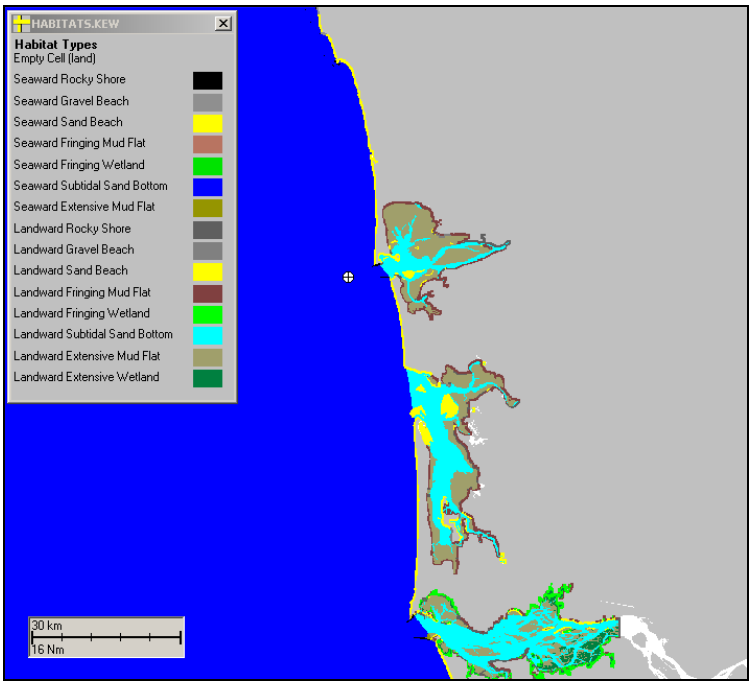


Figure XXVII.B.2-2 Habitat grid used for modeling the potential spills (closer view).

XXVII.B-3. Gridded Depth Data

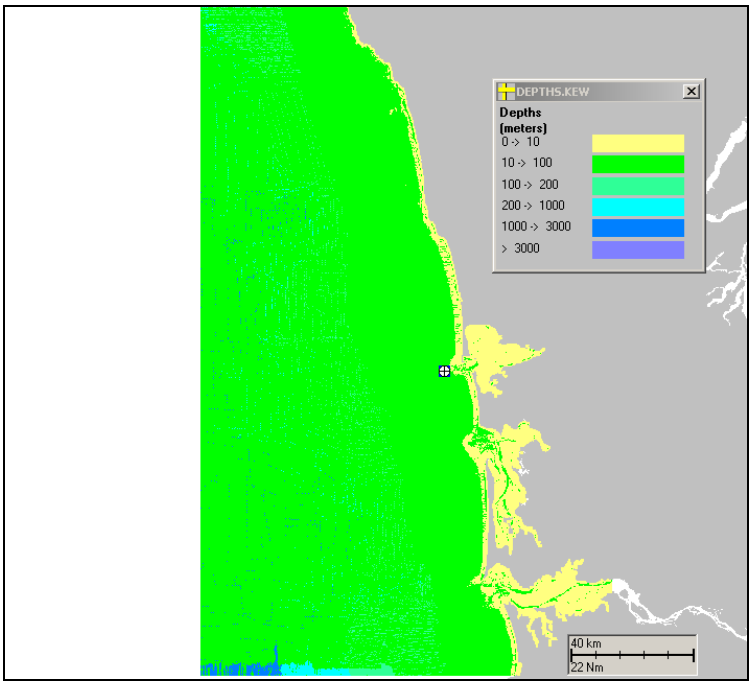


Figure XXVII.B.3-1 Depth grid used for modeling the potential spills.

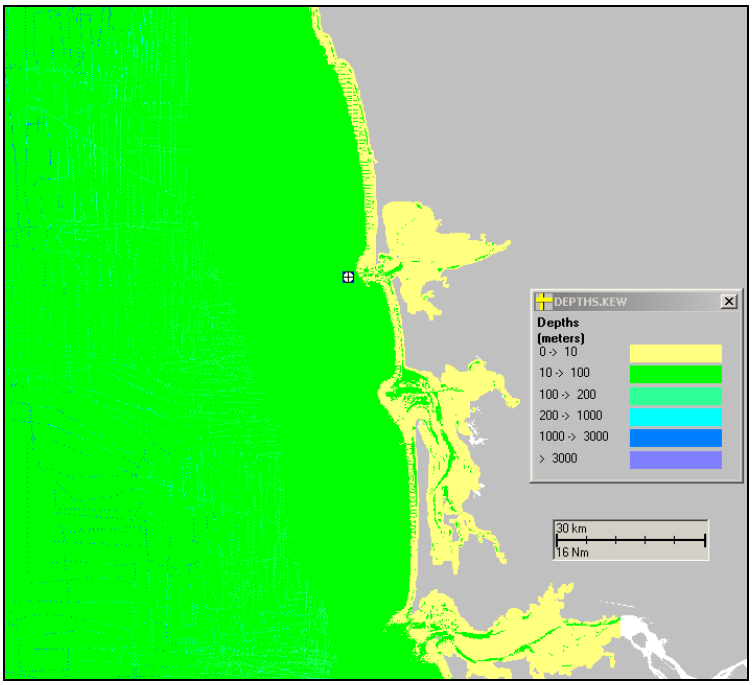


Figure XXVII.B.3-2 Depth grid used for modeling the potential spills (closer view).

XXVII.B-4. Areas Where Response Actions Assumed

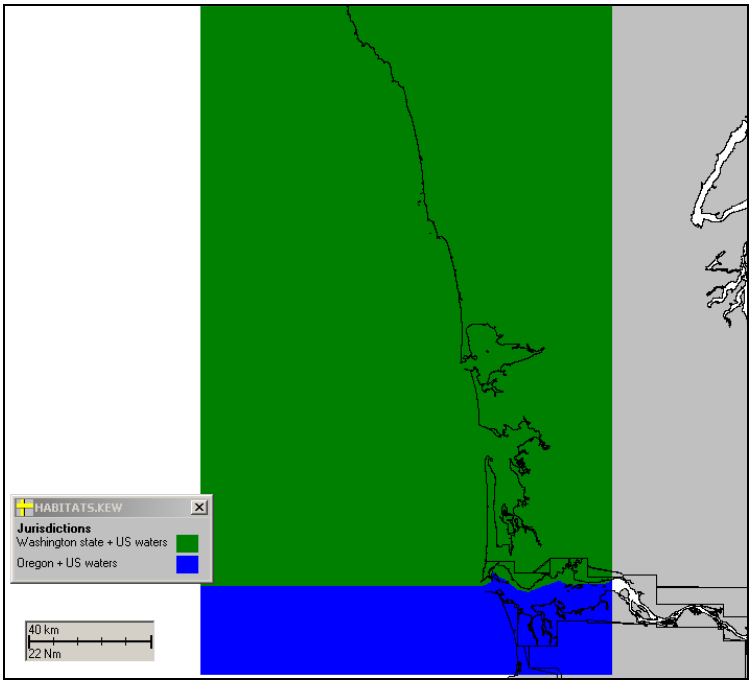


Figure XXVII.B.4-1 Jurisdictions in the area of the potential spills.

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

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

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

XXVII.C. CURRENT DATA

XXVII.C.1. Basis of Current Data

A 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, the 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 22200 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).

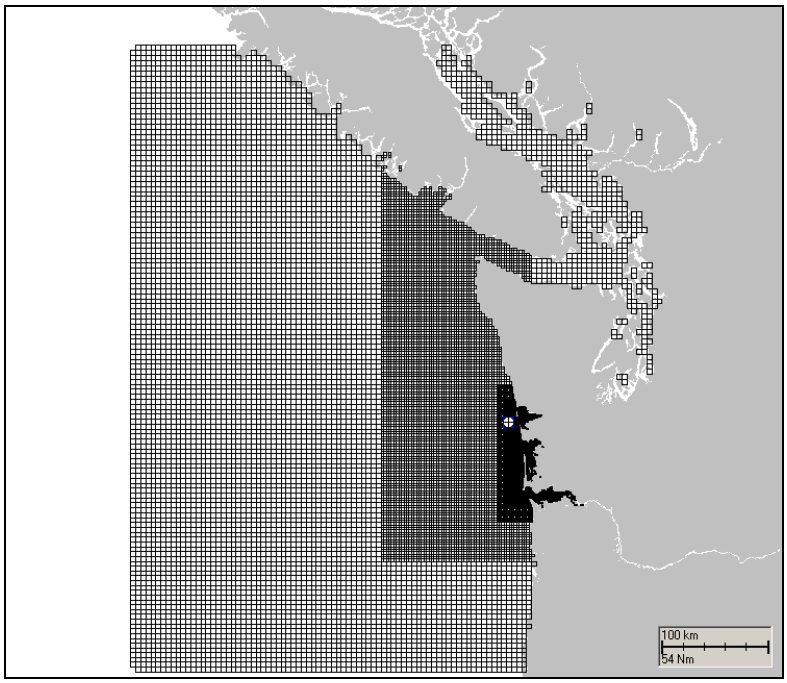


Figure XXVII.C.1-1 Grid used for the hydrodynamic model-generated current data.

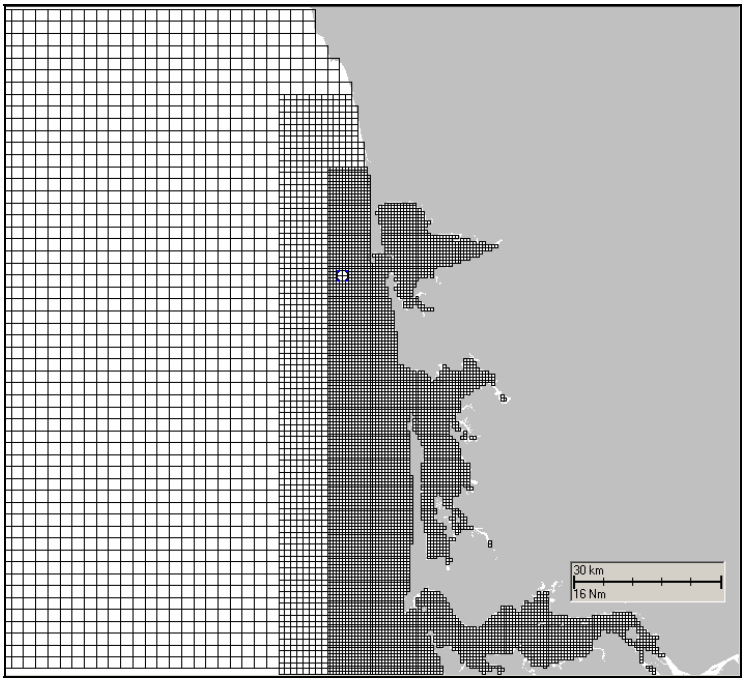


Figure XXVII.C.1-1 Grid used for the hydrodynamic model-generated current data (closer view – Grays Harbor).

XXVII.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.

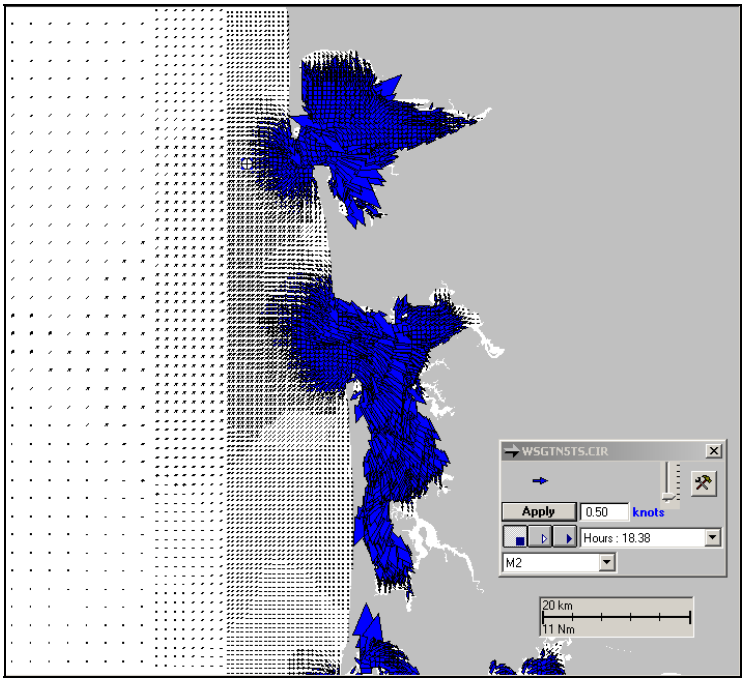


Figure XXVII.C.2-1 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the M_2 component at Grays Harbor.

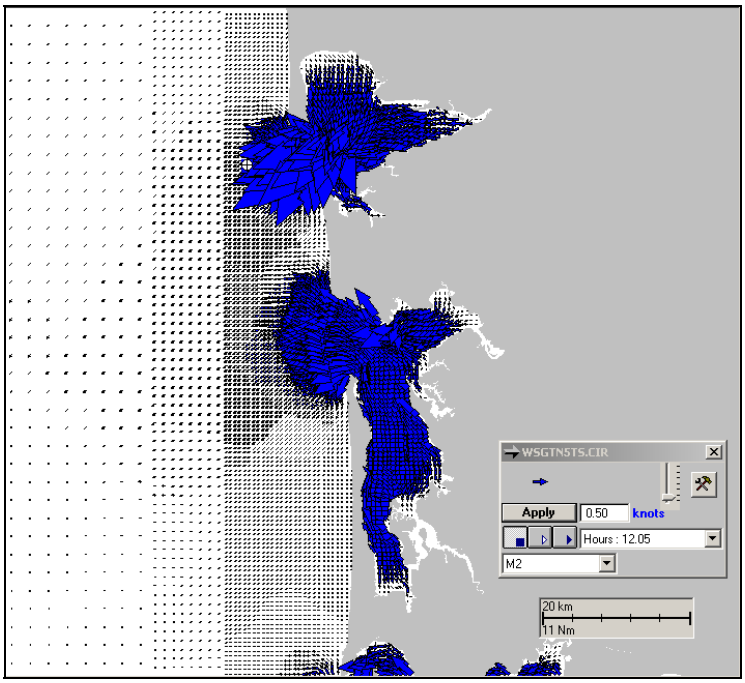


Figure XXVII.C.2-2 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the M_2 component at Grays Harbor.

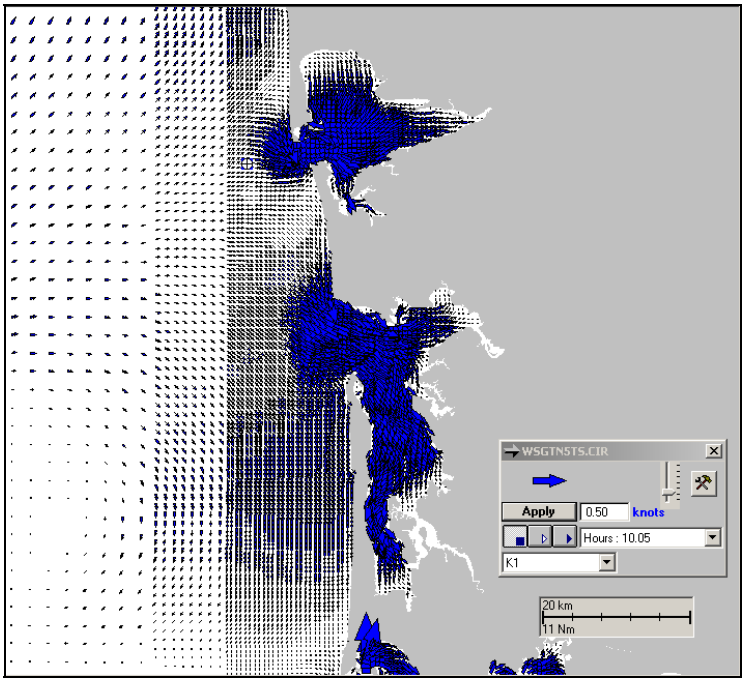


Figure XXVII.C.2-3 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum flood tide for the K_1 component at Grays Harbor.

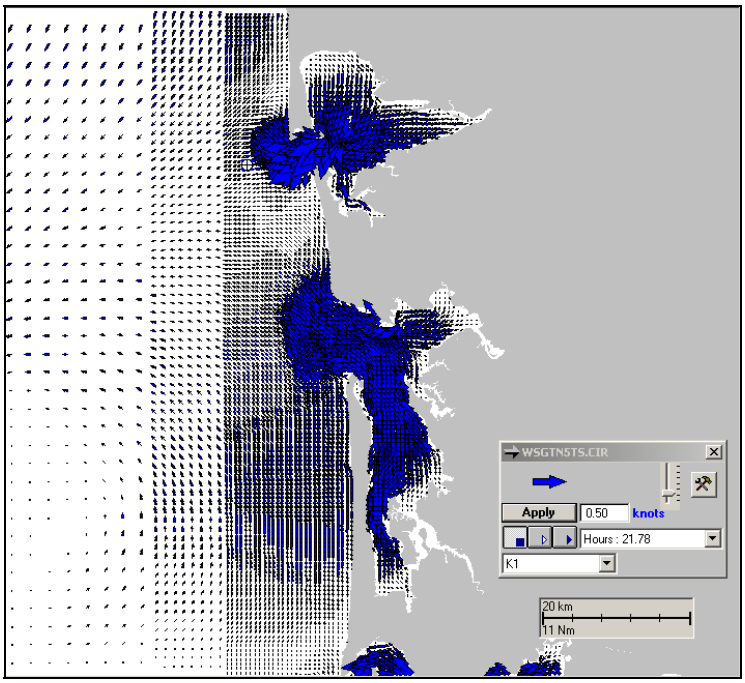


Figure XXVII.C.2-4 Current component data used in modeling. Vector length indicates speed in the indicated direction. This represents maximum ebb tide for the K_1 component at Grays Harbor.

XXVII.D: OIL PROPERTIES

Table XXVII.D-1. Oil properties for Bunker C oil assumed in the modeling.

Property	Value	Reference
Density @ 25 deg. C (g/cm3)	0.9749	Jokuty et al. (1999)
Viscosity @ 25 deg. C (cp)	3180	Jokuty et al. (1999)
Surface Tension (dyne/cm)	27	Jokuty et al. (1999)
Pour Point (deg. C)	7	Whiticar et al. (1994)
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)	0.00	Ostazeski et al. (1997)
Fraction polynuclear aromatic hydrocarbons (PAHs)	0.036093	Ostazeski et al. (1997)
Fraction 2-ring aromatics (included in PAHs above)	0.011987	Ostazeski et al. (1997)
Fraction 3-ring aromatics (included in PAHs above)	0.024106	Ostazeski et al. (1997)
Fraction Non-Aromatic Volatiles: boiling point < 180°C	0.010000	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 180-264°C	0.037013	Jokuty et al. (1999)[1]
Fraction Non-Aromatic Volatiles: boiling point 264-380°C	0.088894	Jokuty et al. (1999)[1]
Minimum Oil Thickness (m)	0.00005	McAuliffe (1987)
Maximum Mousse Water Content (%)	30	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] – Jokuty 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 XXVII.D-2. Aromatic concentrations (mg/kg) for Bunker C 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 XXVII.D-2. Aromatic concentrations (mg/kg) for Bunker C (continued).

Aromatic	Log(Kow)*	Concentration (mg/kg)
dibenzothiophene	4.49	346
C1-dibenzothiophene	4.86	1,072
C2-dibenzothiophene	5.50	1,489
C3-dibenzothiophene	5.73	1,176
phenanthrene	4.57	743
anthracene	4.54	88
C1-phenanthrenes/anthracenes	5.14	2,031
C2-phenanthrenes/anthracenes	5.25	2,661
C3-phenanthrenes/anthracenes	6.00	1,825
C4-phenanthrenes/anthracenes	6.51	930
fluoranthene	5.22	0.0
pyrene	5.18	0.0
Total $\log(K_{ow}) \leq 5.6$	-	32,162.3

*Estimates of $\log(K_{ow})$ are from Mackay et al. (1992a,b) and Neff and Burns (1996).

XXVII.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 XXVII.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	Gray's Harbor
Spill Latitude	Latitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXVII.E-1)
Spill Longitude	Longitude of the spill site	Degrees	Washington DOE	Varied (see Figure XXVII.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	25,000 bbl
Model time step	Time step used for model calculations	Hours	-	0.25
Model duration	Length of each model simulation	Days	-	56 days

Table XXVII.E-1. Inputs to the Fates Model for Stochastic Scenarios (continued).

Name	Description	Units	Source(s) of Information	Value(s)
Number of runs	Number of random start times to run in stochastic mode	#	-	100
Initial number of surface spillets	Initial number of Lagrangian elements used to simulate mass floating on the surface	#	-	160
Number of aromatic spillets	Number of Lagrangian elements used to simulate dissolved aromatics in the water	#	-	2,000
Fates Output Threshold: floating on water surface	Slick or surface mass thickness passing through a grid cell	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: shoreline	Total hydrocarbons deposited on shorelines, averaged over each habitat grid cell.	g/m^2 (microns)	Minimum value for sheens	0.01
Fates Output Threshold: dissolved aromatics in water or sediment	Dissolved concentration of aromatics with $\log(K_{ow}) \leq 5.6$ (bioavailable fraction)	mg/m^3 = μg/L = ppb	Below minimum for effects to sensitive species exposed for at least two weeks	1
Fates Output Threshold: Subsurface (water) total hydrocarbons	Concentration of total hydrocarbons in droplets	mg/m^3 = μg/L = ppb	Minimum value with no potential for impact	10
Fates Output Threshold: Sediment total hydrocarbons	Total hydrocarbon loading to sediments, averaged over each habitat grid cell.	g/m^2	Minimum value with no potential for impact	0.0001 g/m^2 (which is 1.0 mg/m^3 = 1ppb averaged over the top 10cm)

Table XXVII.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 49	32
Surface Water Temperature	Water temperature at the sea surface	Degrees C	French et al. (1996b) province 49	monthly means (see Table XXVII.E-4)
Subsurface Water Temperature	Water temperature for subsurface	Degrees C	French et al. (1996b) province 49	monthly means (see Table XXVII.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

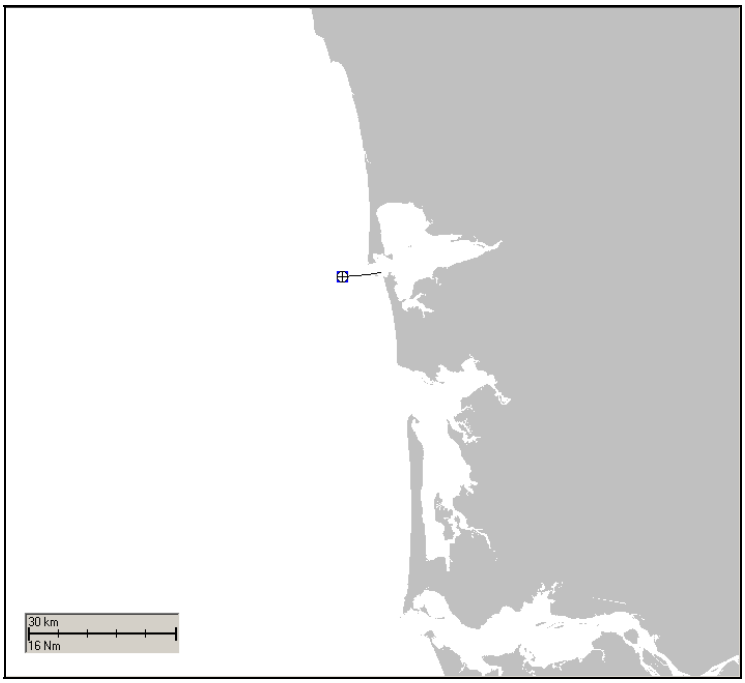


Figure XXIV.E-1. Varied range of spill site, from 3 miles outside entrance of Gray's Harbor to entrance of Gray's Harbor.

Table XXVII.E-2. Time, date and location inputs for each of the 100 stochastic runs.

Run #	Year	Month	Day	Hour	Latitude (° N)	Longitude (° W)
1	1987	11	26	14	46.9109	124.1626
2	2003	4	7	3	46.9057	124.2259
3	1993	4	16	9	46.9075	124.2015
4	1989	7	19	9	46.9121	124.1518
5	2004	6	1	9	46.9053	124.2308
6	1988	9	2	17	46.9117	124.1552
7	1991	7	7	6	46.9087	124.1852
8	1992	9	9	6	46.9077	124.1995
9	1990	6	14	4	46.9081	124.1934
10	1988	5	4	6	46.9070	124.2084
11	1988	8	2	20	46.9061	124.2210
12	1993	11	29	19	46.9059	124.2237
13	2004	2	5	3	46.9129	124.1442
14	2000	10	18	11	46.9044	124.2430
15	1997	2	19	5	46.9079	124.1959
16	2003	1	15	10	46.9082	124.1919
17	1988	7	15	11	46.9074	124.2024
18	1995	6	13	12	46.9064	124.2163
19	1996	3	18	12	46.9065	124.2150
20	1987	7	10	20	46.9045	124.2417
21	1995	11	25	12	46.9079	124.1960
22	1996	6	29	12	46.9066	124.2133
23	1995	12	1	20	46.9065	124.2153
24	1992	3	29	14	46.9079	124.1963
25	2003	10	15	22	46.9086	124.1875
26	1994	5	11	17	46.9050	124.2352
27	1990	3	3	2	46.9058	124.2240
28	1995	6	3	3	46.9084	124.1902
29	2002	7	21	12	46.9068	124.2115
30	1991	6	17	1	46.9075	124.2012
31	2004	9	1	18	46.9089	124.1832
32	1988	4	8	23	46.9053	124.2314
33	2003	8	26	6	46.9090	124.1822
34	1989	9	8	8	46.9114	124.1587
35	2004	2	10	16	46.9053	124.2312
36	2000	1	4	12	46.9060	124.2225
37	1992	12	16	1	46.9093	124.1782
38	2000	8	26	15	46.9099	124.1721
39	1988	9	26	7	46.9056	124.2271
40	2002	7	15	17	46.9091	124.1797
41	2004	7	4	16	46.9089	124.1829
42	2001	10	1	5	46.9130	124.1439
43	2003	1	24	0	46.9063	124.2184
44	1987	9	29	0	46.9046	124.2402
45	1994	7	10	8	46.9089	124.1832
46	1988	3	18	22	46.9069	124.2101
47	1998	7	16	17	46.9090	124.1814
48	1988	3	3	13	46.9091	124.1807
49	1993	1	4	2	46.9089	124.1827
50	1998	8	4	5	46.9073	124.2044

51	2001	9	16	13	46.9115	124.1571
52	1987	12	17	4	46.9119	124.1537
53	2003	10	3	10	46.9102	124.1689
54	2004	8	19	11	46.9064	124.2168
55	1992	2	10	22	46.9121	124.1516
56	2000	4	7	22	46.9114	124.1579
57	1987	10	15	5	46.9057	124.2258
58	2001	10	16	0	46.9092	124.1794
59	1993	2	10	5	46.9075	124.2015
60	1989	8	15	6	46.9129	124.1444
61	1999	8	4	5	46.9095	124.1753
62	1993	2	11	8	46.9073	124.2041
63	2003	7	12	18	46.9058	124.2247
64	1996	8	29	0	46.9127	124.1463
65	1988	1	1	17	46.9114	124.1585
66	2001	4	13	4	46.9122	124.1512
67	1991	8	8	20	46.9108	124.1634
68	2003	11	16	20	46.9124	124.1488
69	1999	12	26	12	46.9068	124.2116
70	2001	8	20	12	46.9078	124.1977
71	1999	7	29	8	46.9078	124.1978
72	2003	11	9	11	46.9100	124.1711
73	2004	10	9	4	46.9123	124.1500
74	1987	7	14	20	46.9044	124.2440
75	1992	10	12	7	46.9103	124.1681
76	2003	10	13	18	46.9054	124.2297
77	1990	4	11	0	46.9046	124.2406
78	2000	4	6	1	46.9091	124.1801
79	2002	12	24	15	46.9073	124.2042
80	1998	9	29	22	46.9104	124.1671
81	2004	7	21	9	46.9046	124.2407
82	1996	3	19	13	46.9109	124.1627
83	1992	5	20	5	46.9052	124.2326
84	2000	3	23	5	46.9129	124.1443
85	1995	6	27	0	46.9106	124.1657
86	1991	3	14	5	46.9106	124.1659
87	1991	8	4	16	46.9127	124.1465
88	2002	7	29	15	46.9063	124.2180
89	2000	3	5	19	46.9115	124.1576
90	1994	3	21	11	46.9087	124.1853
91	1992	5	3	0	46.9058	124.2240
92	1992	3	7	22	46.9079	124.1968
93	1990	4	17	16	46.9074	124.2027
94	1988	1	24	10	46.9123	124.1500
95	1992	4	20	17	46.9113	124.1590
96	1990	9	22	1	46.9108	124.1636
97	2004	7	24	13	46.9100	124.1710
98	1990	4	7	13	46.9052	124.2331
99	2004	5	3	10	46.9115	124.1574
100	2001	11	17	0	46.9089	124.1834

Table XXVII.E-3. Dimensions of the habitat grid cells used to compile statistics for multiple fates model runs.

Habitat grid	OB_HABS-DEPTHS2.HAB
Grid W edge	125° 19.27'W
Grid S edge	45° 58.89'N
Cell size (^{o} longitude)	0.002024 ^{o} W
Cell size (^{o} latitude)	0.002024 ^{o} N
Cell size (m) west-east	156.1
Cell size (m) south-north	224.7
# cells west-east	895
# cells south-north	996
Water cell area (m^2)	35,073.8
Shore cell length (m)	187.3
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 XXVII.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	9	8	20
February	8	8	20
March	9	8	20
April	10	8	20
May	12	8	20
June	13	8	20
July	13	7	10
August	15	7	10
September	14	7	10
October	13	7	20
November	12	7	20
December	9	7	20

Table XXVII.E-5. Wind data sources and records used.

File Name	Location	Latitude Longitude	Dates	Data Source
46041_1987-2004_PST.WNE	Station 46041 – Cape Elizabeth, WA	47º 20.4'N 124º 44.4'W	1987-2004	National Data Buoy Center

The 46041_1987-2004_PST.WNE wind data were downloaded from the buoy Station 46041 - Cape Elizabeth, WA. Figure XXVII.E-1 displays where the buoy is located. 46041_1987-2004_PST.WNE data start on 9 June1987 and end on 31 December 2004.

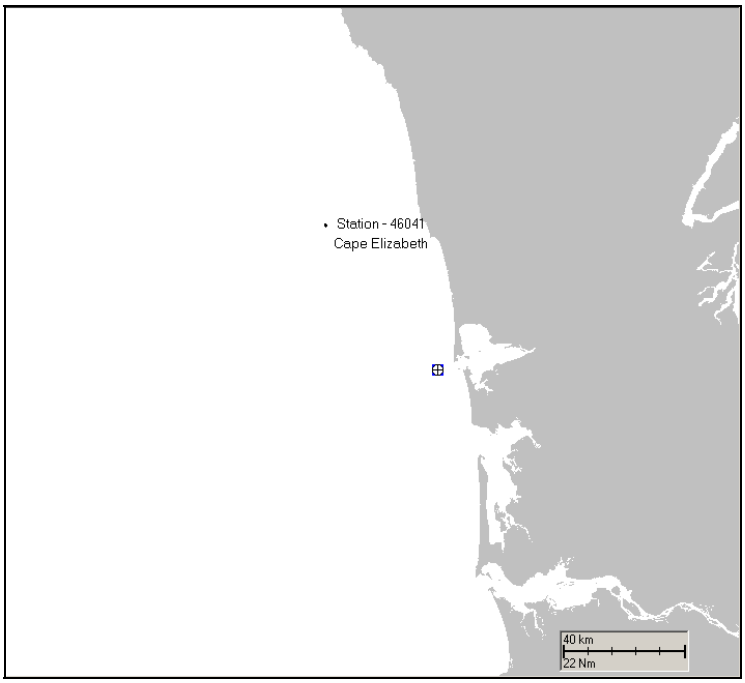


Figure XXVII.E-1. Wind Station Locations.

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 XXVIII: Model Results for Runs Assuming No Response for Grays Harbor – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXVIII.A. Introduction 1
XXVIII.B. Maps of Exposure Probability and Time First Exposed..... 1
XXVIII.C. Statistics for All Model Runs 5
XXVIII.D. Shoreline Areas Exposed by Shore Type 8
XXVIII.E. Exposure for Representative Individual Model Runs..... 10
XXVIII.F. Estimated Biological Impacts: Wildlife..... 23
XXVIII.G. Estimated Biological Impacts: Fish and Invertebrates 26
XXVIII.H. Estimated NRDA Costs: Habitat Restoration Costs..... 28
XXVIII.I. Estimated NRDA Costs: Washington Compensation schedule..... 31

List of Figures

Figure XXVIII.B-1. Grays Harbor, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen). 2
Figure XXVIII.B-2. Grays Harbor, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2..... 2
Figure XXVIII.B-3. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-21 to OC-28. 3
Figure XXVIII.B-4. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs in Grays Harbor. 4
Figure XXVIII.B-5. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs in Willapa Bay. 4
Figure XXVIII.C-1. Grays Harbor, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore. 7
Figure XXVIII.C-2. Grays Harbor, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill..... 7
Figure XXVIII.E-1. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 11
Figure XXVIII.E-2. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs. 11
Figure XXVIII.E-3. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run based on shoreline costs. 12
Figure XXVIII.E-4. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary..... 12
Figure XXVIII.E-5. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary..... 13
Figure XXVIII.E-6. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the Olympia Coast National Marine Sanctuary. 13
Figure XXVIII.E-7. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River. 14
Figure XXVIII.E-8. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River. 14
Figure XXVIII.E-9. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Quileute River. 15
Figure XXVIII.E-10. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River. 15

Figure XXVIII.E-11. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River. 16
Figure XXVIII.E-12. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Hoh River..... 16
Figure XXVIII.E-13. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay. 17
Figure XXVIII.E-14. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay. 17
Figure XXVIII.E-15. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Willapa Bay. 18
Figure XXVIII.E-16. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor. 18
Figure XXVIII.E-17. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor. 19
Figure XXVIII.E-18. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Grays Harbor. 19
Figure XXVIII.E-19. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River. 20
Figure XXVIII.E-20. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River. 20
Figure XXVIII.E-21. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Lower Columbia River. 21
Figure XXVIII.E-22. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs. 21
Figure XXVIII.E-23. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs. 22
Figure XXVIII.E-24. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the GRPs. 22

List of Tables

Table XXVIII.C-1. Grays Harbor, No removal: Summary of on- and in-water exposure indices for 100 stochastic runs. 6
Table XXVIII.D-1. Grays Harbor, No removal: Shoreline area (m^2) oiled above 1 g/m^2 (0.001 mm thick). 8
Table XXVIII.D-2. Grays Harbor, No removal: Shoreline area (m^2) oiled above 10 g/m^2 (0.01 mm thick). 8
Table XXVIII.D-3. Grays Harbor, No removal: Shoreline area (m^2) oiled above 100 g/m^2 (0.1 mm thick). 9
Table XXVIII.D-4. Grays Harbor, No removal: Shoreline area (m^2) oiled above 1000 g/m^2 (1 mm thick). 9
Table XXVIII.F-1. Grays Harbor, no removal: Results of the linear regression of wildlife killed (kg) versus the area oiled above the threshold for a lethal dose. 24
Table XXVIII.F-2. Grays Harbor, no removal: Wildlife injury (as numbers lost). 25
Table XXVIII.G-1. Grays Harbor, no removal: Results of the linear regression of fishes and invertebrates killed (kg) versus the percentage of spilled oil in the water column. 27
Table XXVIII.G-2. Grays Harbor, no removal: Fish and invertebrate injury (as biomass lost in kg). 27
Table XXVIII.H-1. Grays Harbor, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 29
Table XXVIII.H-2. Grays Harbor, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 30
Table XXVIII.I-1. Grays Harbor, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 31

XXVIII.A. INTRODUCTION

The results of the stochastic scenario for the Grays Harbor 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).

XXVIII.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)

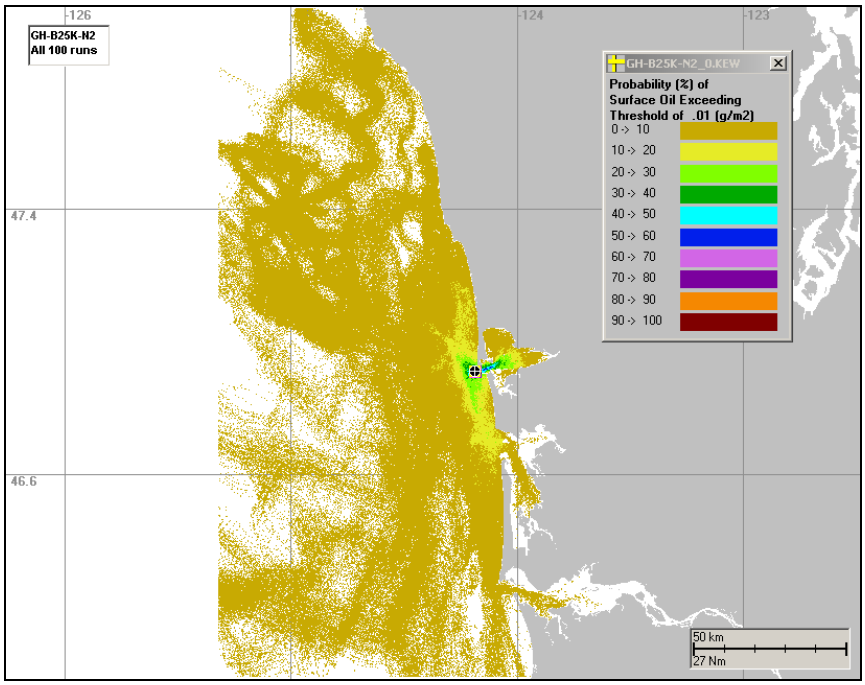


Figure XXVIII.B-1. Grays Harbor, No mechanical removal: Probability (%) of surface floating total hydrocarbons exceeding 0.01 g/m^2 (the minimum thickness for sheen).

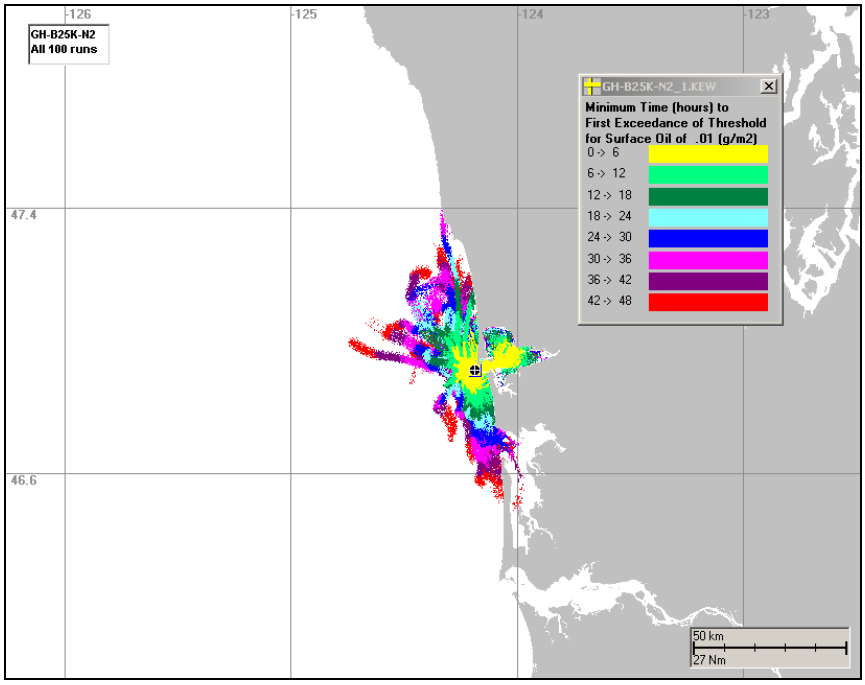


Figure XXVIII.B-2. Grays Harbor, No mechanical removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2.

For all 100 stochastic runs performed for the Grays Harbor location, maximum water column exposure of dissolved aromatic concentration never exceeded 1 ppb averaged over a 0.04 km^2 grid cell. Consequently, maps of such exceedances are not shown here.

Primary areas of concern are the locations of the geographic response plans (GRPs). Figures XXVIII.B-3 to XXVIII.B5 are plots of the time after the spill when the surface floating hydrocarbons could first exceed the threshold of 0.01g/m^2 for the areas of the GRPs.

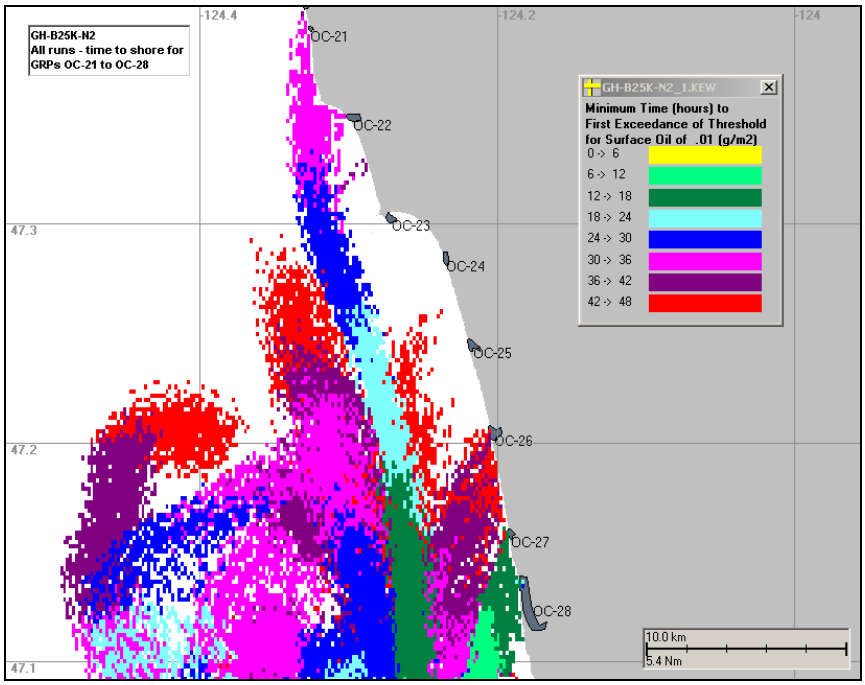


Figure XXVIII.B-3. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs OC-21 to OC-28.

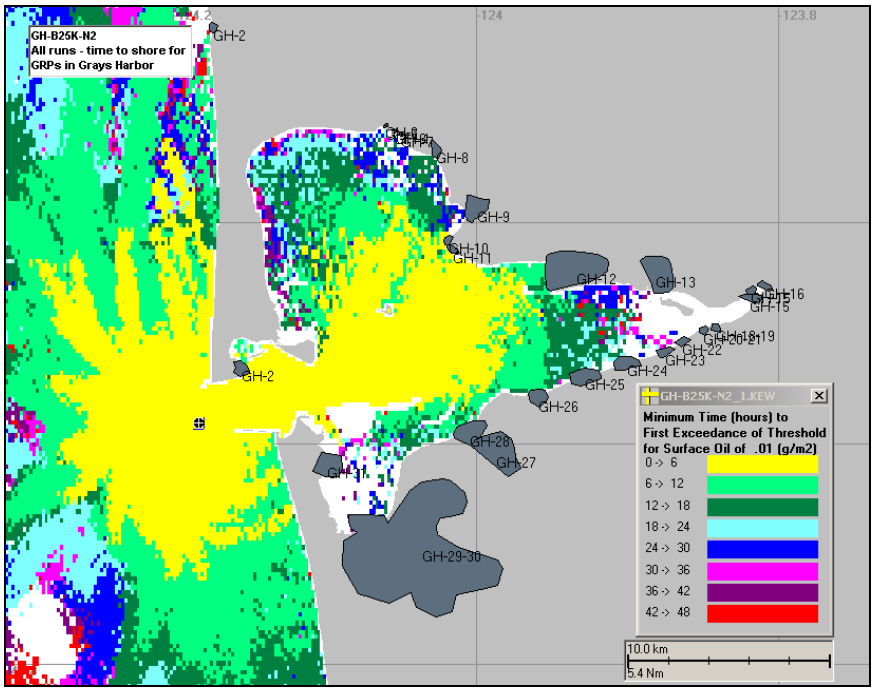


Figure XXVIII.B-4. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs in Grays Harbor.

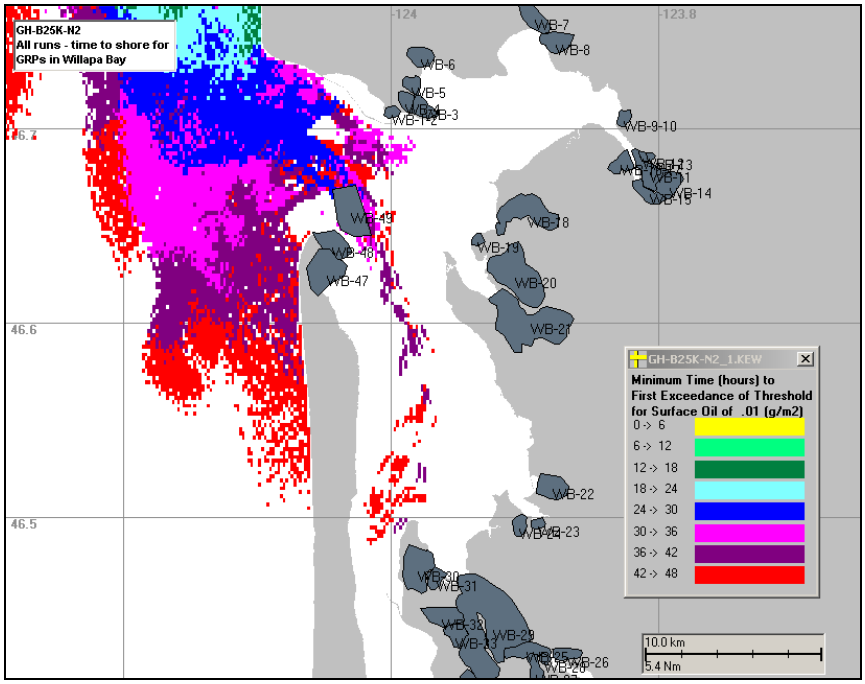


Figure XXVIII.B-5. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the area containing GRPs in Willapa Bay.

XXVIII.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.

Since Bunker fuel is highly viscous, it does not spread to thin sheens and water areas are exposed only to thicker oil. Hence, areas exposed to >0.01 g/m^2 are the same as areas exposed to > 10 g/m^2.

Table XXVIII.C-1. Grays Harbor, No 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)	13	14	41	0	7	44	80
Surface Oil Exposure Exceeding 10g/m^2 (km^2-hr)	13	14	41	0	7	44	80
Surface Oil Exposure Exceeding 0.01g/m^2 (km^2) for all waters	1,207	1,339	3,884	0	656	4,153	7,280
Surface Oil Exposure Exceeding 0.1g/m^2 (km^2) for all waters	1,207	1,339	3,884	0	656	4,153	7,280
Surface Oil Exposure Exceeding 1.0g/m^2 (km^2) for all waters	1,207	1,338	3,883	0	656	4,153	7,280
Surface Oil Exposure Exceeding 10g/m^2 (km^2) for all waters	1,207	1,338	3,882	0	656	4,153	7,280
Surface Oil Exposure Exceeding 100g/m^2 (km^2) for all waters	1,200	1,335	3,871	0	640	4,153	7,243
Surface Oil Exposure Exceeding 1000g/m^2 (km^2) for all waters	417	389	1,196	0	281	1,291	1,774
Maximum Dissolved Aromatic Plume Volume Exceeding 1 ppb (m^3)	0.00E+00	0.00E+00	0.00E+00	100	0.00E+00	0.00E+00	0.00E+00
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 (%)	61.16	15.78	92.73	3	63.89	76.73	80.00
Percent of Spilled Hydrocarbon Mass Settling to Sediments (in subtidal and extensive intertidal habitats, %)	51.2103	16.3566	83.9235	0	59.3531	65.4802	65.9761
Maximum Percent of Spilled Hydrocarbon Mass in the Water Column at Any Time after the Spill (%)	3.40	2.21	7.81	0	2.67	8.35	8.71

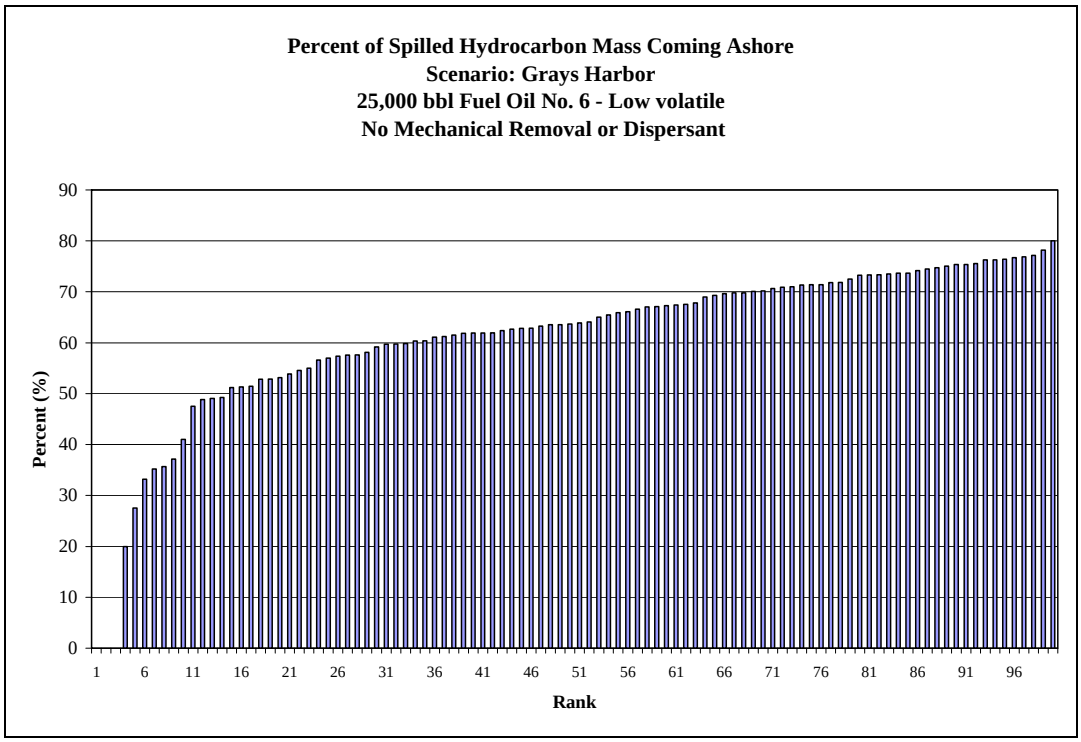


Figure XXVIII.C-1. Grays Harbor, No mechanical removal: Percent of spilled hydrocarbon mass eventually going ashore.

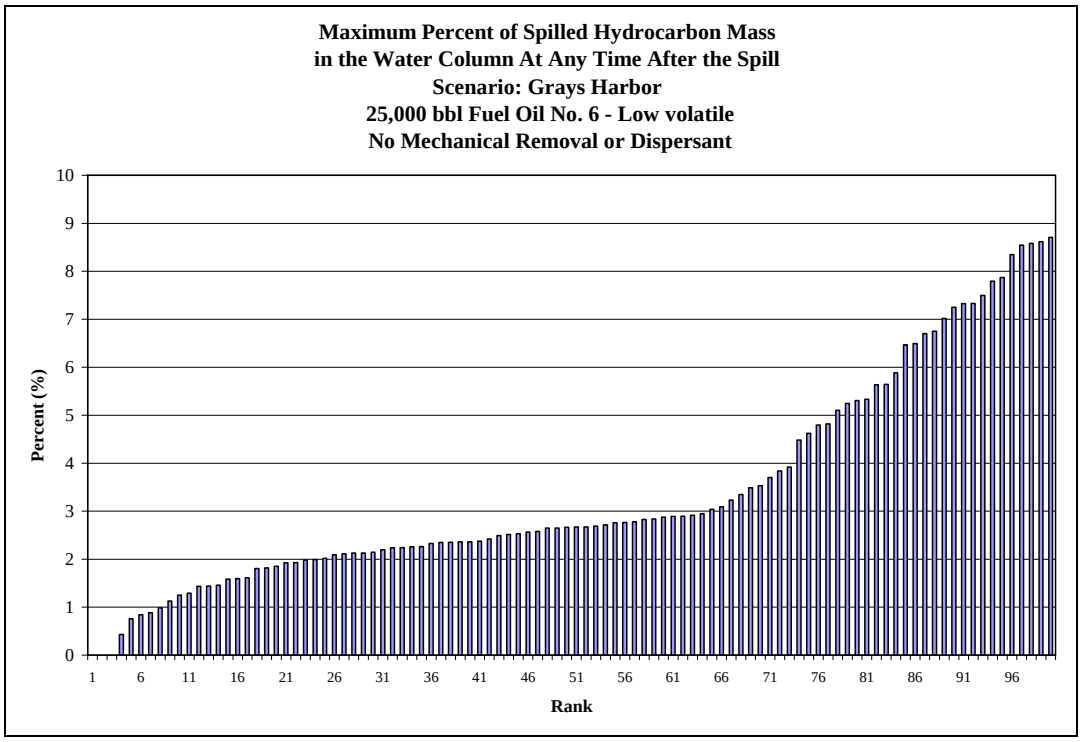


Figure XXVIII.C-2. Grays Harbor, No mechanical removal: Percent of spilled hydrocarbon mass in the water column at any time after the spill.

XXVIII.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 XXVIII.D-1. Grays Harbor, No 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	401,341	15,170	1,311	266,874	117,986	0	0
95th	1,244,475	0	0	25,283	1,219,192	0	0
Maximum	2,026,930	71,916	44,573	390,478	1,966,439	943,891	0
Mean	537,539	13,007	3,566	212,628	292,606	15,732	0
Std. Dev.	382,615	11,929	7,110	79,172	391,349	105,619	0
Mean + 2 Std. Dev.	1,302,769	36,865	17,786	370,972	1,075,304	226,970	0

Table XXVIII.D-2. Grays Harbor, No 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	398,532	15,170	1,311	264,065	117,986	0	0
95th	1,244,475	0	0	25,283	1,219,192	0	0
Maximum	2026930	71916	44573	382051	1966439	943891	0
Mean	532031	12990	3553	209904	289853	15732	0
Std. Dev.	380377	11901	7103	77889	390123	105619	0
Mean + 2 Std. Dev.	1,292,785	36,792	17,759	365,682	1,070,099	226,970	0

Table XXVIII.D-3. Grays Harbor, No 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	299,274	18,541	2,622	238,782	39,329	0	0
95th	1,183,048	11,799	2,622	106,750	1,061,877	0	0
Maximum	1,948,272	71,916	44,573	241,591	1,887,781	904,562	0
Mean	434,235	12,973	3,422	146,865	257,997	12,978	0
Std. Dev.	361,036	11,899	7,011	51,924	371,061	94,874	0
Mean + 2 Std. Dev.	1,156,307	36,771	17,444	250,713	1,000,119	202,726	0

Table XXVIII.D-4. Grays Harbor, No 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	14,608	10,675	3,933	0	0	0	0
95th	249,832	11,237	2,622	0	235,973	0	0
Maximum	511,274	66,297	32,774	56,184	511,274	78,658	0
Mean	51,024	11,849	1,953	1,826	34,609	787	0
Std. Dev.	90,651	10,666	5,125	7,838	89,313	7,866	0
Mean + 2 Std. Dev.	232,326	33,181	12,203	17,502	213,235	16,519	0

XXVIII.E. EXPOSURE FOR REPRESENTATIVE INDIVIDUAL MODEL RUNS.

To examine alternate response scenarios, three representative runs were selected from the 100 stochastic runs involving no response as worst cases for certain locations 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. Maps of oil exposure to the selected sites and other sensitive sites are included below. The representative runs for the alternative response scenarios are numbered 1, 5 and 9 below.

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts for the Olympia Coast National Marine Sanctuary;
3. the worst case run for impacts for the area near Quileute River;
4. the worst case run for impacts for the area near Hoh River;
5. the worst case run for impacts for Willapa Bay;
6. the worst case run for impacts for Grays Harbor;
7. the worst case run for impacts for Lower Columbia River, and
8. the worst case run for impacts to sensitive areas as indicated in Geographic Response Plans (GRPs).

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. This section also contains plots of shoreline exposed to floating hydrocarbons (g/m^2) at any time after the spill, and the time after the spill when the surface floating hydrocarbons could first exceed the threshold of $0.01 g/m^2$. 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.

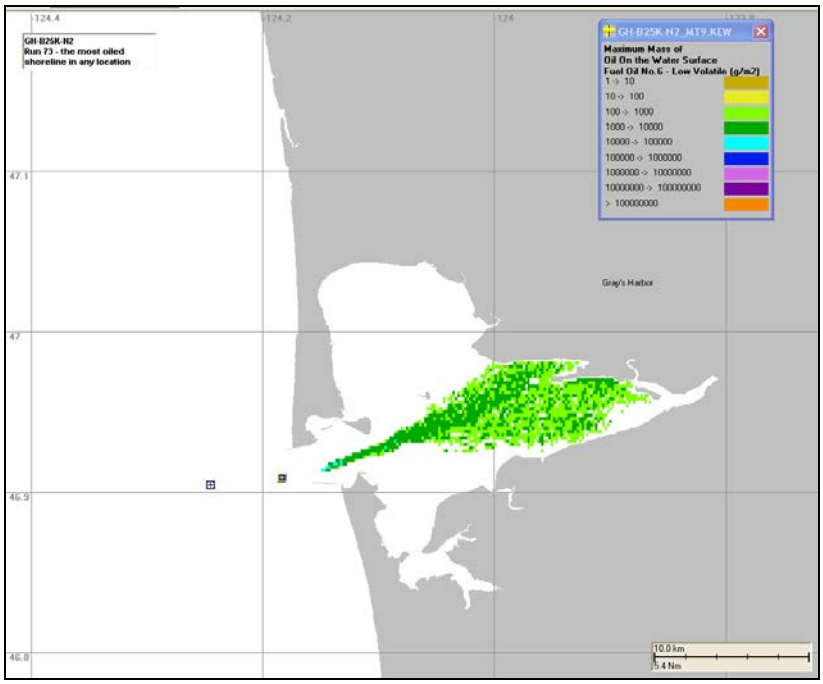


Figure XXVIII.E-1. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

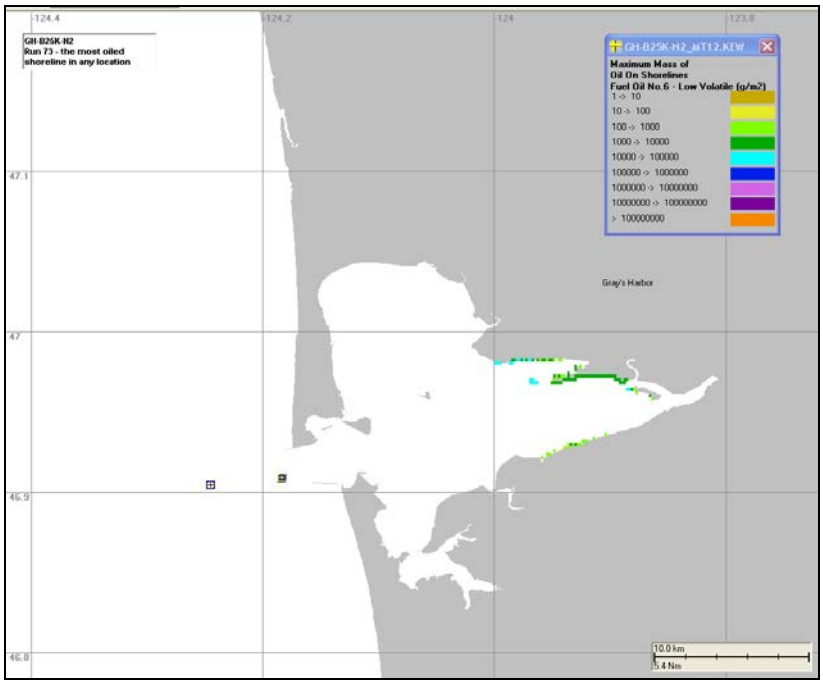


Figure XXVIII.E-2. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run based on shoreline costs.

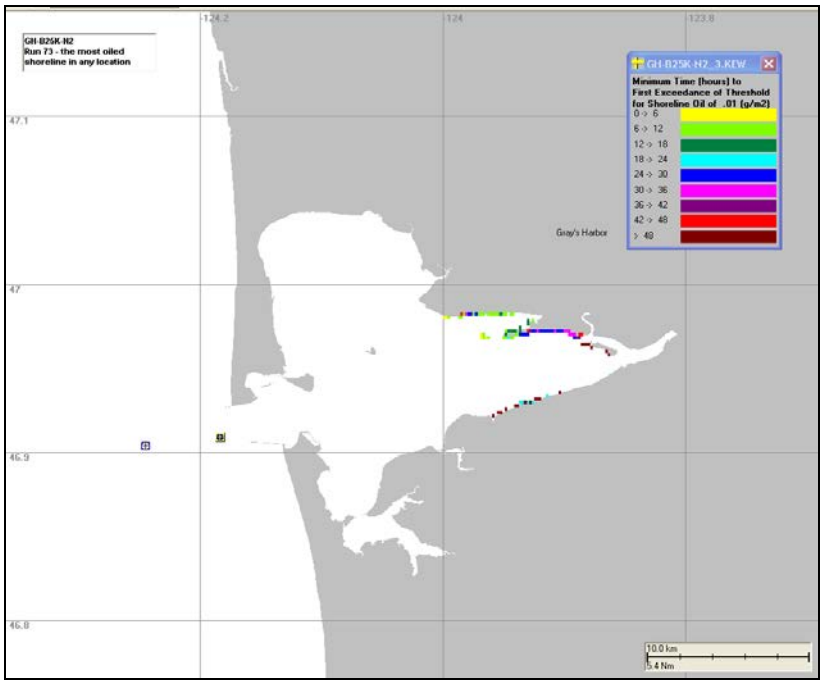


Figure XXVIII.E-3. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run based on shoreline costs.

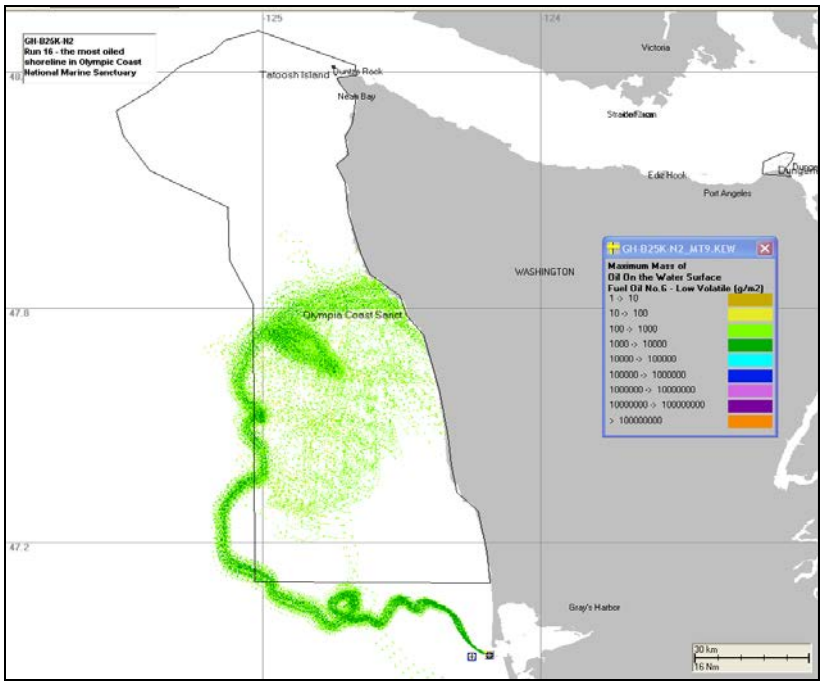


Figure XXVIII.E-4. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary.

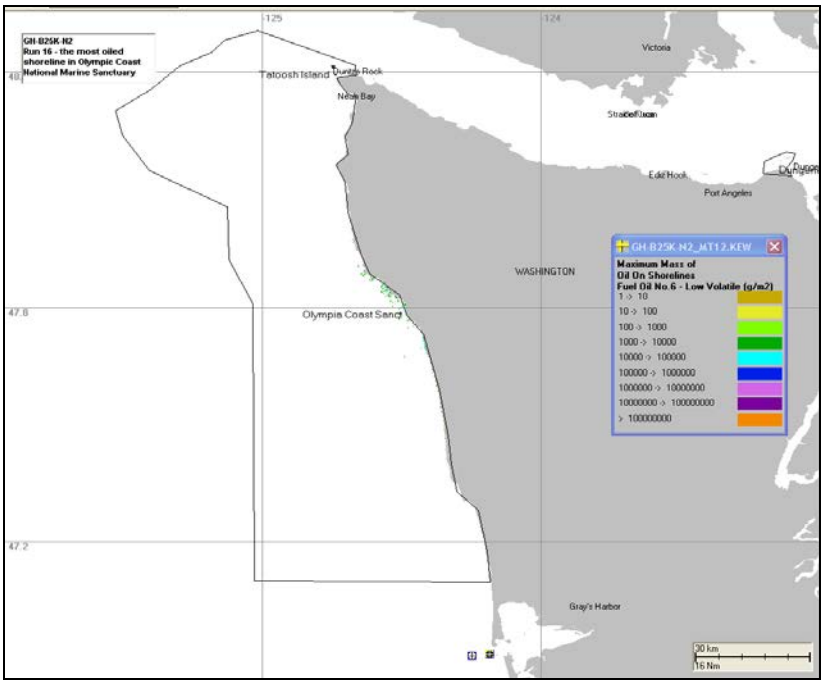


Figure XXVIII.E-5. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the Olympia Coast National Marine Sanctuary.

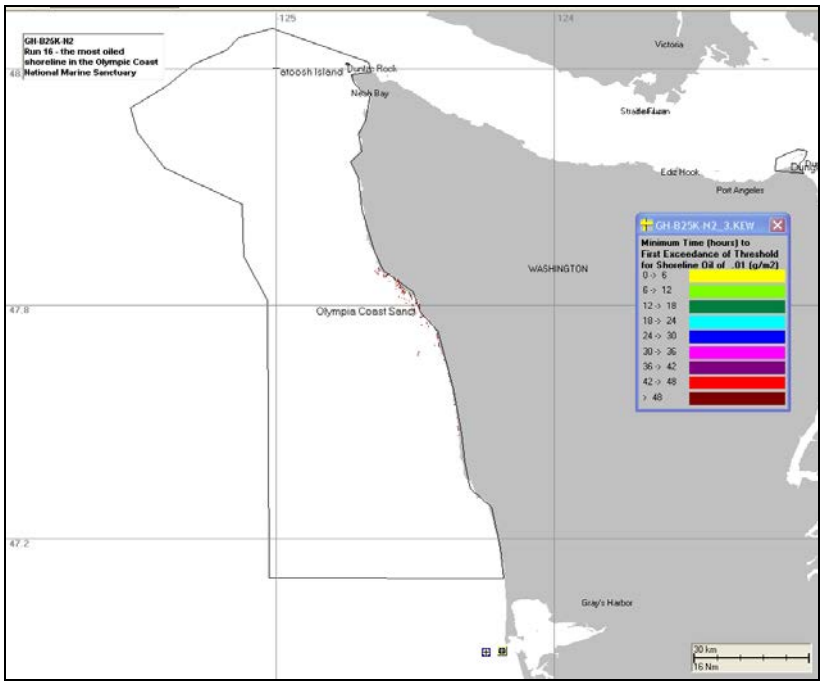


Figure XXVIII.E-6. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the Olympia Coast National Marine Sanctuary.

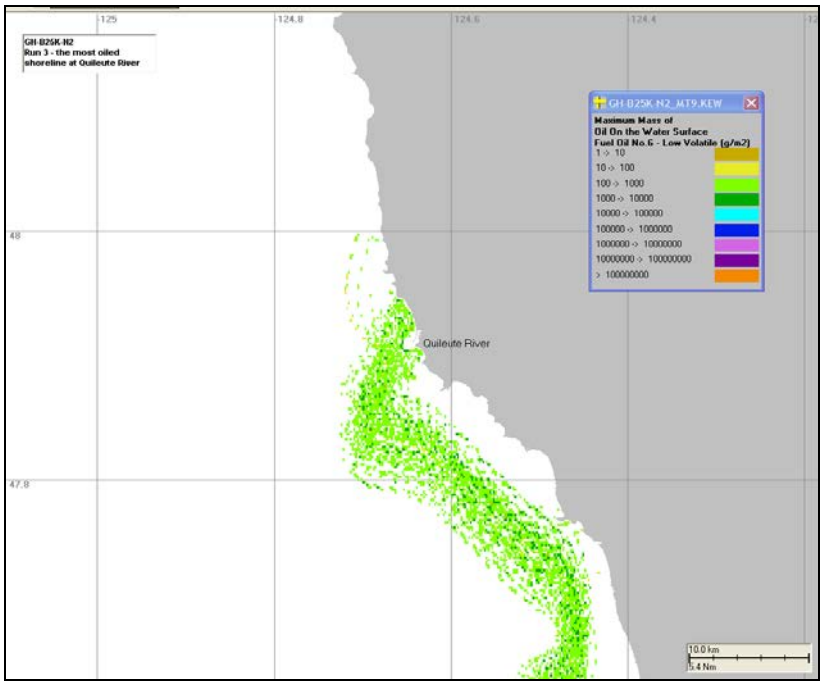


Figure XXVIII.E-7. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River.

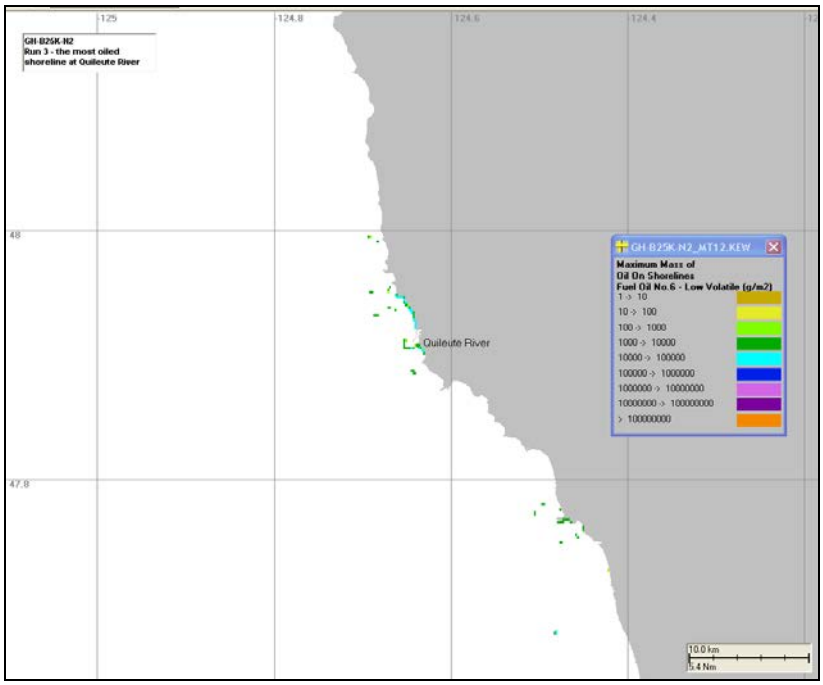


Figure XXVIII.E-8. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Quileute River.

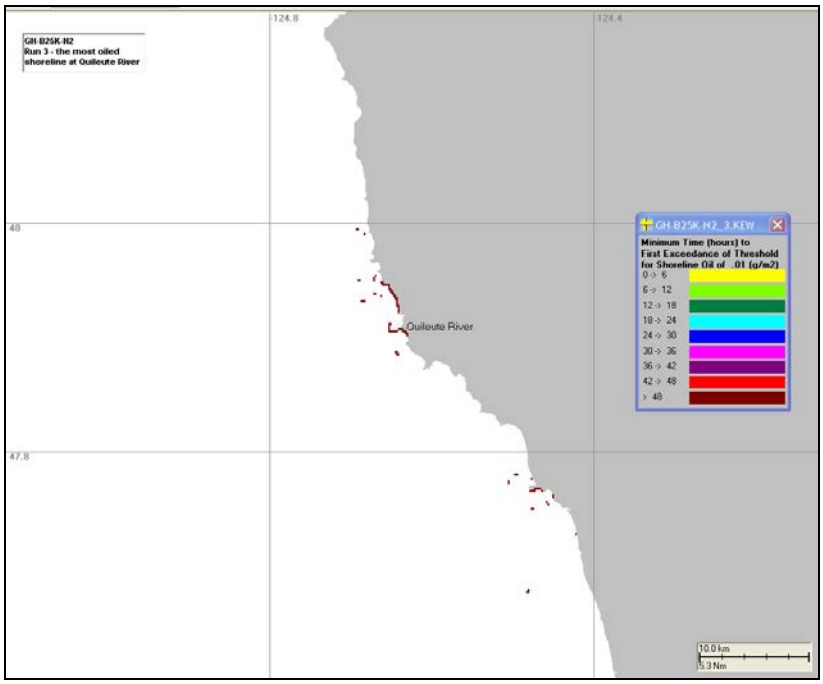


Figure XXVIII.E-9. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Quileute River.

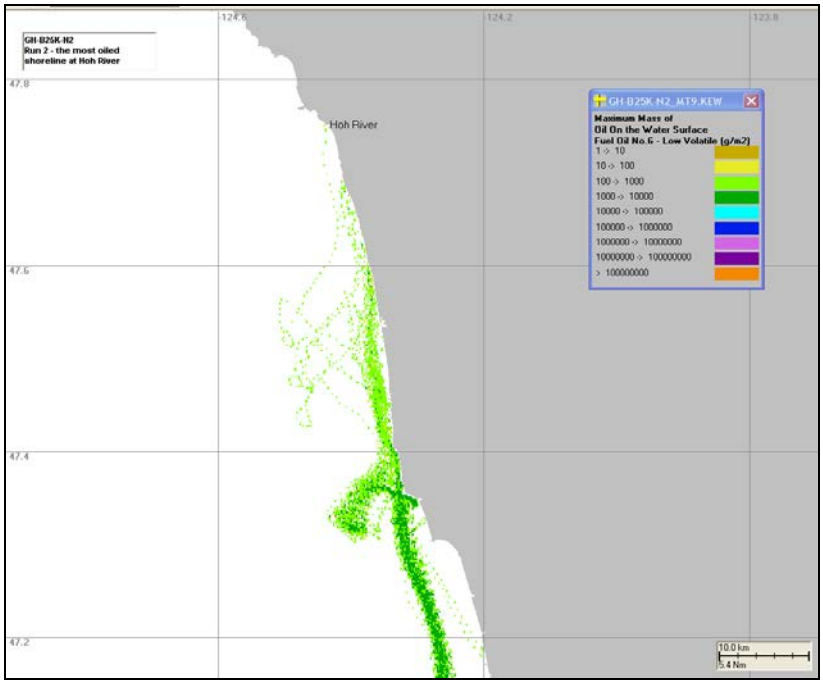


Figure XXVIII.E-10. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River.

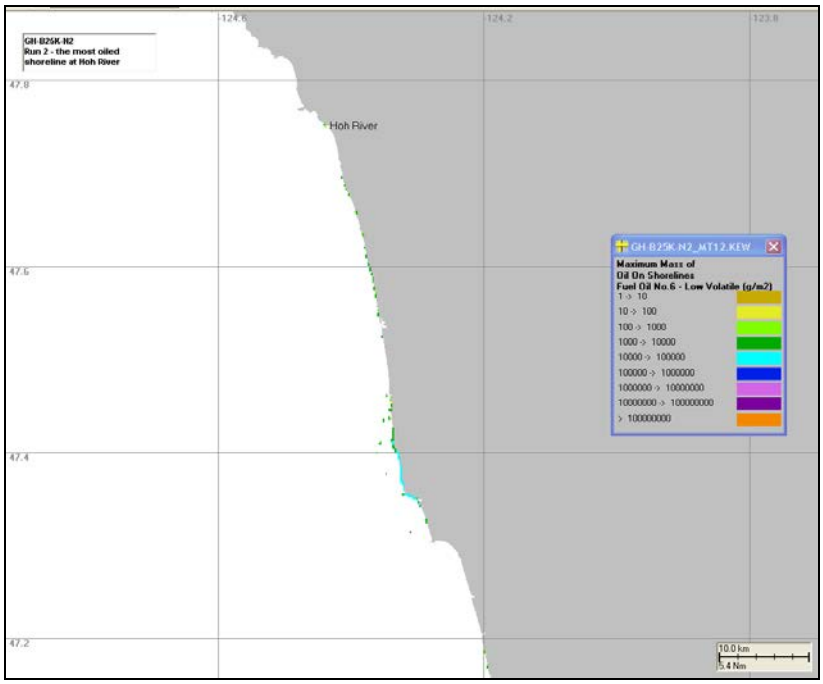


Figure XXVIII.E-11. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Hoh River.

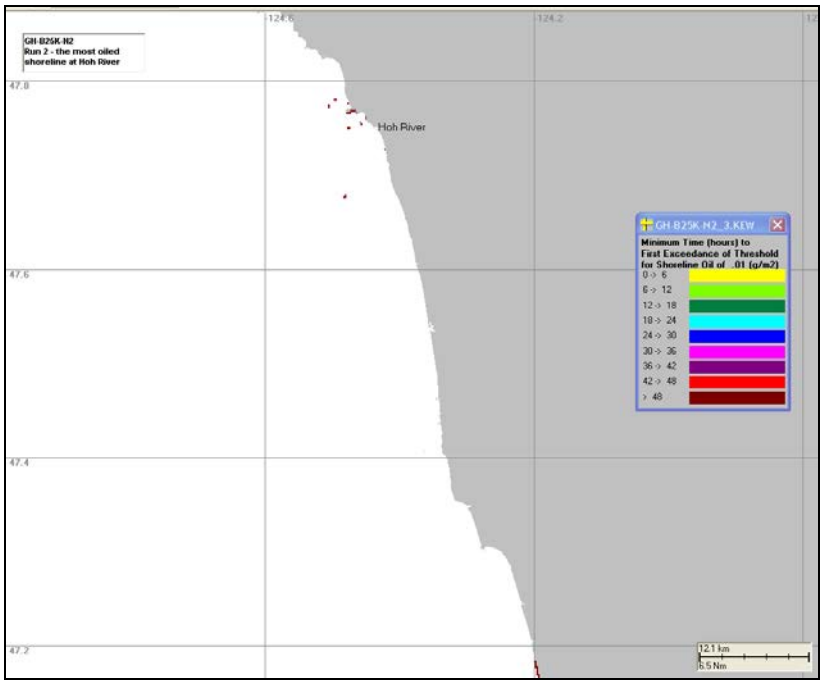


Figure XXVIII.E-12. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Hoh River.

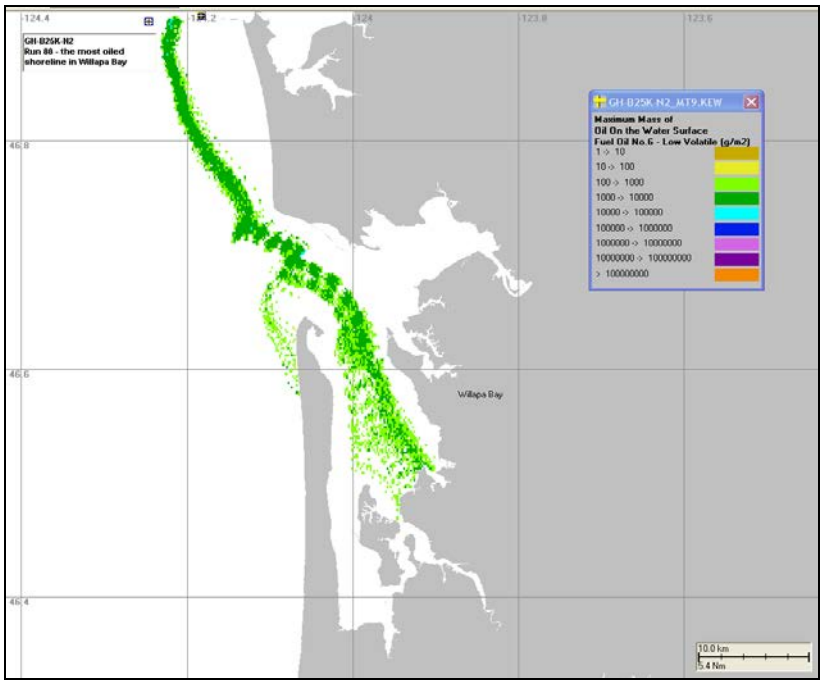


Figure XXVIII.E-13. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay.

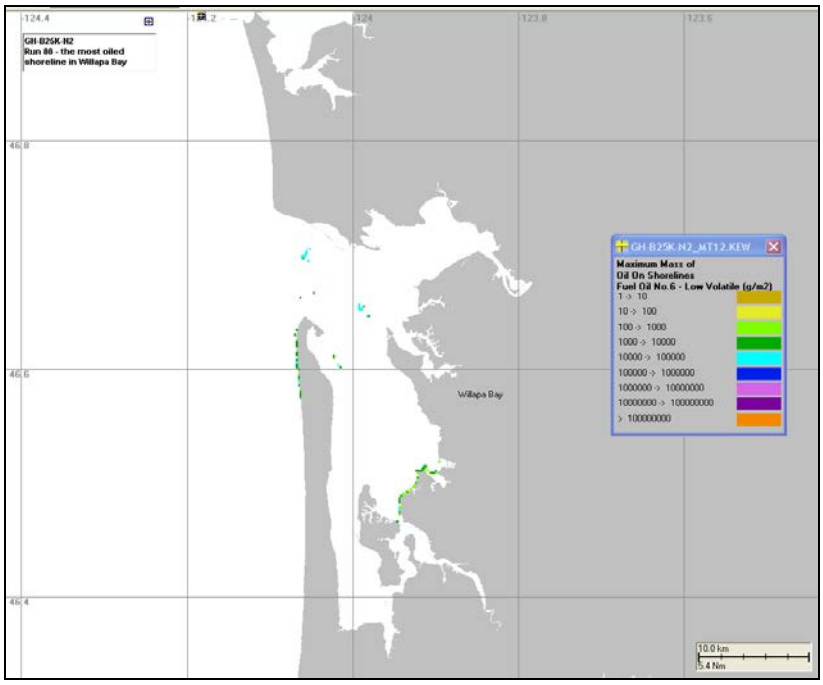


Figure XXVIII.E-14. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Willapa Bay.

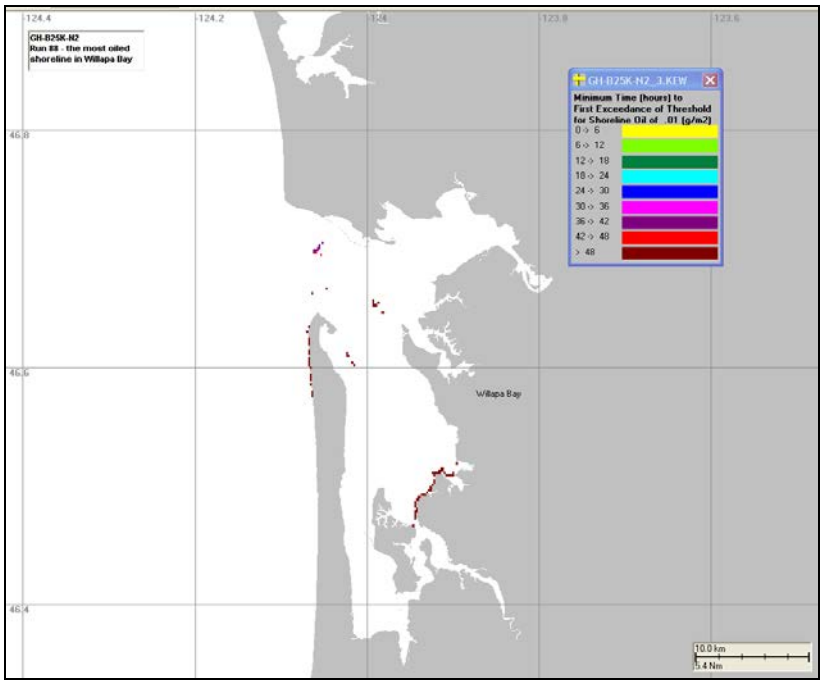


Figure XXVIII.E-15. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Willapa Bay.

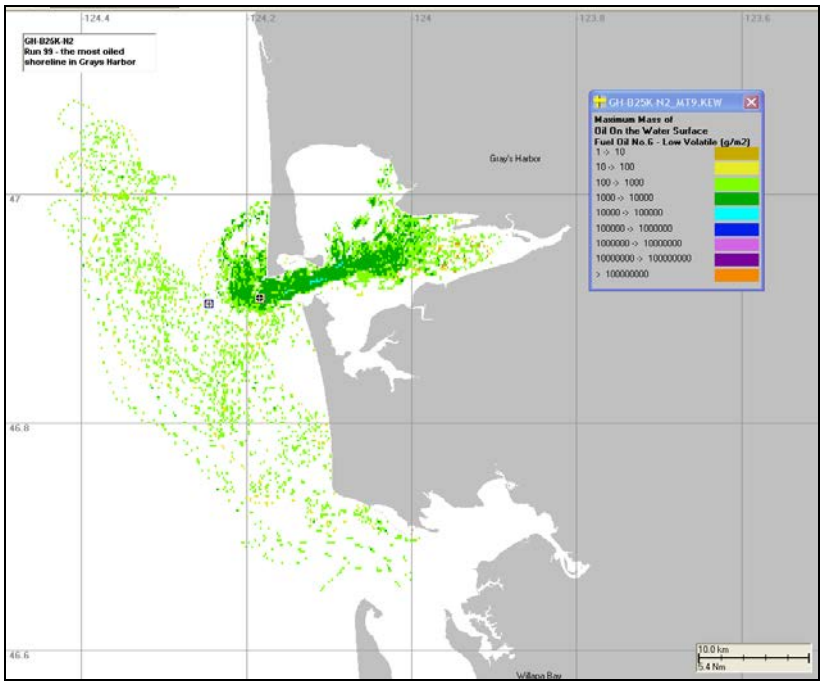


Figure XXVIII.E-16. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor.

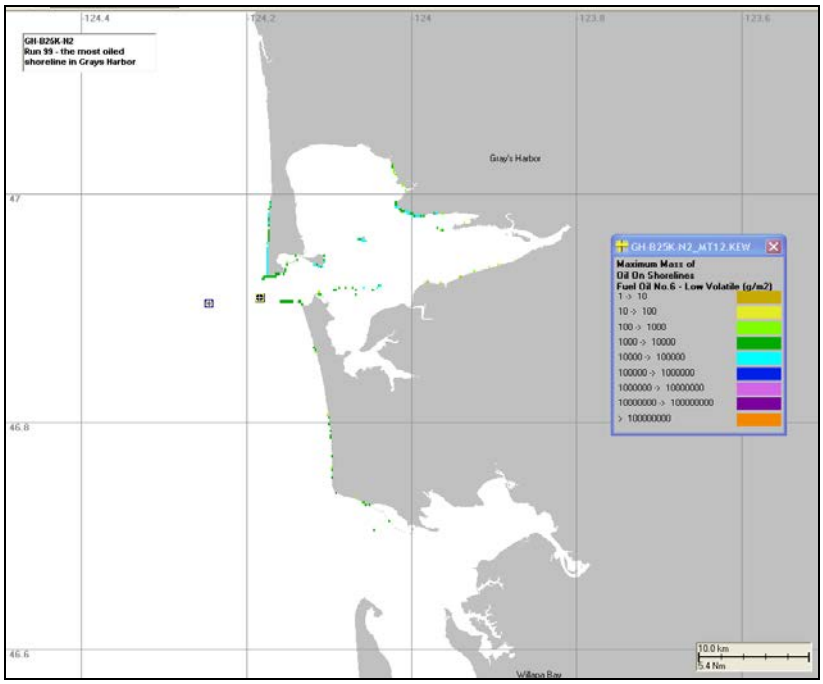


Figure XXVIII.E-17. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Grays Harbor.

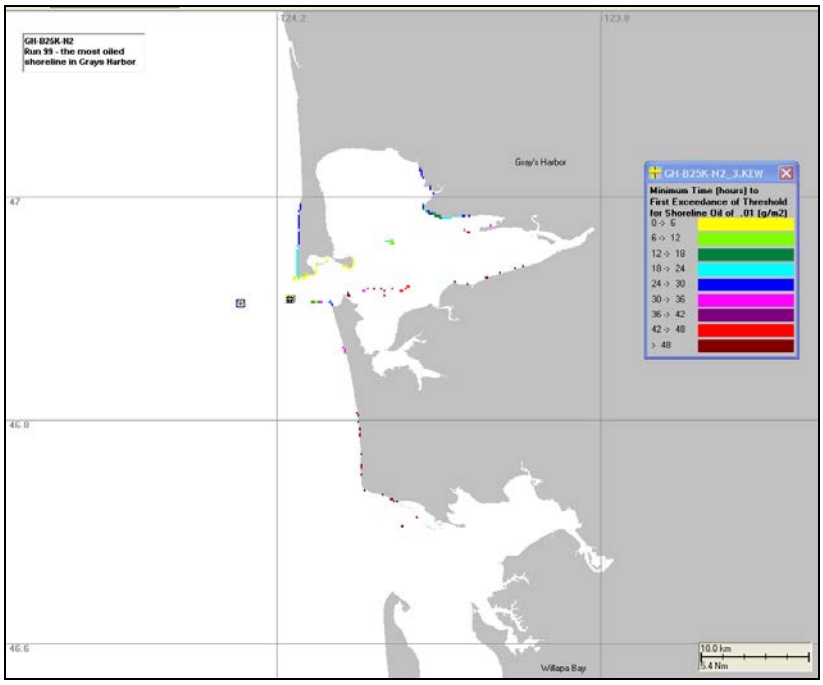


Figure XXVIII.E-18. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Grays Harbor.

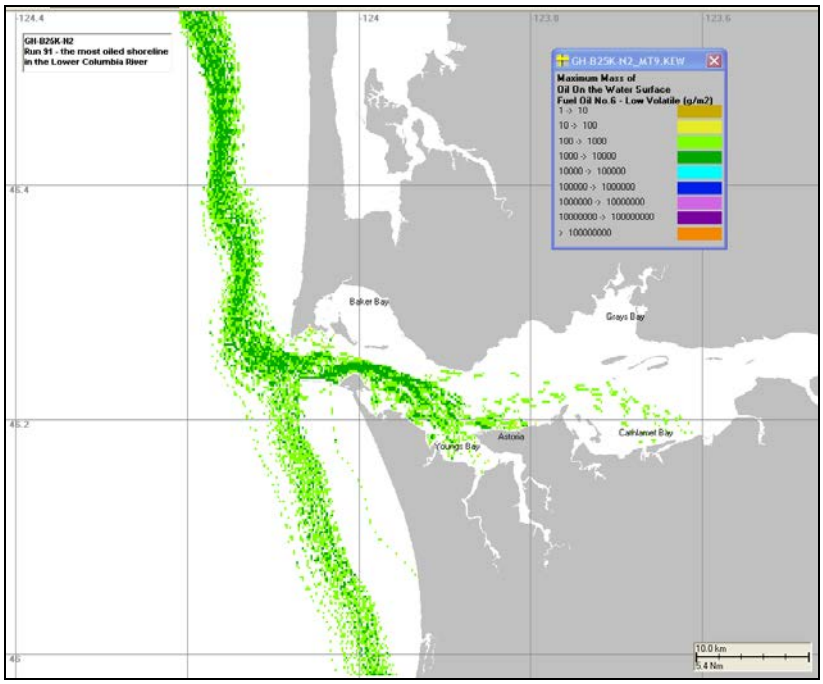


Figure XXVIII.E-19. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River.

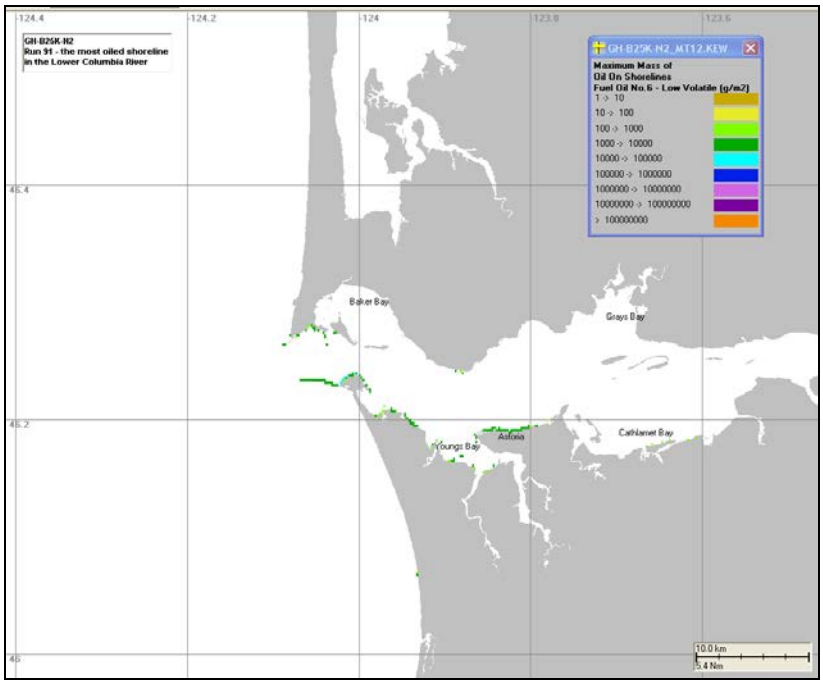


Figure XXVIII.E-20. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for Lower Columbia River.

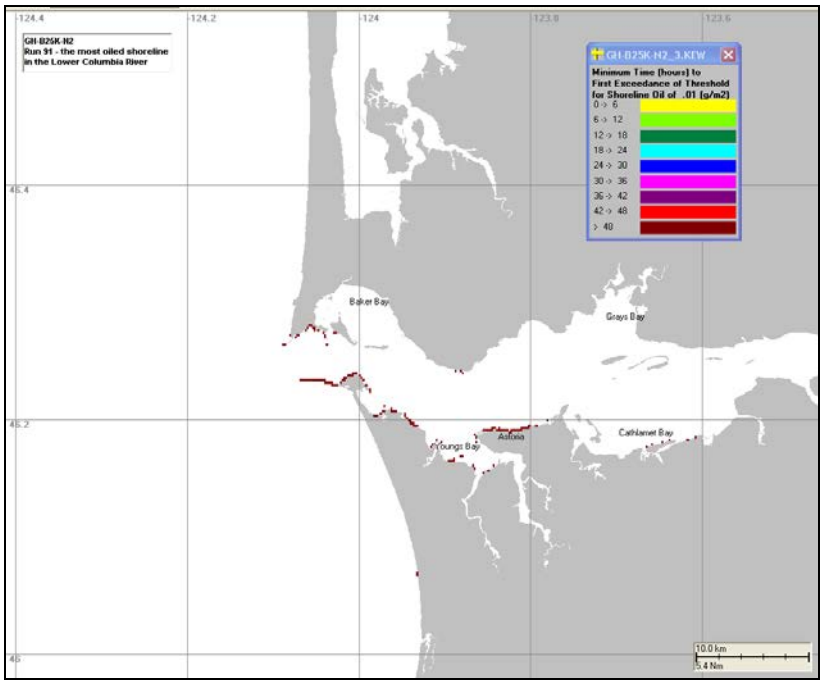


Figure XXVIII.E-21. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for Lower Columbia River.

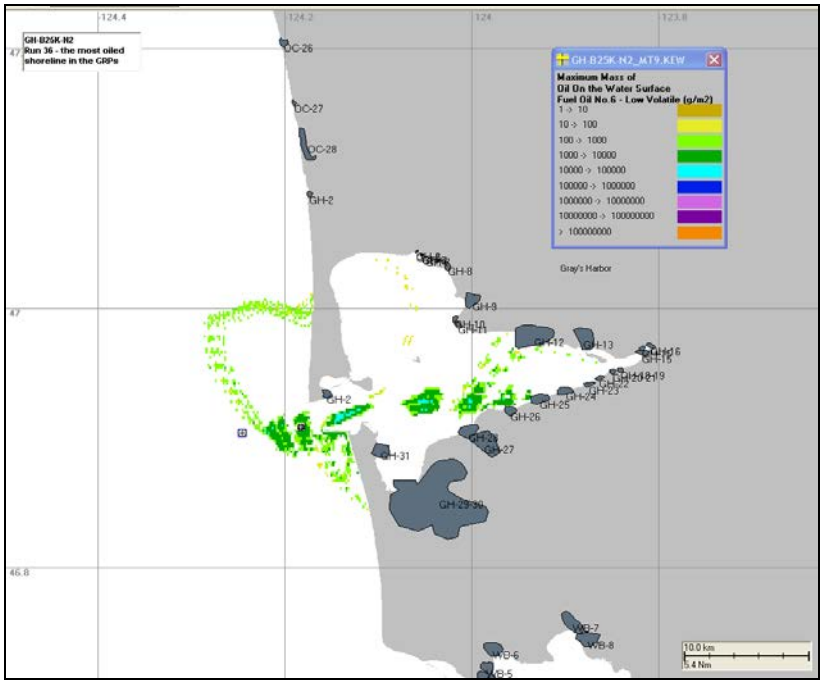


Figure XXVIII.E-22. Grays Harbor, No removal: Water surface exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs.

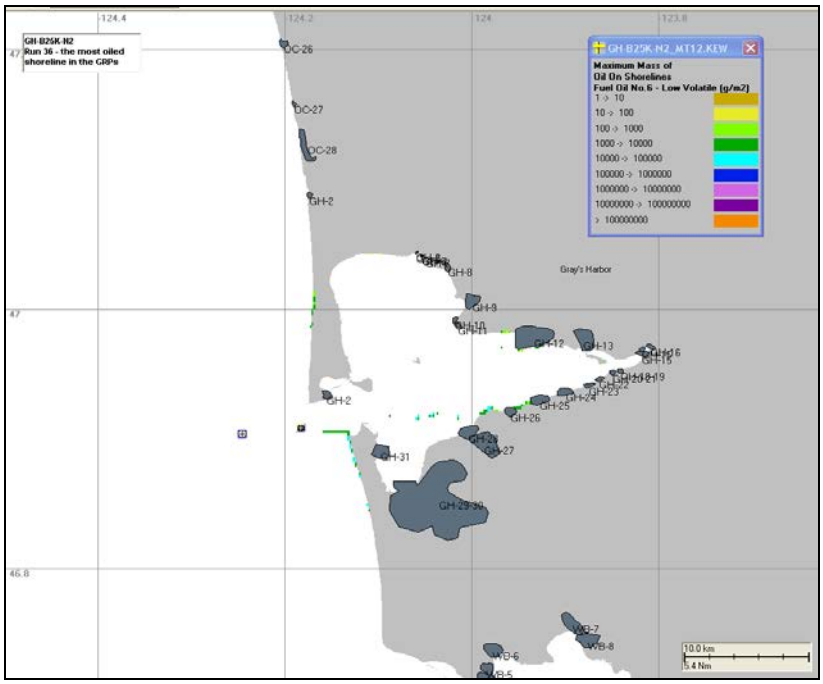


Figure XXVIII.E-23. Grays Harbor, No removal: Shoreline exposure to floating hydrocarbons (g/m^2) for the worst run for the GRPs.

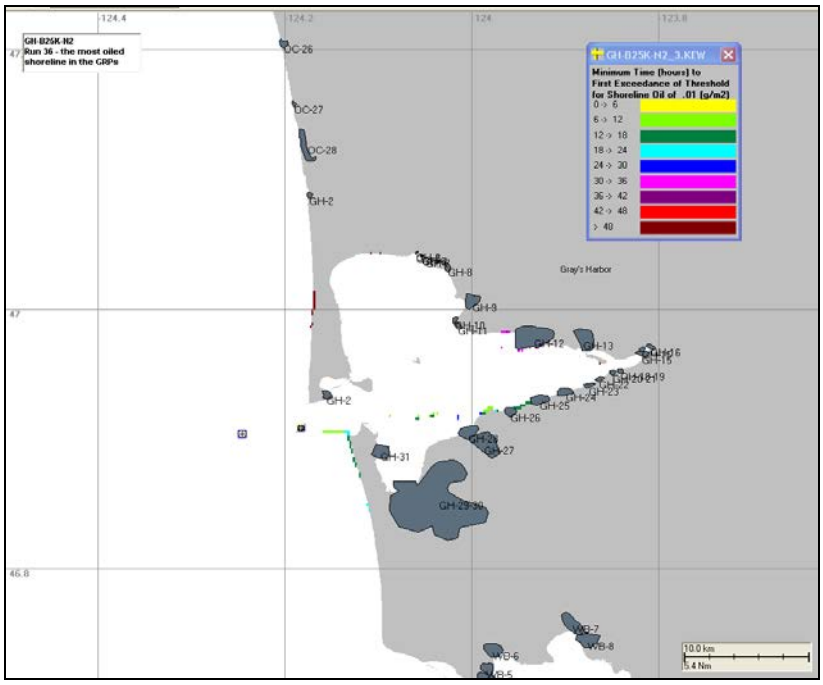


Figure XXVIII.E-24. Grays Harbor, No removal: Time (hrs) after spill when surface floating total hydrocarbons could first exceed 0.01 g/m^2 for the worst run for the GRPs.

XXVIII.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, 30th, 50th, 65th, 80th and 95th percentile runs based on shore cost, including shorelines of all jurisdictions, and
- 5th, 30th, 50th, 65th, 80th and 95th percentile runs based on surface water area swept by $>10 g/m^2$, which is the threshold thickness for oiling wildlife with a lethal dose.

Because wildlife impacts are not necessarily correlated with shore cost, the results for wildlife impact may not be in increasing order from 5th to 95th percentile run by shore cost. However, the impact for a given wildlife groups is proportional to area oiled above the threshold level for a lethal dose, and the 5th to 95th percentile runs based on surface water area swept by $>10 g/m^2$ covers the range of potential impacts. Thus, linear regressions of wildlife killed versus oiled area, using the 12 runs where the biological effects model was run (Table XXVIII.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, 30th, 50th, 65th, 80th 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 XXVIII.F-1. Grays Harbor, no 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	Intercept	Standard Error	R^2	Correlation Coefficient (R)
Waterfowl	9.26E-05	-4.60E+03	1.52E+04	8.20E-01	9.06E-01
Seabirds	1.13E-05	-1.12E+02	7.58E+02	9.65E-01	9.82E-01
Wading birds	1.51E-04	-1.12E+01	3.76E+01	7.59E-01	8.71E-01
Shorebirds	2.14E-04	8.76E+01	1.82E+02	2.12E-01	4.60E-01
Raptors[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kingfishers	2.81E-08	1.67E-02	1.93E-01	8.49E-01	9.22E-01
Cetaceans	2.20E-06	5.64E+02	1.54E+03	2.07E-01	4.55E-01
Pinnipeds (seals)	9.24E-07	1.51E+02	2.20E+02	6.86E-01	8.28E-01
Other mammals	2.89E-07	-2.62E+00	9.56E+00	9.91E-01	9.96E-01

[1] Results of these regressions reflect the fact that no injuries were sustained for these wildlife species.

Table XXVIII.F-2. Grays Harbor, 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	-	1,562	6	453	-	-	2	0	4,666	4,663	2.03
50th Percentile	9,922	4,180	37	2,406	-	0	3	2	18,050	18,046	4.82
95th Percentile	96,683	22,461	135	8,610	-	3	10	12	121,665	121,641	24.65
Mean	21,610	6,558	53	3,448	-	1	3	3	31,677	31,669	7.42
Std Dev (SD)	32,188	6,842	46	2,945	-	1	3	4	38,209	38,202	7.42
Mean - 2SD	-	-	-	-	-	-	-	-	-	-	-
Mean + 2SD	85,987	20,243	146	9,337	-	2	9	11	108,095	108,073	22.26

XXVIII.G. ESTIMATED BIOLOGICAL IMPACTS: FISH AND INVERTEBRATES

Impacts to fish and invertebrates in subtidal habitats were calculated using the biological effects model for the same 12 runs selected from the stochastic model results (assuming no response) as was done for wildlife (see above). Because fish and invertebrate impacts are not necessarily correlated with shore cost or with wildlife impacts, the results for fish and invertebrate impact may not be in increasing order from 5th to 95th percentile run. Linear regressions of fish and invertebrates killed versus percent of spilled oil in the water column, using the 12 runs where the biological effects model was run, were used to estimate subtidal fish and invertebrate impacts for the other 88 runs in the stochastic scenario.

The subtidal fish and invertebrate impacts for all 100 runs were estimated from the regressions for each species group using the methods described in Section 2.3 of Volume I. The 100 estimates of fish and invertebrate impact were calculated by species group, and the 5th, 50th, and 95th percentile results were estimated by sorting results only for the group being considered. These are also listed in the tables, along with the mean and standard deviation of the 100 results. The mean plus or minus two standard deviations gives the range for 95 percent of results, assuming a normal (Gaussian) distribution.

Intertidal mollusk impacts were calculated for clams using estimated density in soft sediment shorelines times the area of soft shorelines oiled above 100 g/m^2.

Table XXVIII.G-1. Grays Harbor, no 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[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total large pelagic fish[1]	1.50E+00	8.36E+00	3.92E+00	4.85E-01	6.96E-01
Total demersal fish	3.61E-01	2.01E+00	9.41E-01	4.85E-01	6.97E-01
Total demersal invertebrates[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total mollusks[1]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

[1] Results of this regression reflect the fact that no injuries were sustained for species in this category.

Table XXVIII.G-2. Grays Harbor, 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	-	9.62	2.31	-	-	1,293	1,305
50th Percentile	-	12.37	2.97	-	-	3,816	3,831
95th Percentile	-	20.21	4.86	-	-	11,850	11,875
Mean	-	13.46	3.24	-	-	5,181	5,198
Std Dev (SD)	-	3.31	0.80	-	-	3,769	3,773
Mean - 2SD	-	6.84	1.64	-	-	-	8
Mean + 2SD	-	20.08	4.83	-	-	12,718	12,743

XXVIII.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 XXVIII.H-1. Grays Harbor, no 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	-	-	-	-	-	-
Large pelagic fish	10	12	20	13	7	20
Demersal fish	2	3	5	3	2	5
Decapods	-	-	-	-	-	-
Molluscs	1,293	3,816	11,850	5,181	-	12,718
Birds:						
Waterfowl (# * kg each)	-	11,121	108,365	24,222	-	96,378
Seabirds (# * kg each)	847	2,268	12,185	3,558	-	10,982
Waders (# * kg each)	3	20	73	29	-	79
Shorebirds (# * kg each)	246	1,305	4,671	1,870	-	5,065
Raptors (# * kg each)	-	-	-	-	-	-
Other wildlife:						
Sea otters, other mammals	0	1	7	2	-	6
Pinnipeds	1	1	5	2	-	5
Cetaceans	-	0	1	0	-	1
Totals:						
Subtotal fish and invertebrates	1,305	3,831	11,875	5,198	8	12,743
Subtotal birds	1,097	14,715	125,294	29,679	-	112,504
Subtotal other wildlife	1	3	13	4	-	12
Total all species	2,402	18,548	137,183	34,880	8	125,259

Table XXVIII.H-2. Grays Harbor, no 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)	5.7	29.4	212.2	53.9	68.6	0.0	191.0
Saltmarsh Area (acres)	14.0	72.6	524.2	133.2	169.4	0.1	472.0
Saltmarsh Cost (in millions of 2004$)	2.6	13.6	98.2	25.0	31.7	0.009	88.4
Eelgrass Area (m^2)	3.5	18.4	132.6	33.7	42.8	0.0	119.4
Eelgrass Area (acres)	8.7	45.4	327.6	83.2	105.9	0.0	295.0
Eelgrass Cost in millions of 2004$)	1.0	5.4	39.1	9.9	12.6	0.004	35.2

XXVIII.I. ESTIMATED NRDA COSTS: WASHINGTON COMPENSATION SCHEDULE

Table XXVIII.I-1. Grays Harbor, no 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.)	17.05	31.03	32.48	28.95	5.22	18.50
% Removed by 24 hours	0.00	0.00	0.00	0.00	0.00	0.00
Compensation (millions $)	17.9	32.6	34.1	30.4	5.5	19.4

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 XXIX: Results of Alternative Response Scenarios for Grays Harbor – Bunker C

by
Deborah French-McCay, Jill Rowe, Nicole Whittier, Rebecca Asch,
Subbayya Sankaranarayanan, and Ann Borowik
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 2005-225
May 2006

Table of Contents

XXIX.A. Introduction 1
XXIX.B. Oil Fate Over Time 3
XXIX.C. Estimated Biological Impacts: Wildlife 43
XXIX.D. Estimated Biological Impacts: Fish and Invertebrates 47
XXIX.E. Estimated NRDA Costs: Habitat Restoration Costs 49
XXIX.F. Estimated NRDA Costs: Washington Compensation schedule 58

List of Figures

Figure XXIX.A-1 Sensitive sites for Grays Harbor scenario. 2
Figure XXIX.B-1 Grays Harbor - Bunker C: 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 XXIX.B-2 Grays Harbor - Bunker C: 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 XXIX.B-3 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). 6
Figure XXIX.B-4 Grays Harbor - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Willapa Bay. 7
Figure XXIX.B-5 Grays Harbor - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Willapa Bay. 8
Figure XXIX.B-6 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Willapa Bay. 9
Figure XXIX.B-7 Grays Harbor - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Willapa Bay..... 10
Figure XXIX.B-8 Grays Harbor - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the GRPs. 11
Figure XXIX.B-9 Grays Harbor - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the the GRPs. 12
Figure XXIX.B-10 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the GRPs. 13
Figure XXIX.B-11 Grays Harbor - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the GRPs 14

List of Tables

Table XXIX.B-1 Grays Harbor - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). 15
Table XXIX.B-2 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.) 17
Table XXIX.B-3 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 19
Table XXIX.B-4 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)..... 21
Table XXIX.B-5 Grays Harbor - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa Bay. 23
Table XXIX.B-6 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa Bay. 25
Table XXIX.B-7 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa Bay..... 27
Table XXIX.B-8 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa Bay. 29
Table XXIX.B-9 Grays Harbor - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 31
Table XXIX.B-10 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 33
Table XXIX.B-11 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 35
Table XXIX.B-12 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs. 37
Table XXIX.B-13 Grays Harbor - Bunker C, 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..... 39
Table XXIX.B-14 Grays Harbor - Bunker C, 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..... 40
Table XXIX.B-15 Grays Harbor - Bunker C, 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. 41
Table XXIX.B-16 Grays Harbor - Bunker C, 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. 42
Table XXIX.C-1 Grays Harbor - Bunker C, no removal: Wildlife injury (as numbers lost). 43
Table XXIX.C-2 Grays Harbor - Bunker C, federal mechanical removal: Wildlife injury (as numbers lost). 44
Table XXIX.C-3 Grays Harbor - Bunker C, WA state mechanical removal: Wildlife injury (as numbers lost). 45
Table XXIX.C-4 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Wildlife injury (as numbers lost). 46
Table XXIX.D-1. Grays Harbor - Bunker C, no removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XXIX.D-2. Grays Harbor - Bunker C, federal mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 47
Table XXIX.D-3. Grays Harbor - Bunker C, WA state mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXIX.D-4. Grays Harbor - Bunker C, 3rd alternative mechanical removal: Fish and invertebrate injury (as biomass lost in kg). 48
Table XXIX.E-1. Grays Harbor - Bunker C, no removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 50
Table XXIX.E-2. Grays Harbor - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration. 51
Table XXIX.E-3. Grays Harbor - Bunker C, federal mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 52
Table XXIX.E-4. Grays Harbor - Bunker C, federal mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 53
Table XXIX.E-5. Grays Harbor - Bunker C, WA state mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 54
Table XXIX.E-6. Grays Harbor - Bunker C, WA state mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 55
Table XXIX.E-7. Grays Harbor - Bunker C, 3rd alternative mechanical removal: Total Injury (kg, wet weight), by trophic group, to be compensated by habitat restoration. 56
Table XXIX.E-8. Grays Harbor - Bunker C, 3rd alternative mechanical removal: Area and costs (in millions of 2004$) for compensatory restoration. 57
Table XXIX.F-1. Grays Harbor - Bunker C, no removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XXIX.F-2. Grays Harbor - Bunker C, federal mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XXIX.F-3. Grays Harbor - Bunker C, WA state mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 58
Table XXIX.F-4. Grays Harbor - Bunker C, 3rd alternative mechanical removal: NRDA costs (in millions of 2004$) based on the Washington state compensatory schedule. 59

XXIX.A. INTRODUCTION

The results of the alternate response scenarios for the Grays Harbor – Bunker C 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 representative runs were selected from the 100 stochastic runs and rerun with each set of response assumptions:

1. the worst case (99th percentile) run based on shoreline oiling and area-based costs for cleanup;
2. the worst case run for impacts at Willapa Bay, and
3. the worst case run for impacts to sensitive sites identified in the Geographic Response Plans (GRPs).

Locations of the sensitive sites are shown in Figure XXIX.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.

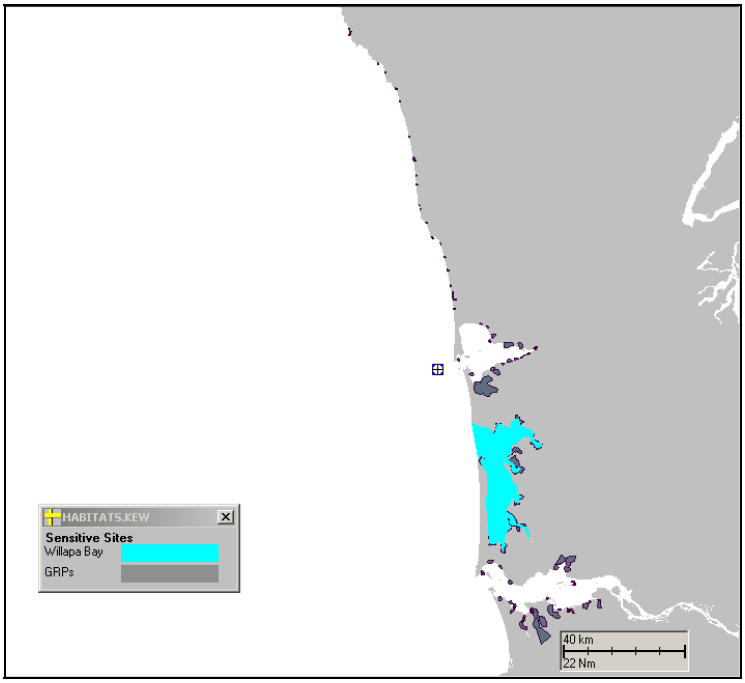


Figure XXIX.A-1 Sensitive sites for Grays Harbor scenario.

XXIX.B. OIL FATE OVER TIME

The tables in this section summarize the fate of the oil over time. Tables XXIX.B-1 to XXIX.B-12 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 XXIX.B-1 to XXIX.B-11 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 XXIX.B-13 to XXIX.B-16 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 Etkin 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 some cases.

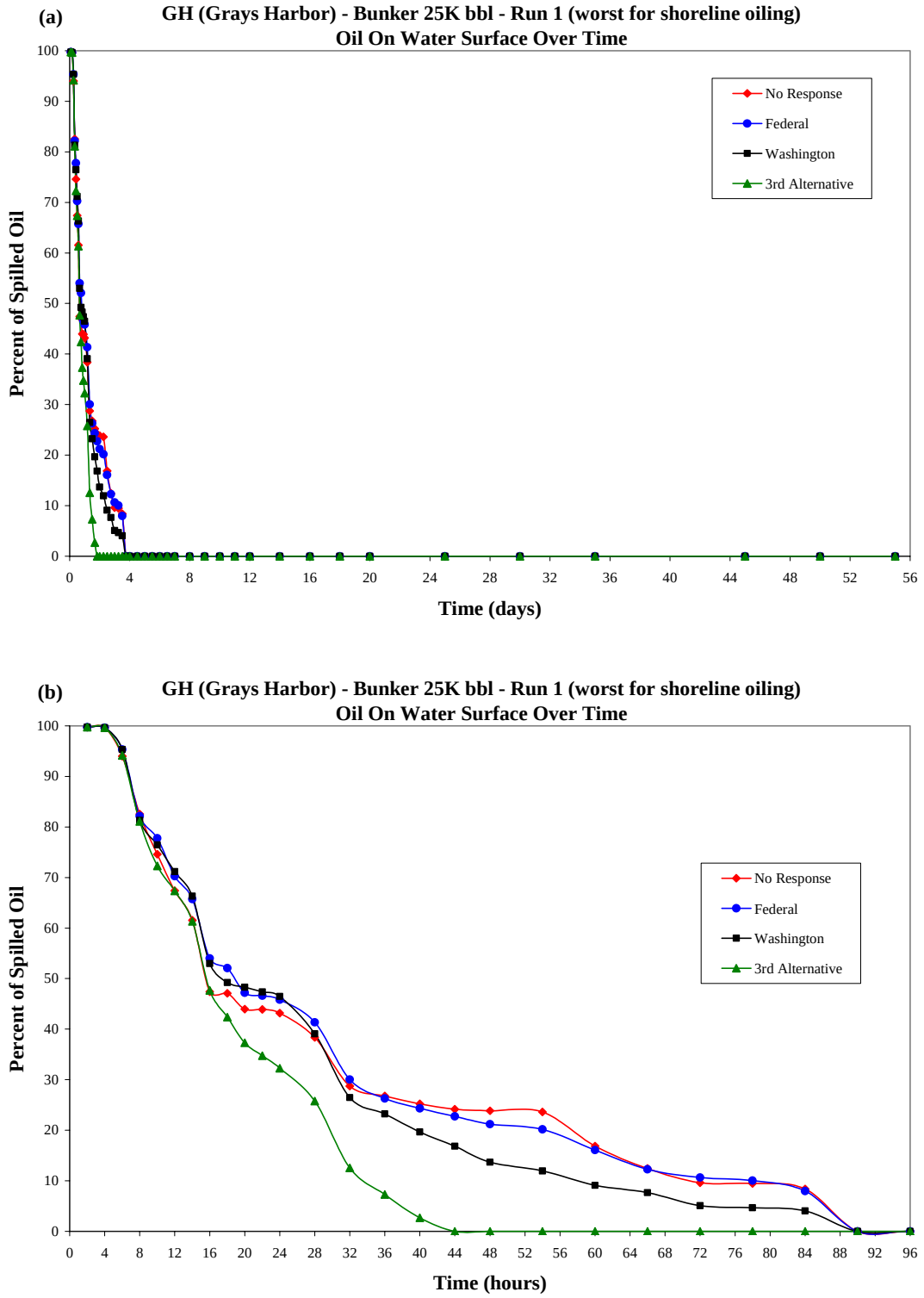
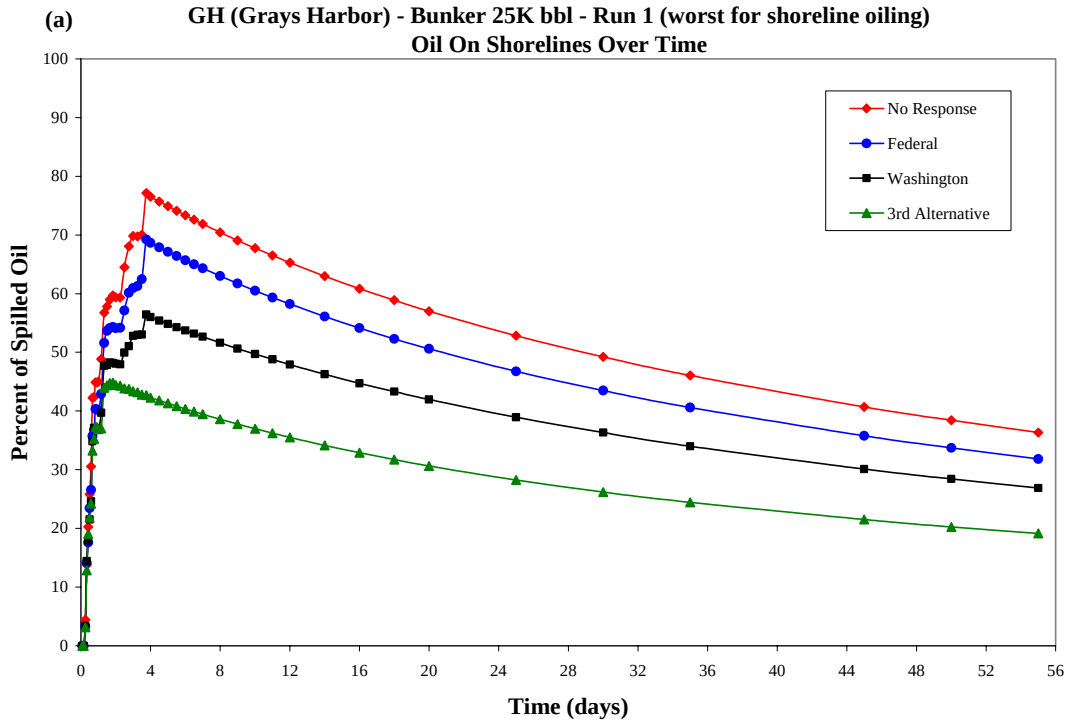


Figure XXIX.B-1 Grays Harbor - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b is a subset of Part a.



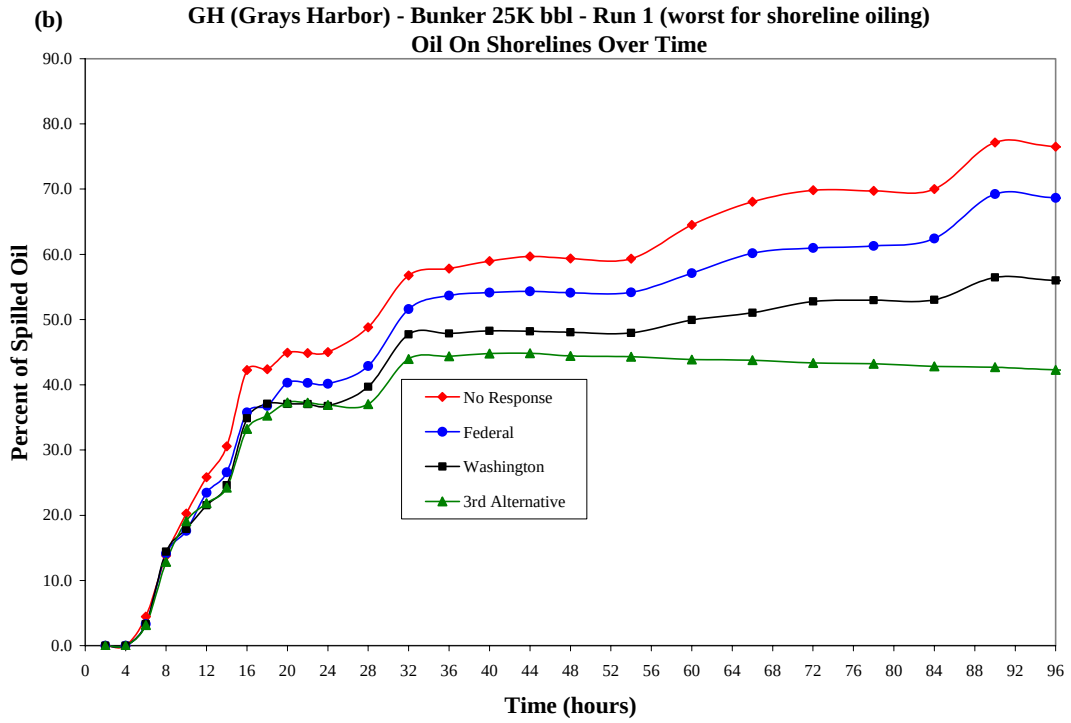
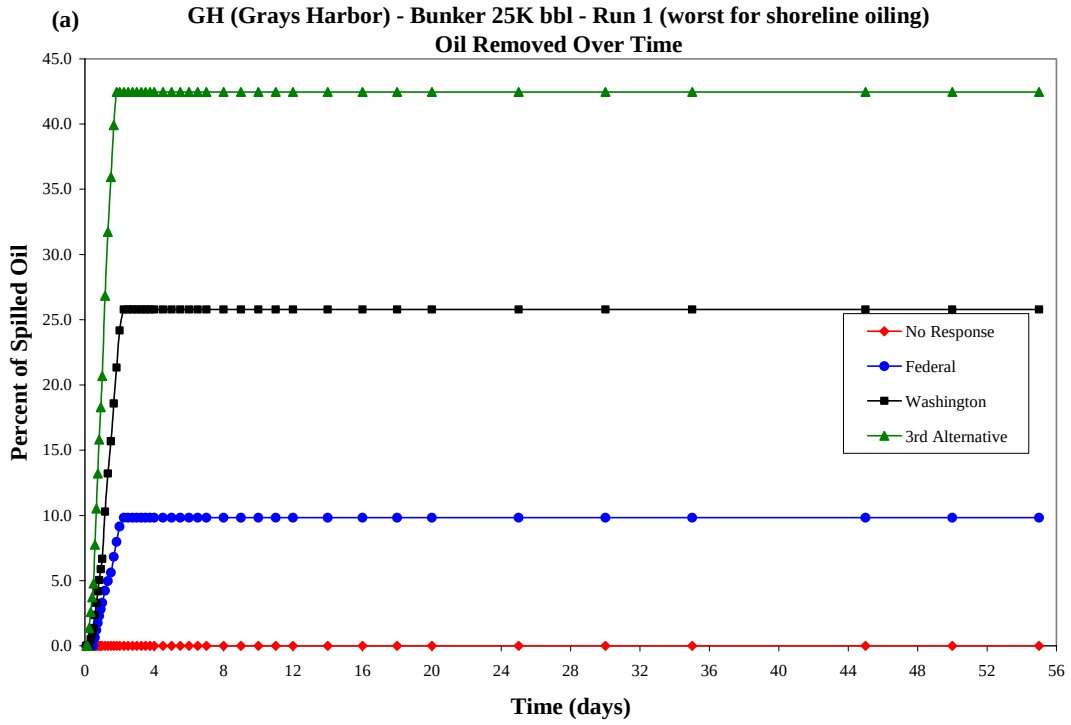


Figure XXIX.B-2 Grays Harbor - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



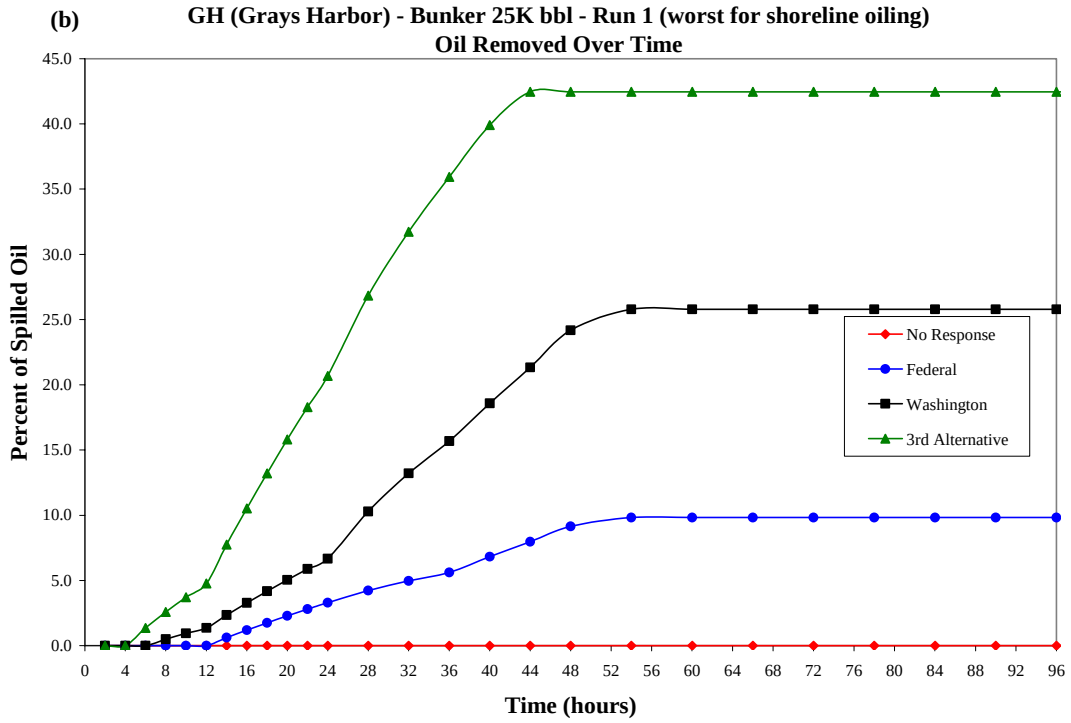
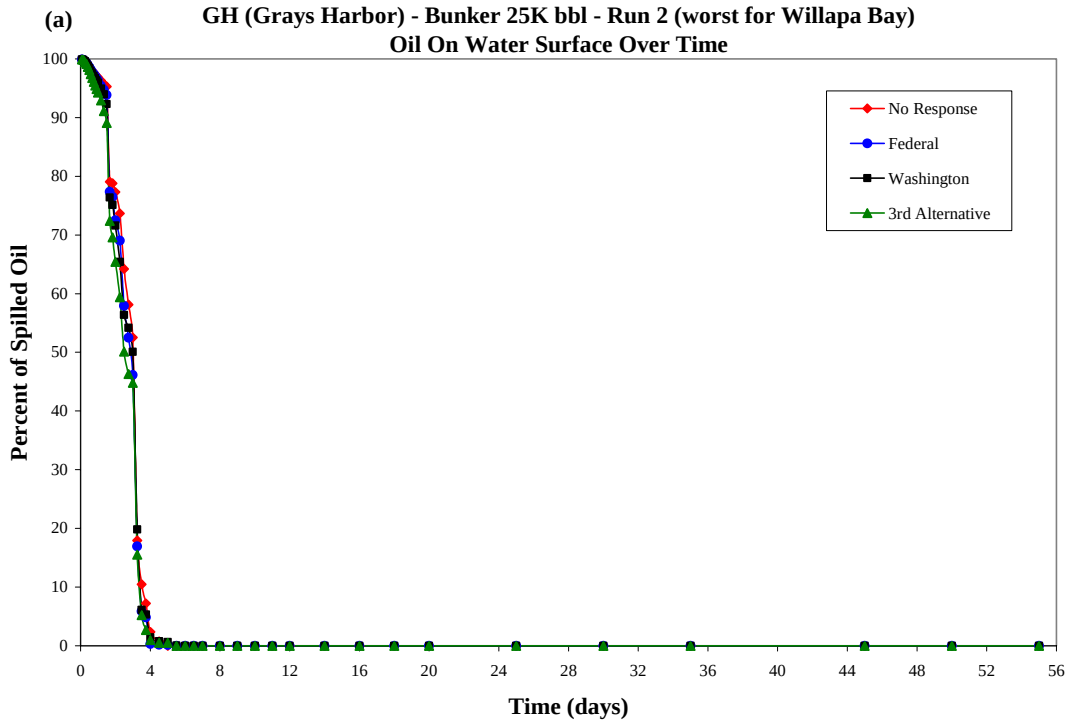


Figure XXIX.B-3 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the 99th percentile run (based on shore cost). Part b of this figure is a subset of Part a.



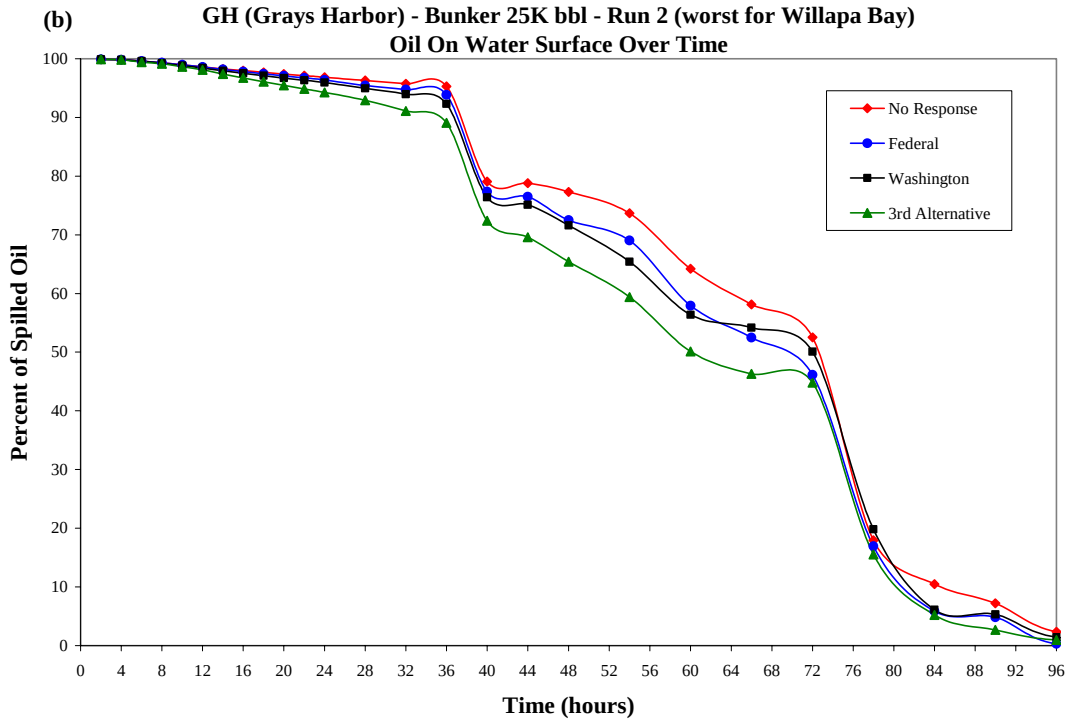
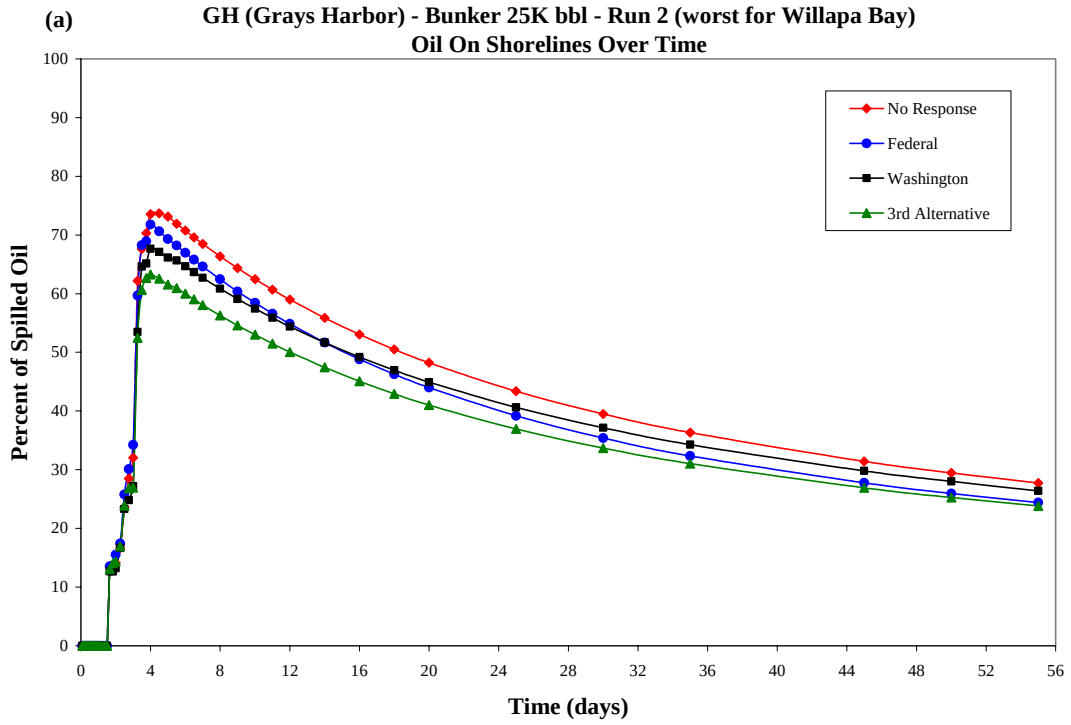


Figure XXIX.B-4 Grays Harbor - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for Willapa Bay. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



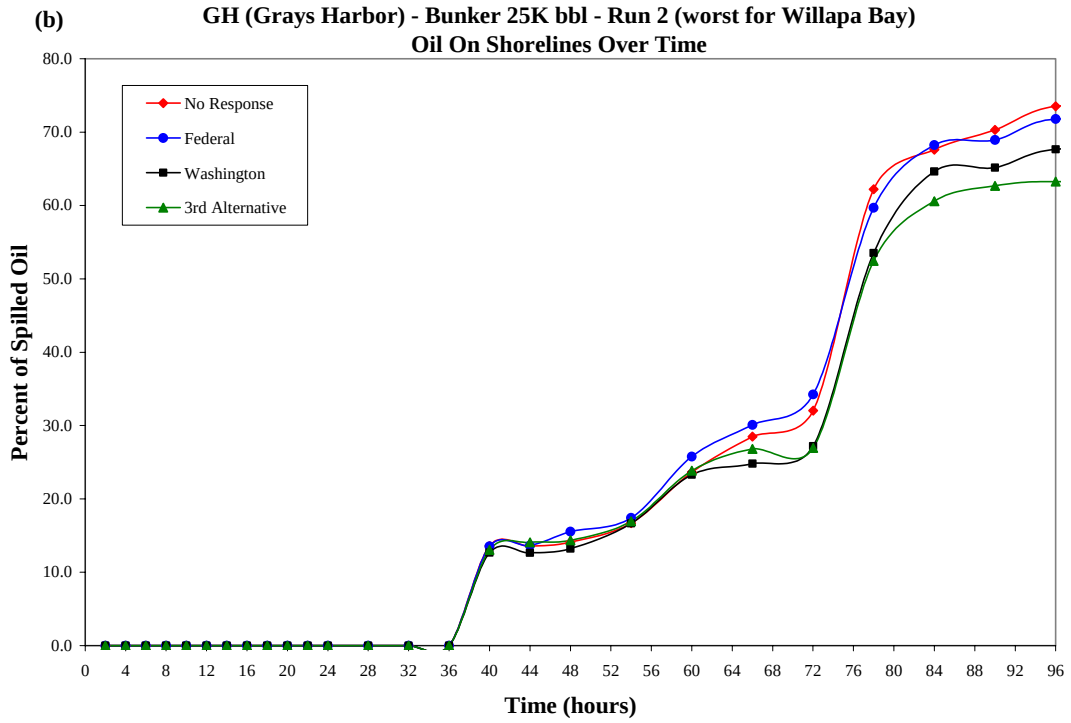
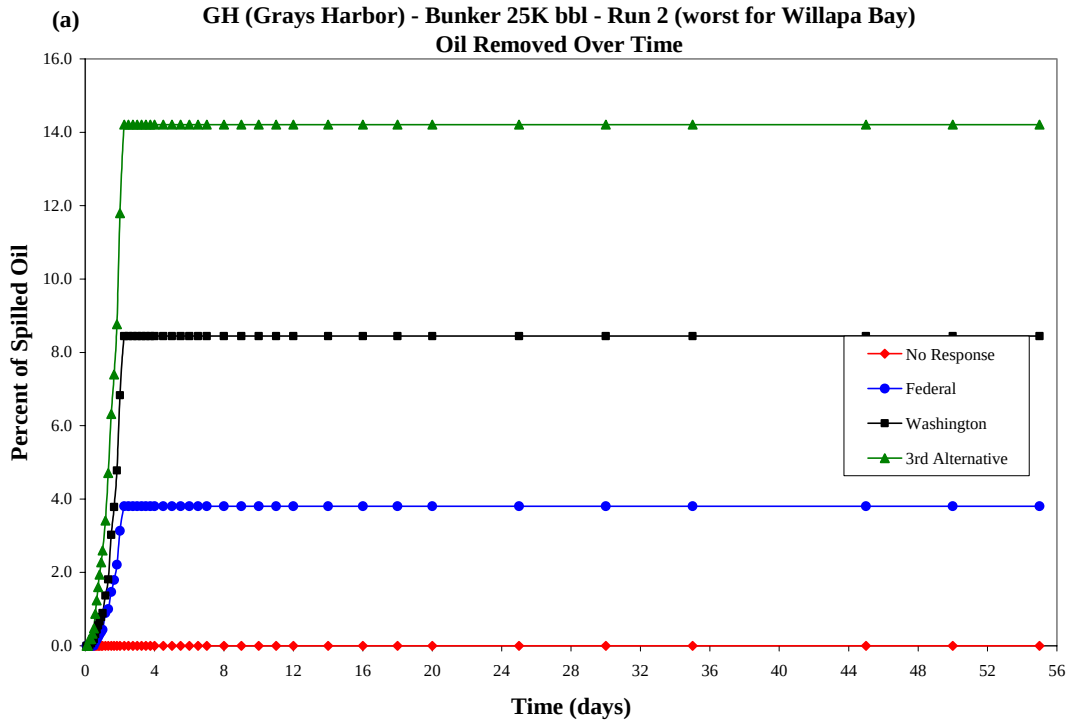


Figure XXIX.B-5 Grays Harbor - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for Willapa Bay. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)



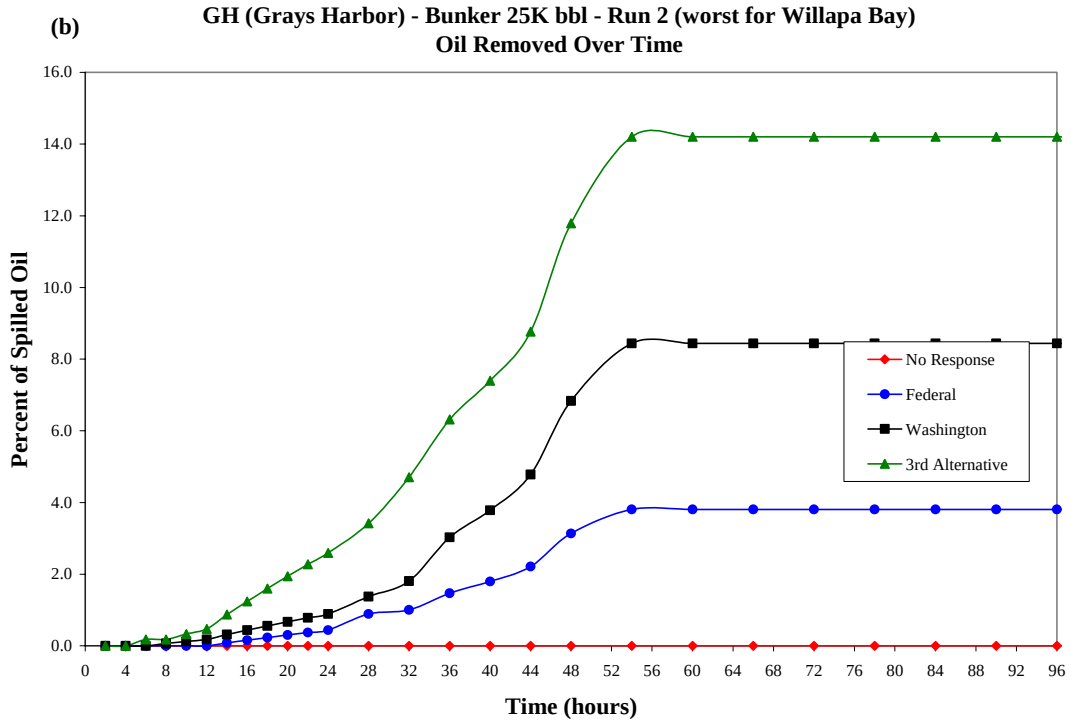
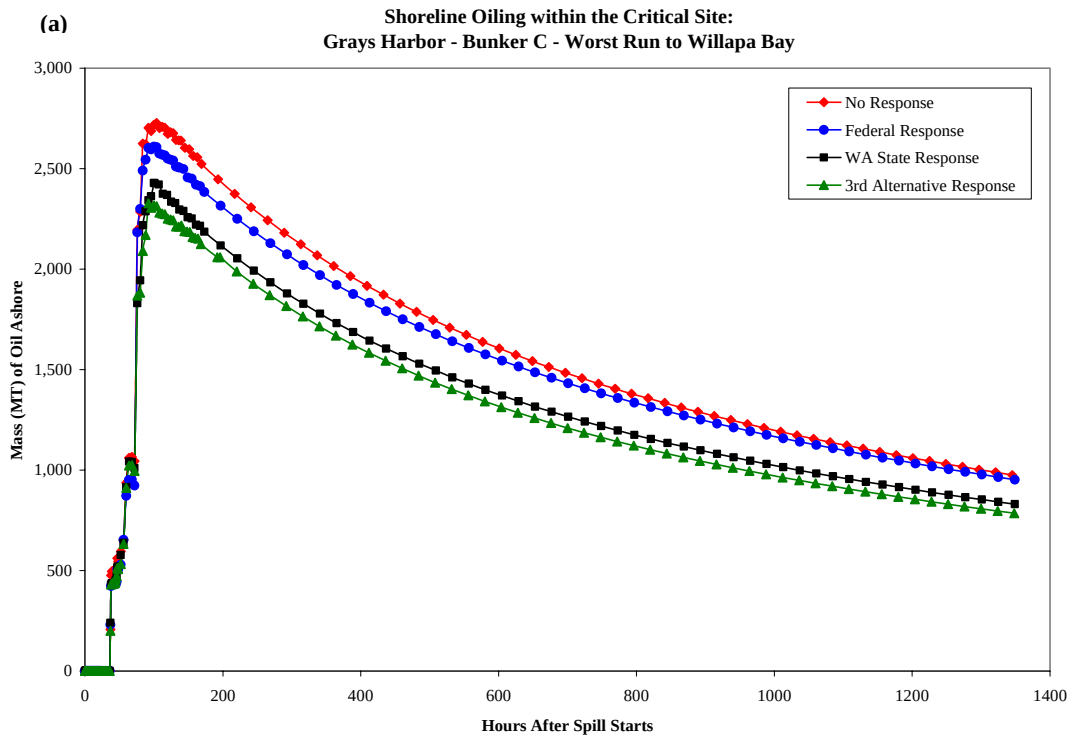


Figure XXIX.B-6 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for Willapa Bay. Part b is a subset of Part a.



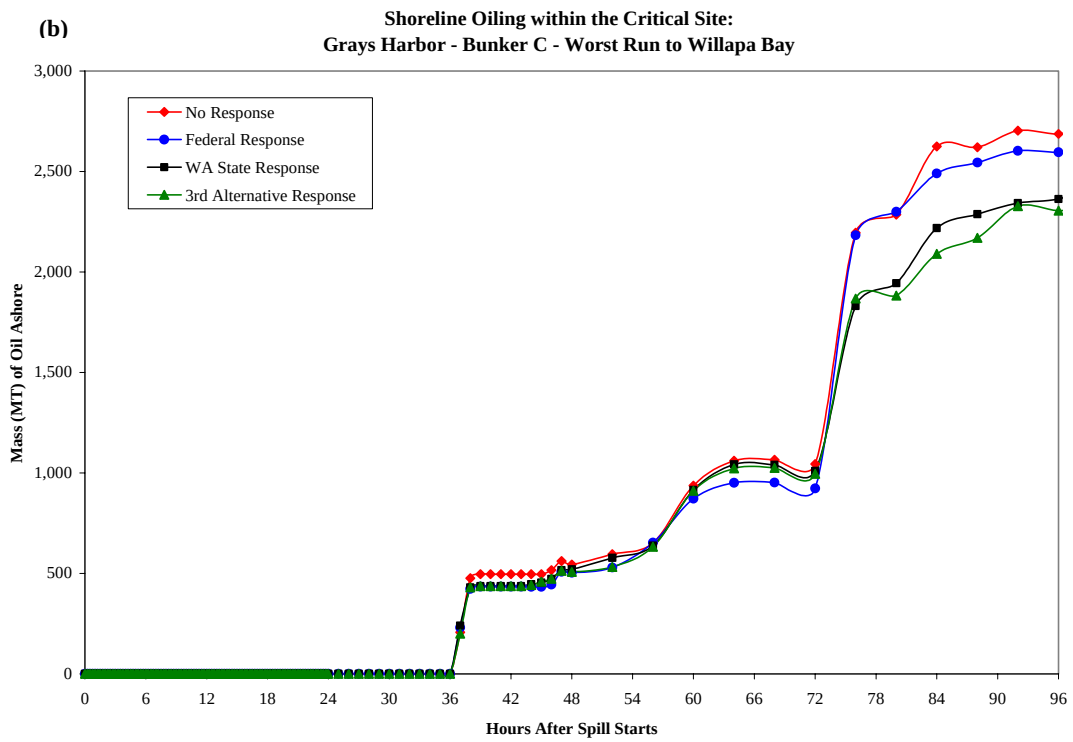


Figure XXIX.B-7 Grays Harbor - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for Willapa Bay. Part b is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

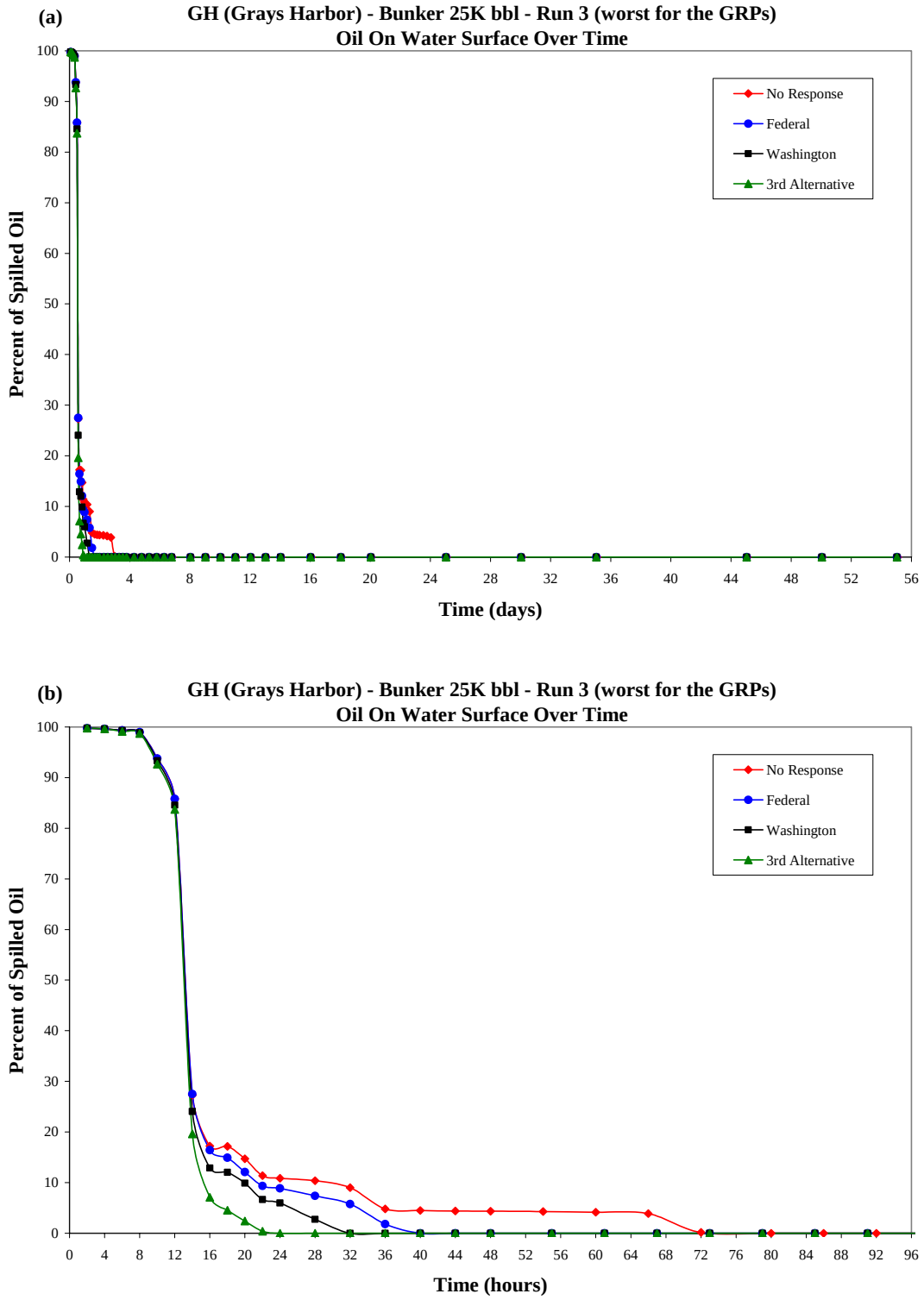
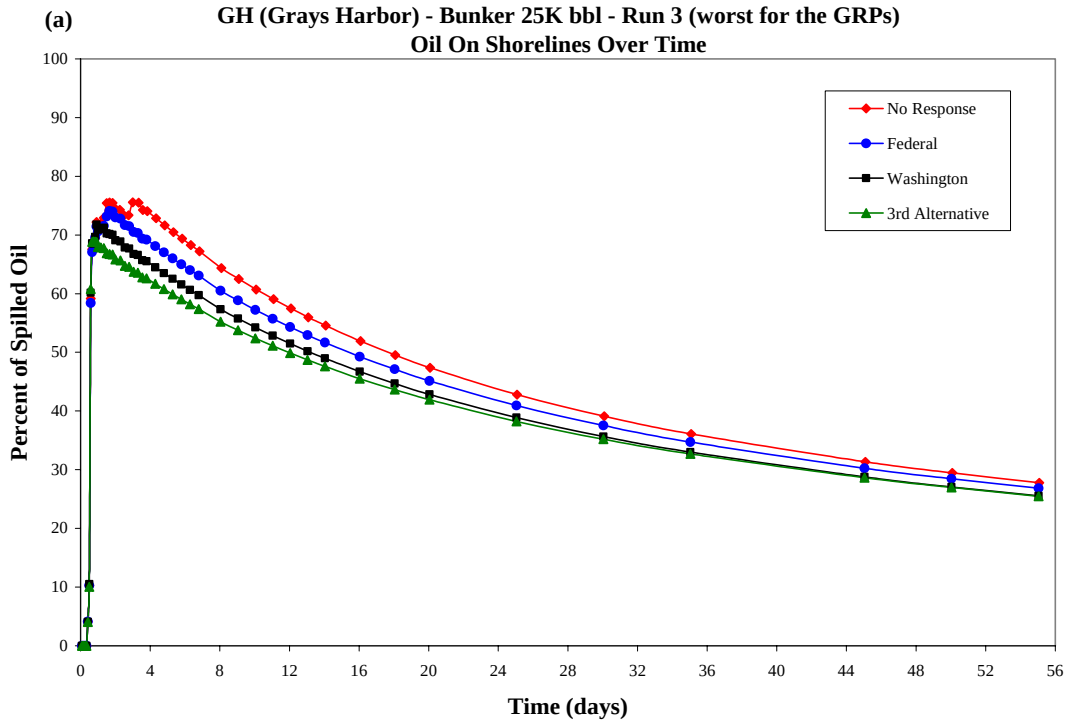


Figure XXIX.B-8 Grays Harbor - Bunker C: Percent of oil floating on the water surface over time for the 4 alternative response scenarios for the GRPs. Part b of this figure is a subset of Part a.



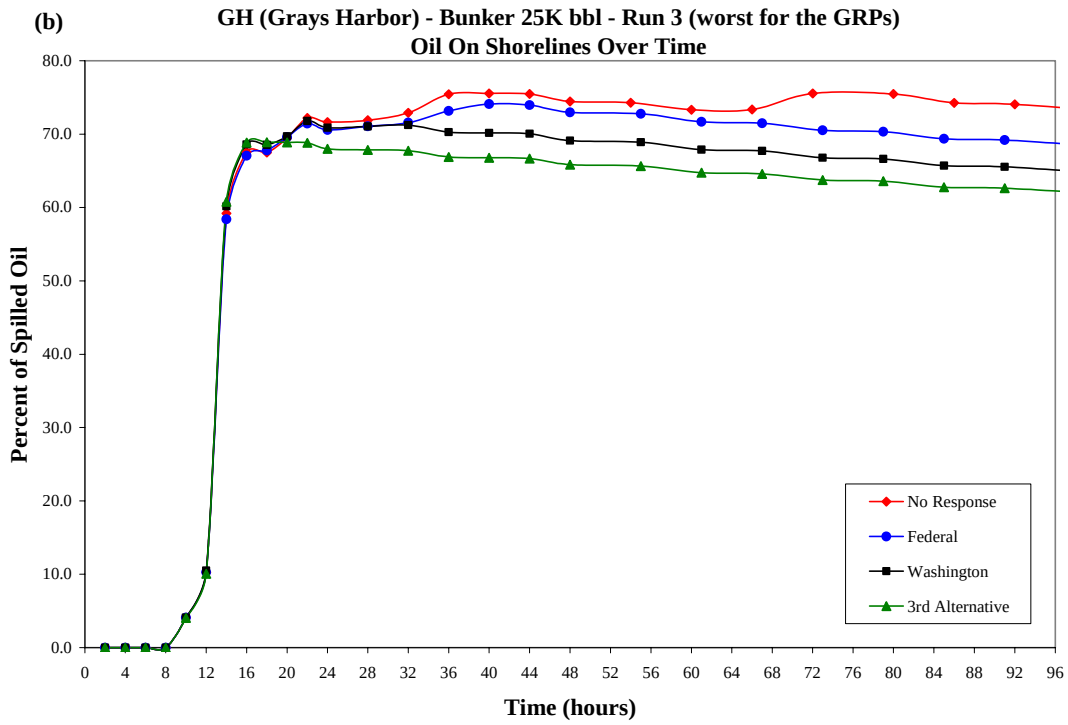


Figure XXIX.B-9 Grays Harbor - Bunker C: Percent of oil on the shoreline over time for the 4 alternative response scenarios for the the GRPs. Part b of this figure is a subset of Part a. (Differences between runs are less than the randomized variability in the model and are not significant.)

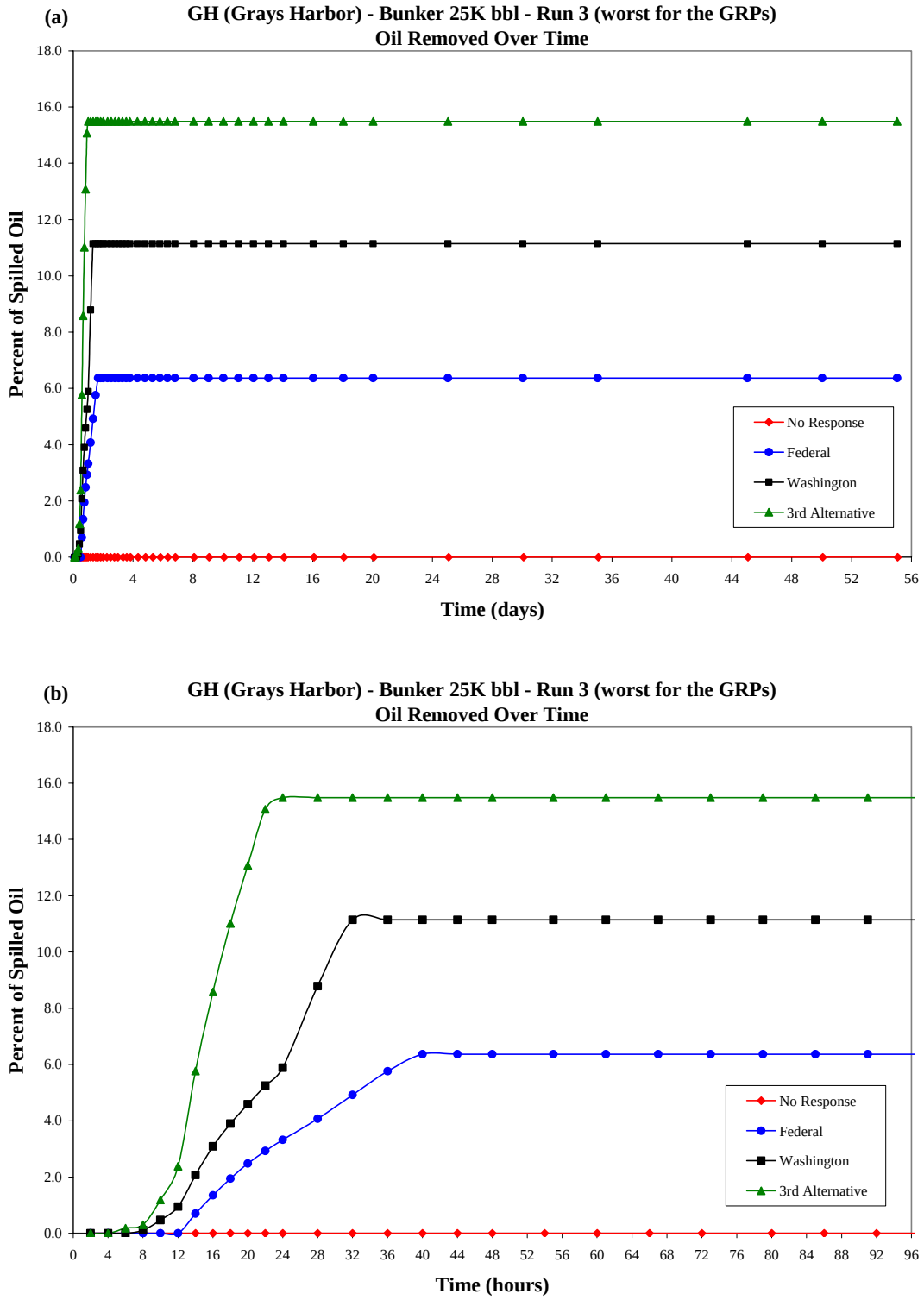


Figure XXIX.B-10 Grays Harbor - Bunker C: Percent of oil mechanically removed over time for the 4 alternative response scenarios for the GRPs. Part b of this figure is a subset of Part a.

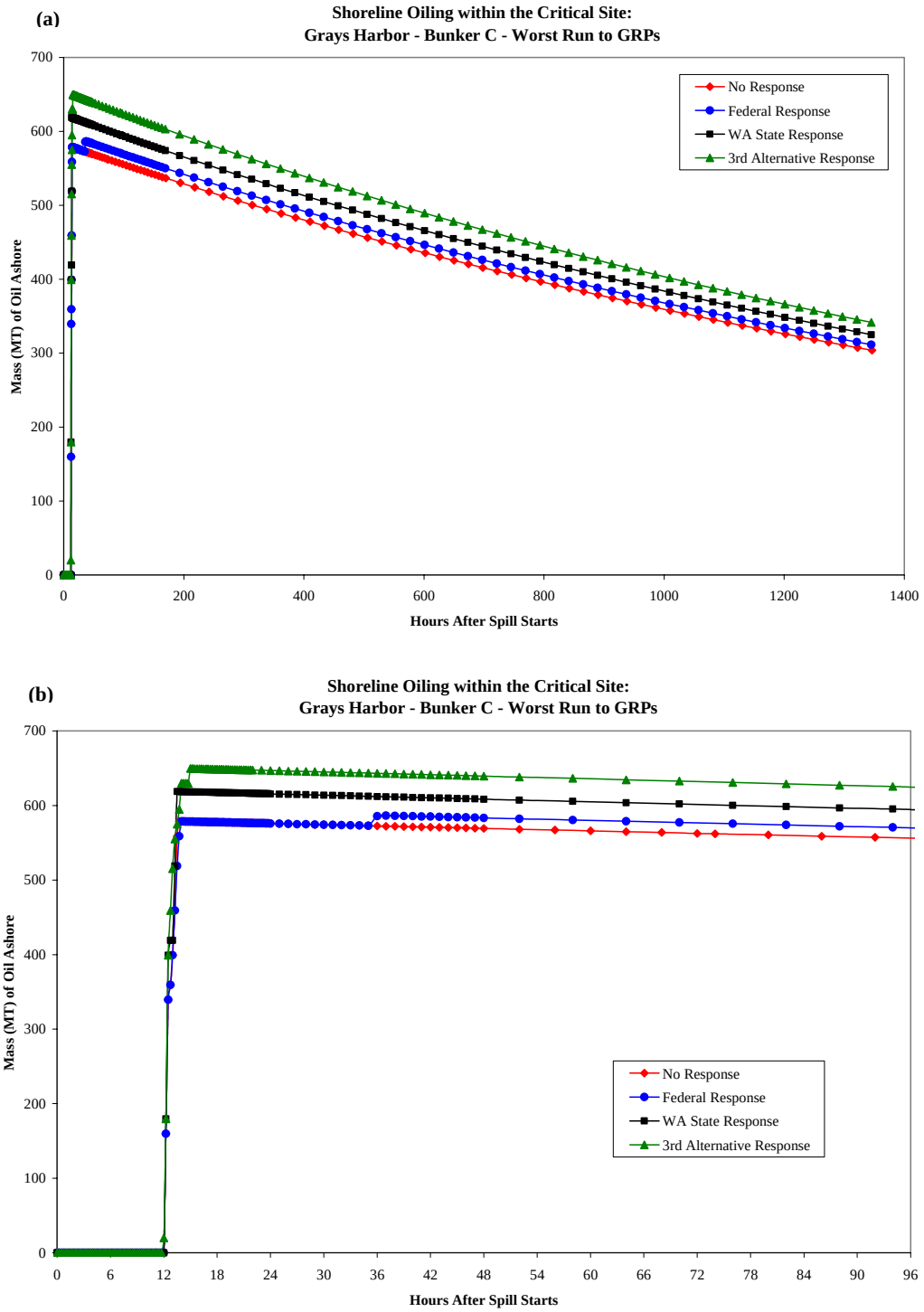


Figure XXIX.B-11 Grays Harbor - Bunker C: Amount of oil on the shoreline within the critical site over time for the 4 alternative response scenarios for the GRPs. (For this run, booming corralled oil into the critical site. Focused removal of corralled oil was not simulated, and so model results show oil collecting on shore within the site.)

Table XXIX.B-1 Grays Harbor - Bunker C, 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	0.083	99.7392	0.2141	0	0	0	0.0468	0	0	99.7392
4	0.167	99.6223	0.2893	0.0001	0	0	0.0883	0	0	99.6223
6	0.25	93.9801	1.3974	0.0001	0	4.4514	0.171	0	0	93.9801
8	0.333	82.5408	3.4135	0.0001	0	13.7933	0.2523	0	0	82.5408
10	0.417	74.5924	4.8172	0	0	20.2585	0.3318	0	0	74.5924
12	0.5	67.3696	6.107	0.2897	0	25.8235	0.4102	0	0	67.3696
14	0.583	61.535	7.1292	0.2541	0.033	30.5589	0.4899	0	0	61.535
16	0.667	47.4079	9.4855	0.1935	0.0902	42.2542	0.5687	0	0	47.4079
18	0.75	47.0985	9.6008	0.146	0.134	42.3737	0.647	0	0	47.0985
20	0.833	43.9639	10.1253	0.1235	0.1528	44.9095	0.7251	0	0	43.9639
22	0.917	43.8865	10.166	0.1028	0.1697	44.8721	0.8029	0	0	43.8865
24	1	43.1877	10.3155	0.4247	0.1869	45.0047	0.8806	0	0	43.1877
28	1.167	38.3804	11.1457	0.3058	0.2973	48.8357	1.0351	0	0	38.3804
32	1.333	28.7386	12.7091	0.1816	0.4122	56.7704	1.1881	0	0	28.7386
36	1.5	26.7782	13.0881	0.4763	0.4849	57.8327	1.3399	0	0	26.7782
40	1.667	25.2268	13.3587	0.369	0.5817	58.973	1.4909	0	0	25.2268
44	1.833	24.1678	13.559	0.2483	0.692	59.6917	1.6412	0	0	24.1678
48	2	23.8705	13.64	0.5595	0.7606	59.3785	1.791	0	0	23.8705
54	2.25	23.6198	13.7304	0.3792	0.9249	59.3313	2.0145	0	0	23.6198
60	2.5	16.8728	14.7241	0.5977	1.0713	64.4975	2.2366	0	0	16.8728
66	2.75	12.4544	15.3694	0.3726	1.2788	68.0683	2.4565	0	0	12.4544
72	3	9.6275	15.7678	0.7129	1.3872	69.8299	2.6746	0	0	9.6275
78	3.25	9.4874	15.8059	0.5626	1.5185	69.734	2.8916	0	0	9.4874
84	3.5	8.3711	15.9895	0.7597	1.7647	70.0076	3.1073	0	0	8.3711

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
90	3.75	0	17.0234	0.3081	2.1965	77.1512	3.3208	0	0	0
96	4	0	17.0234	0.5829	2.352	76.5092	3.5326	0	0	0
108	4.5	0	17.0234	0.6509	2.68	75.6926	3.953	0	0	0
120	5	0	17.0234	0.5701	3.1442	74.8936	4.3687	0	0	0
132	5.5	0	17.0234	0.5371	3.5483	74.1117	4.7795	0	0	0
144	6	0	17.0234	0.4719	3.973	73.3463	5.1854	0	0	0
156	6.5	0	17.0234	0.4588	4.3339	72.597	5.5869	0	0	0
168	7	0	17.0234	0.4543	4.675	71.8632	5.9841	0	0	0
192	8	0	17.0234	0.4565	5.3136	70.4406	6.7659	0	0	0
216	9	0	17.0234	0.396	5.9746	69.075	7.531	0	0	0
240	10	0	17.0234	0.3351	6.598	67.7631	8.2804	0	0	0
264	11	0	17.0234	0.3676	7.0929	66.5018	9.0144	0	0	0
288	12	0	17.0234	0.3345	7.6193	65.2882	9.7346	0	0	0
336	14	0	17.0234	0.2883	8.5617	62.9938	11.1328	0	0	0
384	16	0	17.0234	0.2438	9.3932	60.8603	12.4794	0	0	0
432	18	0	17.0234	0.2402	10.0893	58.8707	13.7764	0	0	0
480	20	0	17.0234	0.2622	10.675	57.0098	15.0296	0	0	0
600	25	0	17.0234	0.1535	12.0048	52.839	17.9793	0	0	0
720	30	0	17.0234	0.1279	12.9187	49.2296	20.7005	0	0	0
840	35	0	17.0234	0.111	13.5828	46.0606	23.2223	0	0	0
1080	45	0	17.0234	0.0801	14.4351	40.7114	27.75	0	0	0
1200	50	0	17.0234	0.0549	14.7153	38.4162	29.7902	0	0	0
1320	55	0	17.0234	0.0623	14.8944	36.3202	31.6998	0	0	0

Table XXIX.B-2 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7392	0.2141	0	0	0	0.0468	0	0	99.7392
4	0.167	99.6223	0.2893	0.0001	0	0	0.0883	0	0	99.6223
6	0.25	95.3331	1.1735	0.0001	0	3.3223	0.171	0	0	95.3331
8	0.333	82.151	3.4853	0.0001	0	14.1115	0.2522	0	0	82.151
10	0.417	77.7494	4.311	0	0	17.6076	0.332	0	0	77.7494
12	0.5	70.2654	5.631	0.2476	0	23.4453	0.4107	0	0	70.2654
14	0.583	65.718	6.3487	0.2171	0.0281	26.5804	0.4905	0.6171	0	65.718
16	0.667	54.0176	8.2313	0.1654	0.0771	35.7503	0.5691	1.1893	0	54.0176
18	0.75	52.0906	8.5235	0.1248	0.1145	36.752	0.6467	1.748	0	52.0906
20	0.833	47.196	9.2425	0.1056	0.1304	40.3194	0.7234	2.2826	0	47.196
22	0.917	46.6004	9.2858	0.0878	0.1447	40.2859	0.7995	2.7958	0	46.6004
24	1	45.8223	9.3724	0.3353	0.1592	40.1459	0.8751	3.2897	0	45.8223
28	1.167	41.3694	10.0093	0.2407	0.2464	42.8842	1.0243	4.2257	0	41.3694
32	1.333	30.0539	11.7239	0.1429	0.3358	51.6039	1.1705	4.969	0	30.0539
36	1.5	26.2837	12.2814	0.4461	0.3917	53.6745	1.3144	5.6081	0	26.2837
40	1.667	24.3257	12.4328	0.3477	0.4805	54.1413	1.4561	6.816	0	24.3257
44	1.833	22.7684	12.5365	0.2343	0.5844	54.321	1.5952	7.9602	0	22.7684
48	2	21.1944	12.6278	0.5277	0.6493	54.1219	1.7318	9.147	0	21.1944
54	2.25	20.1807	12.7248	0.3576	0.8048	54.182	1.9329	9.8173	0	20.1807
60	2.5	16.0779	13.3445	0.5645	0.9435	57.12	2.1323	9.8173	0	16.0779
66	2.75	12.2868	13.9055	0.3519	1.1403	60.1683	2.3299	9.8173	0	12.2868
72	3	10.6458	14.1482	0.6528	1.2439	60.9659	2.526	9.8173	0	10.6458
78	3.25	10.0461	14.2484	0.5142	1.3658	61.2872	2.7211	9.8173	0	10.0461
84	3.5	7.9623	14.5557	0.7118	1.5915	62.4465	2.9149	9.8173	0	7.9623
90	3.75	0	15.5453	0.2893	1.9961	69.2454	3.1066	9.8173	0	0

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	0	15.5453	0.5566	2.1429	68.6411	3.2967	9.8173	0	0
108	4.5	0	15.5453	0.6241	2.4583	67.8811	3.674	9.8173	0	0
120	5	0	15.5453	0.5474	2.9055	67.1376	4.0469	9.8173	0	0
132	5.5	0	15.5453	0.516	3.2958	66.4103	4.4153	9.8173	0	0
144	6	0	15.5453	0.4535	3.7062	65.6986	4.7791	9.8173	0	0
156	6.5	0	15.5453	0.4411	4.0554	65.0021	5.1388	9.8173	0	0
168	7	0	15.5453	0.4369	4.3858	64.3203	5.4945	9.8173	0	0
192	8	0	15.5453	0.4393	5.0047	62.9991	6.1943	9.8173	0	0
216	9	0	15.5453	0.3814	5.6457	61.7318	6.8786	9.8173	0	0
240	10	0	15.5453	0.323	6.2509	60.5153	7.5483	9.8173	0	0
264	11	0	15.5453	0.3545	6.7326	59.3466	8.2037	9.8173	0	0
288	12	0	15.5453	0.3228	7.2451	58.2231	8.8464	9.8173	0	0
336	14	0	15.5453	0.2786	8.1643	56.1016	10.0929	9.8173	0	0
384	16	0	15.5453	0.2359	8.9775	54.1324	11.2917	9.8173	0	0
432	18	0	15.5453	0.2327	9.6606	52.2992	12.4449	9.8173	0	0
480	20	0	15.5453	0.2542	10.2374	50.588	13.5578	9.8173	0	0
600	25	0	15.5453	0.1492	11.5511	46.765	16.172	9.8173	0	0
720	30	0	15.5453	0.1246	12.4625	43.4727	18.5777	9.8173	0	0
840	35	0	15.5453	0.1082	13.131	40.596	20.8022	9.8173	0	0
1080	45	0	15.5453	0.0781	14.0016	35.7726	24.7852	9.8173	0	0
1200	50	0	15.5453	0.0533	14.2923	33.716	26.5758	9.8173	0	0
1320	55	0	15.5453	0.0604	14.4827	31.8445	28.2497	9.8173	0	0

Table XXIX.B-3 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7392	0.2141	0	0	0	0.0468	0	0	99.7392
4	0.167	99.6223	0.2893	0.0001	0	0	0.0883	0	0	99.6223
6	0.25	95.3331	1.1735	0.0001	0	3.3223	0.171	0	0	95.3331
8	0.333	81.2885	3.5481	0.0001	0	14.4223	0.252	0.489	0	81.2885
10	0.417	76.4682	4.3634	0	0	17.8967	0.3313	0.9403	0	76.4682
12	0.5	71.1736	5.2629	0.2582	0	21.5336	0.4094	1.3623	0	71.1736
14	0.583	66.3252	5.9739	0.2265	0.0296	24.5993	0.488	2.3575	0	66.3252
16	0.667	52.9605	8.0668	0.1725	0.0809	34.8739	0.5652	3.2803	0	52.9605
18	0.75	49.2306	8.5876	0.1302	0.12	37.1096	0.6408	4.1811	0	49.2306
20	0.833	48.2886	8.6258	0.1101	0.1369	37.0797	0.7156	5.0433	0	48.2886
22	0.917	47.3767	8.6701	0.0916	0.1522	37.0488	0.7895	5.871	0	47.3767
24	1	46.4832	8.7281	0.3363	0.1678	36.7546	0.8627	6.6674	0	46.4832
28	1.167	39.1003	9.4019	0.241	0.2561	39.7062	1.0046	10.2899	0	39.1003
32	1.333	26.4568	10.9826	0.1431	0.3464	47.7232	1.1396	13.2083	0	26.4568
36	1.5	23.2431	11.1695	0.373	0.4033	47.8599	1.2691	15.682	0	23.2431
40	1.667	19.6748	11.3042	0.289	0.4788	48.2789	1.3936	18.5808	0	19.6748
44	1.833	16.8398	11.3521	0.1944	0.5649	48.209	1.5129	21.327	0	16.8398
48	2	13.6766	11.424	0.4243	0.6183	48.0542	1.6272	24.1754	0	13.6766
54	2.25	11.9556	11.4715	0.287	0.7428	47.9683	1.7908	25.7841	0	11.9556
60	2.5	9.1184	11.8966	0.4478	0.853	49.9475	1.9526	25.7841	0	9.1184
66	2.75	7.6504	12.1249	0.279	1.0085	51.0401	2.1131	25.7841	0	7.6504
72	3	5.0746	12.4812	0.5073	1.0895	52.791	2.2723	25.7841	0	5.0746
78	3.25	4.6897	12.5426	0.3991	1.1834	52.9704	2.4308	25.7841	0	4.6897
84	3.5	4.0584	12.6433	0.5377	1.3574	53.0308	2.5883	25.7841	0	4.0584

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
90	3.75	0	13.1417	0.2181	1.6625	56.4493	2.7444	25.7841	0	0
96	4	0	13.1417	0.4118	1.7721	55.991	2.8994	25.7841	0	0
108	4.5	0	13.1417	0.4596	2.0029	55.4048	3.2069	25.7841	0	0
120	5	0	13.1417	0.4024	2.3297	54.8311	3.5111	25.7841	0	0
132	5.5	0	13.1417	0.379	2.6139	54.2696	3.8117	25.7841	0	0
144	6	0	13.1417	0.3329	2.9126	53.7199	4.1089	25.7841	0	0
156	6.5	0	13.1417	0.3236	3.1662	53.1816	4.4028	25.7841	0	0
168	7	0	13.1417	0.3203	3.4058	52.6545	4.6937	25.7841	0	0
192	8	0	13.1417	0.3217	3.854	51.6322	5.2664	25.7841	0	0
216	9	0	13.1417	0.2789	4.3178	50.6504	5.8271	25.7841	0	0
240	10	0	13.1417	0.2359	4.7548	49.707	6.3765	25.7841	0	0
264	11	0	13.1417	0.2587	5.1012	48.7995	6.9148	25.7841	0	0
288	12	0	13.1417	0.2353	5.4697	47.9261	7.4431	25.7841	0	0
336	14	0	13.1417	0.2026	6.1284	46.2737	8.4695	25.7841	0	0
384	16	0	13.1417	0.1712	6.7087	44.7358	9.4586	25.7841	0	0
432	18	0	13.1417	0.1686	7.1935	43.3001	10.412	25.7841	0	0
480	20	0	13.1417	0.1839	7.6006	41.9561	11.3337	25.7841	0	0
600	25	0	13.1417	0.1075	8.5234	38.9381	13.5052	25.7841	0	0
720	30	0	13.1417	0.0896	9.1545	36.3191	15.5111	25.7841	0	0
840	35	0	13.1417	0.0778	9.6113	34.0132	17.3719	25.7841	0	0
1080	45	0	13.1417	0.0564	10.1948	30.1058	20.7173	25.7841	0	0
1200	50	0	13.1417	0.0388	10.3861	28.4231	22.2263	25.7841	0	0
1320	55	0	13.1417	0.0443	10.5075	26.8832	23.6393	25.7841	0	0

Table XXIX.B-4 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the 99th percentile run (based on shore cost). (Note that occasional storms cause short-lived peaks in the percent in the water column, followed by resurfacing of oil.)

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	0.083	99.7392	0.2141	0	0	0	0.0468	0	0	99.7392
4	0.167	99.6223	0.2893	0.0001	0	0	0.0883	0	0	99.6223
6	0.25	94.1723	1.1414	0.0001	0	3.1601	0.1706	1.3556	0	94.1723
8	0.333	81.095	3.2364	0.0001	0	12.8403	0.2501	2.5781	0	81.095
10	0.417	72.2872	4.5968	0	0	19.0824	0.3271	3.7063	0	72.2872
12	0.5	67.3576	5.3432	0.2816	0	21.8538	0.4025	4.7613	0	67.3576
14	0.583	61.3401	5.9204	0.247	0.0325	24.2354	0.4776	7.747	0	61.3401
16	0.667	47.6697	7.763	0.1882	0.0887	33.2257	0.5496	10.5152	0	47.6697
18	0.75	42.3947	8.2378	0.142	0.1318	35.2573	0.6187	13.2178	0	42.3947
20	0.833	37.2948	8.6611	0.1201	0.1505	37.2836	0.6854	15.8044	0	37.2948
22	0.917	34.7467	8.6962	0.0999	0.1675	37.2526	0.7498	18.2873	0	34.7467
24	1	32.285	8.7407	0.3824	0.1848	36.9187	0.812	20.6765	0	32.285
28	1.167	25.7963	8.8566	0.2745	0.2859	37.0229	0.929	26.8348	0	25.7963
32	1.333	12.5382	10.1963	0.163	0.3904	43.9513	1.0355	31.7253	0	12.5382
36	1.5	7.2906	10.3884	0.4318	0.4568	44.3681	1.1336	35.9306	0	7.2906
40	1.667	2.6969	10.491	0.3347	0.5459	44.8031	1.2244	39.904	0	2.6969
44	1.833	0	10.5133	0.2252	0.6474	44.8397	1.3086	42.4657	0	0
48	2	0	10.5133	0.4943	0.7111	44.4245	1.391	42.4657	0	0
54	2.25	0	10.5133	0.3345	0.8589	44.3138	1.5138	42.4657	0	0
60	2.5	0	10.5133	0.5211	0.9904	43.8734	1.636	42.4657	0	0
66	2.75	0	10.5133	0.3246	1.175	43.7641	1.7573	42.4657	0	0
72	3	0	10.5133	0.5337	1.2737	43.3356	1.8779	42.4657	0	0
78	3.25	0	10.5133	0.4169	1.3786	43.2277	1.9978	42.4657	0	0
84	3.5	0	10.5133	0.5294	1.564	42.8106	2.117	42.4657	0	0

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
90	3.75	0	10.5133	0.2136	1.8683	42.704	2.2351	42.4657	0	0
96	4	0	10.5133	0.3919	1.9787	42.298	2.3524	42.4657	0	0
108	4.5	0	10.5133	0.4345	2.2041	41.7975	2.5849	42.4657	0	0
120	5	0	10.5133	0.3796	2.5183	41.3087	2.8145	42.4657	0	0
132	5.5	0	10.5133	0.3572	2.7916	40.8311	3.0411	42.4657	0	0
144	6	0	10.5133	0.3135	3.0782	40.3645	3.2647	42.4657	0	0
156	6.5	0	10.5133	0.3046	3.3222	39.9086	3.4856	42.4657	0	0
168	7	0	10.5133	0.3013	3.5528	39.4629	3.7039	42.4657	0	0
192	8	0	10.5133	0.3024	3.9843	38.6013	4.133	42.4657	0	0
216	9	0	10.5133	0.2619	4.43	37.7772	4.5519	42.4657	0	0
240	10	0	10.5133	0.2212	4.8498	36.9884	4.9615	42.4657	0	0
264	11	0	10.5133	0.2423	5.1841	36.2329	5.3617	42.4657	0	0
288	12	0	10.5133	0.2201	5.5384	35.5087	5.7538	42.4657	0	0
336	14	0	10.5133	0.189	6.1722	34.1468	6.5129	42.4657	0	0
384	16	0	10.5133	0.1592	6.7305	32.8897	7.2416	42.4657	0	0
432	18	0	10.5133	0.1563	7.1979	31.7256	7.9412	42.4657	0	0
480	20	0	10.5133	0.1699	7.5911	30.6445	8.6154	42.4657	0	0
600	25	0	10.5133	0.0984	8.4784	28.249	10.1952	42.4657	0	0
720	30	0	10.5133	0.081	9.087	26.2079	11.6451	42.4657	0	0
840	35	0	10.5133	0.0694	9.528	24.4402	12.9834	42.4657	0	0
1080	45	0	10.5133	0.0487	10.0913	21.5057	15.3752	42.4657	0	0
1200	50	0	10.5133	0.0329	10.2751	20.2637	16.4494	42.4657	0	0
1320	55	0	10.5133	0.0368	10.394	19.1371	17.4531	42.4657	0	0

Table XXIX.B-5 Grays Harbor - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa 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	0.083	99.8997	0.0535	0	0	0	0.0468	0	0	99.8997
4	0.167	99.8347	0.0767	0.0001	0	0	0.0884	0	0	99.8347
6	0.25	99.6035	0.2249	0.0001	0	0	0.1715	0	0	99.6035
8	0.333	99.3188	0.4267	0.0001	0	0	0.2544	0	0	99.3188
10	0.417	98.953	0.7099	0	0	0	0.337	0	0	98.953
12	0.5	98.5843	0.9963	0	0.0001	0	0.4193	0	0	98.5843
14	0.583	98.2542	1.2444	0	0.0001	0	0.5013	0	0	98.2542
16	0.667	97.9602	1.4566	0	0.0001	0	0.5831	0	0	97.9602
18	0.75	97.6686	1.6668	0	0.0001	0	0.6646	0	0	97.6686
20	0.833	97.3791	1.875	0	0.0001	0	0.7458	0	0	97.3791
22	0.917	97.1067	2.0664	0	0.0001	0	0.8268	0	0	97.1067
24	1	96.8381	2.2541	0	0.0001	0	0.9076	0	0	96.8381
28	1.167	96.2998	2.6315	0	0.0001	0	1.0686	0	0	96.2998
32	1.333	95.7487	3.0226	0	0.0001	0	1.2286	0	0	95.7487
36	1.5	95.2855	3.3267	0	0.0001	0	1.3877	0	0	95.2855
40	1.667	79.0716	5.8121	0	0	13.5728	1.5434	0	0	79.0716
44	1.833	78.7781	5.9659	0	0	13.5585	1.6976	0	0	78.7781
48	2	77.2995	6.2971	0.4315	0	14.1207	1.8511	0	0	77.2995
54	2.25	73.6613	7.1395	0.1745	0.2524	16.6895	2.0828	0	0	73.6613
60	2.5	64.2053	8.7075	0.7864	0.357	23.6321	2.3117	0	0	64.2053
66	2.75	58.1454	9.6911	0.3594	0.7762	28.4902	2.5377	0	0	58.1454
72	3	52.5334	10.5832	1.1146	0.9787	32.029	2.7611	0	0	52.5334
78	3.25	17.9432	14.7991	0.3989	1.6792	62.1998	2.9798	0	0	17.9432
84	3.5	10.4874	15.6947	1.1235	1.8961	67.6027	3.1956	0	0	10.4874
90	3.75	7.2169	16.0718	0.5459	2.4544	70.3018	3.4092	0	0	7.2169
96	4	2.3728	16.5827	1.2104	2.698	73.515	3.621	0	0	2.3728

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	4.5	0.7571	16.7538	1.1344	3.6394	73.6768	4.0385	0	0	0.7571
120	5	0	16.8253	1.2085	4.4013	73.116	4.4489	0	0	0
132	5.5	0	16.8253	1.2203	5.1958	71.9059	4.8527	0	0	0
144	6	0	16.8253	1.0736	6.1211	70.7309	5.2492	0	0	0
156	6.5	0	16.8253	1.1198	6.8261	69.5898	5.639	0	0	0
168	7	0	16.8253	1.1097	7.5613	68.4815	6.0223	0	0	0
192	8	0	16.8253	1.2526	8.7918	66.3586	6.7717	0	0	0
216	9	0	16.8253	0.9458	10.379	64.3541	7.4959	0	0	0
240	10	0	16.8253	0.9981	11.5197	62.46	8.1969	0	0	0
264	11	0	16.8253	0.9523	12.6747	60.6693	8.8784	0	0	0
288	12	0	16.8253	0.6532	14.0099	58.9751	9.5366	0	0	0
336	14	0	16.8253	0.6931	15.833	55.8515	10.7971	0	0	0
384	16	0	16.8253	0.5086	17.6332	53.044	11.9888	0	0	0
432	18	0	16.8253	0.5058	19.0381	50.5131	13.1177	0	0	0
480	20	0	16.8253	0.4914	20.2691	48.2244	14.1898	0	0	0
600	25	0	16.8253	0.3225	22.8178	43.3767	16.6576	0	0	0
720	30	0	16.8253	0.1997	24.6054	39.4985	18.8712	0	0	0
840	35	0	16.8253	0.1895	25.7774	36.3286	20.8792	0	0	0
1080	45	0	16.8253	0.0952	27.2442	31.4285	24.4069	0	0	0
1200	50	0	16.8253	0.0888	27.6403	29.4732	25.9724	0	0	0
1320	55	0	16.8253	0.0637	27.9326	27.7495	27.4289	0	0	0

Table XXIX.B-6 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa 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	0.083	99.8997	0.0535	0	0	0	0.0468	0	0	99.8997
4	0.167	99.8347	0.0767	0.0001	0	0	0.0884	0	0	99.8347
6	0.25	99.6035	0.2249	0.0001	0	0	0.1715	0	0	99.6035
8	0.333	99.3188	0.4267	0.0001	0	0	0.2544	0	0	99.3188
10	0.417	98.953	0.7099	0	0	0	0.337	0	0	98.953
12	0.5	98.5843	0.9963	0	0.0001	0	0.4193	0	0	98.5843
14	0.583	98.172	1.2444	0	0.0001	0	0.5013	0.0823	0	98.172
16	0.667	97.8018	1.4566	0	0.0001	0	0.5829	0.1586	0	97.8018
18	0.75	97.4359	1.6667	0	0.0001	0	0.6643	0.2331	0	97.4359
20	0.833	97.0755	1.8748	0	0.0001	0	0.7453	0.3043	0	97.0755
22	0.917	96.7352	2.0658	0	0.0001	0	0.8261	0.3728	0	96.7352
24	1	96.4018	2.253	0	0.0001	0	0.9065	0.4386	0	96.4018
28	1.167	95.4166	2.6283	0	0.0001	0	1.0664	0.8886	0	95.4166
32	1.333	94.7569	3.0165	0	0.0001	0	1.2249	1.0017	0	94.7569
36	1.5	93.8325	3.3175	0	0.0001	0	1.382	1.4679	0	93.8325
40	1.667	77.3343	5.7956	0	0	13.5397	1.535	1.7954	0	77.3343
44	1.833	76.486	5.9659	0	0	13.6504	1.6859	2.2118	0	76.486
48	2	72.5071	6.5127	0.4748	0	15.5366	1.8351	3.1336	0	72.5071
54	2.25	69.0254	7.2267	0.192	0.2779	17.4165	2.0576	3.8039	0	69.0254
60	2.5	57.9149	8.9769	0.8583	0.3931	25.7761	2.2769	3.8039	0	57.9149
66	2.75	52.5009	9.8594	0.3923	0.8508	30.0995	2.4932	3.8039	0	52.5009
72	3	46.1377	10.8406	1.2066	1.0718	34.2326	2.7069	3.8039	0	46.1377
78	3.25	16.9371	14.4159	0.4318	1.8316	59.6637	2.9161	3.8039	0	16.9371
84	3.5	5.863	15.697	1.2205	2.0681	68.2251	3.1225	3.8039	0	5.863
90	3.75	4.8457	15.825	0.5931	2.6762	68.9296	3.3264	3.8039	0	4.8457
96	4	0.3187	16.3002	1.3191	2.943	71.7865	3.5286	3.8039	0	0.3187

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	4.5	0.1551	16.3174	1.2265	3.9734	70.5971	3.9268	3.8039	0	0.1551
120	5	0.1535	16.3182	1.3025	4.802	69.3024	4.3176	3.8039	0	0.1535
132	5.5	0	16.3318	1.3141	5.663	68.1858	4.7015	3.8039	0	0
144	6	0	16.3318	1.1555	6.6639	66.9671	5.0778	3.8039	0	0
156	6.5	0	16.3318	1.2049	7.4273	65.7848	5.4473	3.8039	0	0
168	7	0	16.3318	1.1937	8.2229	64.6377	5.81	3.8039	0	0
192	8	0	16.3318	1.3468	9.5553	62.4445	6.5177	3.8039	0	0
216	9	0	16.3318	1.0162	11.2704	60.3783	7.1994	3.8039	0	0
240	10	0	16.3318	1.0718	12.5046	58.4306	7.8573	3.8039	0	0
264	11	0	16.3318	1.0221	13.7532	56.5938	8.4953	3.8039	0	0
288	12	0	16.3318	0.7005	15.1944	54.8603	9.1091	3.8039	0	0
336	14	0	16.3318	0.7423	17.165	51.6769	10.2801	3.8039	0	0
384	16	0	16.3318	0.5439	19.108	48.8311	11.3813	3.8039	0	0
432	18	0	16.3318	0.5401	20.6248	46.2804	12.4191	3.8039	0	0
480	20	0	16.3318	0.5238	21.9533	43.9875	13.3998	3.8039	0	0
600	25	0	16.3318	0.3421	24.6994	39.1822	15.6406	3.8039	0	0
720	30	0	16.3318	0.2105	26.6225	35.3996	17.6318	3.8039	0	0
840	35	0	16.3318	0.1984	27.8831	32.3582	19.4246	3.8039	0	0
1080	45	0	16.3318	0.0978	29.4561	27.7623	22.5482	3.8039	0	0
1200	50	0	16.3318	0.0901	29.8812	25.9672	23.9259	3.8039	0	0
1320	55	0	16.3318	0.0639	30.1938	24.4026	25.2041	3.8039	0	0

Table XXIX.B-7 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa 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	0.083	99.8997	0.0535	0	0	0	0.0468	0	0	99.8997
4	0.167	99.8347	0.0767	0.0001	0	0	0.0884	0	0	99.8347
6	0.25	99.6035	0.2249	0.0001	0	0	0.1715	0	0	99.6035
8	0.333	99.2537	0.4266	0.0001	0	0	0.2544	0.0652	0	99.2537
10	0.417	98.8278	0.7098	0	0	0	0.3369	0.1254	0	98.8278
12	0.5	98.4031	0.9961	0	0.0001	0	0.4191	0.1816	0	98.4031
14	0.583	97.9407	1.244	0	0.0001	0	0.5009	0.3143	0	97.9407
16	0.667	97.5244	1.4558	0	0.0001	0	0.5823	0.4374	0	97.5244
18	0.75	97.114	1.665	0	0.0001	0	0.6634	0.5575	0	97.114
20	0.833	96.7115	1.8718	0	0.0001	0	0.7442	0.6724	0	96.7115
22	0.917	96.3307	2.0618	0	0.0001	0	0.8246	0.7828	0	96.3307
24	1	95.9579	2.2482	0	0.0001	0	0.9047	0.889	0	95.9579
28	1.167	94.943	2.6211	0	0.0001	0	1.0638	1.372	0	94.943
32	1.333	93.9633	3.0056	0	0.0001	0	1.2212	1.8098	0	93.9633
36	1.5	92.2934	3.3033	0	0.0001	0	1.3767	3.0264	0	92.2934
40	1.667	76.3922	5.6277	0	0	12.6714	1.527	3.7817	0	76.3922
44	1.833	75.1096	5.7761	0	0	12.6587	1.6745	4.781	0	75.1096
48	2	71.6048	6.0983	0.4046	0	13.2405	1.8192	6.8325	0	71.6048
54	2.25	65.4222	7.0429	0.1636	0.2366	16.6623	2.031	8.4412	0	65.4222
60	2.5	56.3813	8.5253	0.7724	0.3343	23.3062	2.2393	8.4412	0	56.3813
66	2.75	54.1929	9.0116	0.3531	0.7463	24.8099	2.445	8.4412	0	54.1929
72	3	50.0693	9.7282	0.9762	0.946	27.1905	2.6484	8.4412	0	50.0693
78	3.25	19.8478	13.4482	0.349	1.5603	53.5058	2.8477	8.4412	0	19.8478
84	3.5	6.119	15.0387	0.9701	1.7495	64.6373	3.0442	8.4412	0	6.119
90	3.75	5.3204	15.144	0.4713	2.2304	65.1541	3.2385	8.4412	0	5.3204

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	1.444	15.5564	1.0431	2.4398	67.6443	3.4313	8.4412	0	1.444
108	4.5	0.7892	15.6289	0.9699	3.249	67.1101	3.8117	8.4412	0	0.7892
120	5	0.6508	15.6441	1.0305	3.8987	66.1489	4.1858	8.4412	0	0.6508
132	5.5	0.0174	15.7004	1.04	4.574	65.6728	4.5542	8.4412	0	0.0174
144	6	0	15.7019	0.9147	5.3603	64.6656	4.9162	8.4412	0	0
156	6.5	0	15.7019	0.954	5.9589	63.6716	5.2724	8.4412	0	0
168	7	0	15.7019	0.9453	6.583	62.7056	5.6229	8.4412	0	0
192	8	0	15.7019	1.0669	7.6269	60.8541	6.3089	8.4412	0	0
216	9	0	15.7019	0.8054	8.9745	59.1041	6.9729	8.4412	0	0
240	10	0	15.7019	0.8498	9.9415	57.4489	7.6166	8.4412	0	0
264	11	0	15.7019	0.8107	10.9207	55.8823	8.2432	8.4412	0	0
288	12	0	15.7019	0.5559	12.0531	54.3984	8.8494	8.4412	0	0
336	14	0	15.7019	0.5897	13.5963	51.658	10.0129	8.4412	0	0
384	16	0	15.7019	0.4326	15.1197	49.1887	11.1159	8.4412	0	0
432	18	0	15.7019	0.4301	16.3065	46.9568	12.1634	8.4412	0	0
480	20	0	15.7019	0.4177	17.3454	44.9331	13.1607	8.4412	0	0
600	25	0	15.7019	0.274	19.4926	40.6248	15.4654	8.4412	0	0
720	30	0	15.7019	0.1696	20.9934	37.1509	17.543	8.4412	0	0
840	35	0	15.7019	0.161	21.9723	34.2882	19.4353	8.4412	0	0
1080	45	0	15.7019	0.0812	23.1892	29.8108	22.7757	8.4412	0	0
1200	50	0	15.7019	0.0759	23.5135	28.0038	24.2637	8.4412	0	0
1320	55	0	15.7019	0.0548	23.7512	26.4006	25.6503	8.4412	0	0

Table XXIX.B-8 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for Willapa 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	0.083	99.8997	0.0535	0	0	0	0.0468	0	0	99.8997
4	0.167	99.8347	0.0767	0.0001	0	0	0.0884	0	0	99.8347
6	0.25	99.4228	0.2249	0.0001	0	0	0.1715	0.1807	0	99.4228
8	0.333	99.1385	0.4265	0.0001	0	0	0.2542	0.1807	0	99.1385
10	0.417	98.6228	0.7093	0	0	0	0.3366	0.3312	0	98.6228
12	0.5	98.1145	0.995	0	0.0001	0	0.4186	0.4718	0	98.1145
14	0.583	97.3884	1.2416	0	0.0001	0	0.5	0.8699	0	97.3884
16	0.667	96.7281	1.4518	0	0.0001	0	0.5809	1.239	0	96.7281
18	0.75	96.0801	1.6592	0	0.0001	0	0.6613	1.5994	0	96.0801
20	0.833	95.451	1.8636	0	0.0001	0	0.7411	1.9442	0	95.451
22	0.917	94.8534	2.0508	0	0.0001	0	0.8204	2.2753	0	94.8534
24	1	94.2734	2.2335	0	0.0001	0	0.8992	2.5939	0	94.2734
28	1.167	92.9312	2.5985	0	0.0001	0	1.0552	3.415	0	92.9312
32	1.333	91.1087	2.9735	0	0.0001	0	1.209	4.7087	0	91.1087
36	1.5	89.0604	3.2609	0	0.0001	0	1.3593	6.3194	0	89.0604
40	1.667	72.3879	5.6478	0	0	13.0639	1.5038	7.3966	0	72.3879
44	1.833	69.5706	5.9515	0	0	14.0667	1.6449	8.7664	0	69.5706
48	2	65.4152	6.2199	0.4386	0	14.3529	1.7818	11.7914	0	65.4152
54	2.25	59.4184	7.0029	0.1774	0.2566	16.9605	1.9798	14.2045	0	59.4184
60	2.5	50.1283	8.4889	0.794	0.3629	23.8475	2.1739	14.2045	0	50.1283
66	2.75	46.318	9.1568	0.3629	0.7863	26.8061	2.3655	14.2045	0	46.318
72	3	44.8005	9.5257	0.9729	0.9917	26.9498	2.5549	14.2045	0	44.8005
78	3.25	15.5302	13.1192	0.3477	1.6042	52.4538	2.7405	14.2045	0	15.5302
84	3.5	5.2241	14.3031	0.9628	1.7932	60.589	2.9234	14.2045	0	5.2241
90	3.75	2.6985	14.5894	0.4677	2.271	62.6646	3.1043	14.2045	0	2.6985

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	0.9773	14.7752	1.0342	2.4797	63.2454	3.2838	14.2045	0	0.9773
108	4.5	0.5181	14.8266	0.9602	3.2839	62.569	3.6377	14.2045	0	0.5181
120	5	0.513	14.8292	1.0194	3.929	61.5194	3.9856	14.2045	0	0.513
132	5.5	0	14.8751	1.0285	4.599	60.9652	4.3278	14.2045	0	0
144	6	0	14.8751	0.9043	5.3786	59.9736	4.6639	14.2045	0	0
156	6.5	0	14.8751	0.9429	5.9723	59.0108	4.9944	14.2045	0	0
168	7	0	14.8751	0.934	6.5911	58.0759	5.3195	14.2045	0	0
192	8	0	14.8751	1.0537	7.6263	56.2856	5.9549	14.2045	0	0
216	9	0	14.8751	0.795	8.9607	54.5957	6.5691	14.2045	0	0
240	10	0	14.8751	0.8383	9.9189	52.9995	7.1638	14.2045	0	0
264	11	0	14.8751	0.7993	10.8883	51.4908	7.742	14.2045	0	0
288	12	0	14.8751	0.5477	12.0082	50.064	8.3005	14.2045	0	0
336	14	0	14.8751	0.5803	13.535	47.4345	9.3706	14.2045	0	0
384	16	0	14.8751	0.4251	15.0401	45.0725	10.3828	14.2045	0	0
432	18	0	14.8751	0.4221	16.2121	42.9442	11.342	14.2045	0	0
480	20	0	14.8751	0.4093	17.2371	41.0206	12.2535	14.2045	0	0
600	25	0	14.8751	0.2673	19.3511	36.9484	14.3537	14.2045	0	0
720	30	0	14.8751	0.1645	20.8238	33.692	16.2401	14.2045	0	0
840	35	0	14.8751	0.1552	21.7813	31.0301	17.9538	14.2045	0	0
1080	45	0	14.8751	0.0769	22.9629	26.9101	20.9706	14.2045	0	0
1200	50	0	14.8751	0.0712	23.2747	25.2626	22.312	14.2045	0	0
1320	55	0	14.8751	0.0508	23.501	23.8075	23.5612	14.2045	0	0

Table XXIX.B-9 Grays Harbor - Bunker C, no removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7681	0.1852	0	0	0	0.0468	0	0	99.7681
4	0.167	99.6138	0.2978	0.0001	0	0	0.0883	0	0	99.6138
6	0.25	99.3005	0.5283	0.0001	0	0	0.1712	0	0	99.3005
8	0.333	98.9798	0.7664	0	0	0	0.2538	0	0	98.9798
10	0.417	93.7632	1.7908	0	0	4.11	0.336	0	0	93.7632
12	0.5	85.7963	3.2452	0.2617	0	10.2799	0.4168	0	0	85.7963
14	0.583	27.2819	12.792	0.2054	0.0525	59.173	0.4952	0	0	27.2819
16	0.667	17.2218	14.4136	0.1397	0.1125	67.5407	0.5717	0	0	17.2218
18	0.75	17.1513	14.4562	0.0923	0.1542	67.498	0.648	0	0	17.1513
20	0.833	14.7134	14.8627	0.0606	0.1802	69.459	0.7241	0	0	14.7134
22	0.917	11.3859	15.3919	0.0414	0.1933	72.1876	0.7999	0	0	11.3859
24	1	10.8789	15.4876	0.9271	0.2	71.6309	0.8755	0	0	10.8789
28	1.167	10.3941	15.5764	0.7016	0.4121	71.8898	1.026	0	0	10.3941
32	1.333	9.0223	15.8037	0.4301	0.6706	72.8976	1.1758	0	0	9.0223
36	1.5	4.8004	16.4446	1.1218	0.8828	75.4258	1.3246	0	0	4.8004
40	1.667	4.4936	16.5112	0.6058	1.3848	75.5326	1.472	0	0	4.4936
44	1.833	4.3912	16.5486	0.2651	1.7122	75.4645	1.6183	0	0	4.3912
48	2	4.3541	16.5782	0.9965	1.8536	74.4536	1.764	0	0	4.3541
54	2.25	4.2868	16.6212	0.3198	2.5103	74.2814	1.9805	0	0	4.2868
60	2.5	4.1753	16.6475	0.9978	2.6688	73.3153	2.1953	0	0	4.1753
66	2.75	3.8993	16.6908	0.5269	3.1194	73.355	2.4086	0	0	3.8993
72	3	0.1869	17.0829	1.1183	3.4331	75.5586	2.6201	0	0	0.1869
80	3.333	0	17.1021	0.6814	3.8422	75.475	2.8993	0	0	0
86	3.583	0	17.1021	1.4723	4.0751	74.2432	3.1073	0	0	0
92	3.833	0	17.1021	0.9678	4.5584	74.0584	3.3132	0	0	0
104	4.333	0	17.1021	1.0404	5.3069	72.8306	3.7201	0	0	0

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
116	4.833	0	17.1021	1.1897	5.9492	71.6385	4.1205	0	0	0
128	5.333	0	17.1021	1.0965	6.8062	70.481	4.5142	0	0	0
140	5.833	0	17.1021	1.2582	7.3809	69.3569	4.9019	0	0	0
152	6.333	0	17.1021	1.3844	7.9643	68.265	5.2841	0	0	0
164	6.833	0	17.1021	1.5753	8.4572	67.2044	5.661	0	0	0
194	8.083	0	17.1021	2.5224	9.4366	64.3588	6.5801	0	0	0
218	9.083	0	17.1021	2.892	10.2225	62.4884	7.2949	0	0	0
242	10.083	0	17.1021	2.4755	11.7172	60.7199	7.9853	0	0	0
266	11.083	0	17.1021	2.5159	12.6784	59.0467	8.6568	0	0	0
290	12.083	0	17.1021	2.2784	13.8492	57.4625	9.3077	0	0	0
314	13.083	0	17.1021	2.29	14.7048	55.9616	9.9415	0	0	0
338	14.083	0	17.1021	1.5378	16.2704	54.5385	10.5512	0	0	0
386	16.083	0	17.1021	1.8649	17.3982	51.9058	11.729	0	0	0
434	18.083	0	17.1021	1.6109	18.9074	49.5283	12.8513	0	0	0
482	20.083	0	17.1021	1.5697	20.0345	47.3741	13.9196	0	0	0
602	25.083	0	17.1021	1.4469	22.2609	42.7948	16.3953	0	0	0
722	30.083	0	17.1021	0.5696	24.6231	39.1098	18.5954	0	0	0
842	35.083	0	17.1021	0.5157	25.7079	36.0792	20.5951	0	0	0
1082	45.083	0	17.1021	0.4106	27.0217	31.351	24.1146	0	0	0
1202	50.083	0	17.1021	0.285	27.4848	29.447	25.6812	0	0	0
1322	55.083	0	17.1021	0.1462	27.8577	27.7596	27.1344	0	0	0

Table XXIX.B-10 Grays Harbor - Bunker C, federal mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7681	0.1852	0	0	0	0.0468	0	0	99.7681
4	0.167	99.6138	0.2978	0.0001	0	0	0.0883	0	0	99.6138
6	0.25	99.3005	0.5283	0.0001	0	0	0.1712	0	0	99.3005
8	0.333	98.9798	0.7664	0	0	0	0.2538	0	0	98.9798
10	0.417	93.7632	1.7908	0	0	4.11	0.336	0	0	93.7632
12	0.5	85.7963	3.2452	0.2617	0	10.2799	0.4168	0	0	85.7963
14	0.583	27.5101	12.6445	0.2054	0.0525	58.3932	0.4949	0.6994	0	27.5101
16	0.667	16.4487	14.323	0.1397	0.1125	67.0575	0.5707	1.3479	0	16.4487
18	0.75	14.9174	14.4963	0.0923	0.1542	67.7504	0.6456	1.9438	0	14.9174
20	0.833	12.0961	14.8763	0.0606	0.1802	69.5886	0.7199	2.4784	0	12.0961
22	0.917	9.3673	15.2441	0.0414	0.1934	71.4329	0.7935	2.9275	0	9.3673
24	1	8.8673	15.2749	0.8969	0.2001	70.5716	0.8666	3.3226	0	8.8673
28	1.167	7.3768	15.3999	0.6786	0.4053	71.0569	1.0112	4.0714	0	7.3768
32	1.333	5.775	15.5279	0.416	0.6551	71.5504	1.1538	4.9219	0	5.775
36	1.5	1.8375	15.995	1.0949	0.8601	73.1569	1.294	5.7616	0	1.8375
40	1.667	0	16.1723	0.7138	1.2275	74.0862	1.4316	6.3687	0	0
44	1.833	0	16.1723	0.4721	1.4559	73.9629	1.568	6.3687	0	0
48	2	0	16.1723	1.1765	1.6089	72.9696	1.7039	6.3687	0	0
55	2.292	0	16.1723	0.7323	2.0294	72.7574	1.9399	6.3687	0	0
61	2.542	0	16.1723	1.4288	2.2225	71.667	2.1407	6.3687	0	0
67	2.792	0	16.1723	1.2153	2.4149	71.4884	2.3403	6.3687	0	0
73	3.042	0	16.1723	1.7727	2.6467	70.5009	2.5388	6.3687	0	0
79	3.292	0	16.1723	1.3103	3.0879	70.3253	2.7354	6.3687	0	0
85	3.542	0	16.1723	1.6283	3.5318	69.3685	2.9304	6.3687	0	0
91	3.792	0	16.1723	1.0472	4.0927	69.1958	3.1232	6.3687	0	0
103	4.292	0	16.1723	1.0017	4.8548	68.0988	3.5038	6.3687	0	0

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
115	4.792	0	16.1723	1.1535	5.394	67.033	3.8785	6.3687	0	0
127	5.292	0	16.1723	1.0105	6.2039	65.9976	4.247	6.3687	0	0
139	5.792	0	16.1723	0.9802	6.8778	64.9915	4.6095	6.3687	0	0
151	6.292	0	16.1723	1.2343	7.2439	64.0136	4.9672	6.3687	0	0
163	6.792	0	16.1723	1.4853	7.59	63.0631	5.3206	6.3687	0	0
193	8.042	0	16.1723	2.2113	8.5483	60.5168	6.1827	6.3687	0	0
217	9.042	0	16.1723	2.7218	9.0458	58.8358	6.8557	6.3687	0	0
241	10.042	0	16.1723	2.3272	10.3811	57.2443	7.5064	6.3687	0	0
265	11.042	0	16.1723	2.163	11.4214	55.7366	8.138	6.3687	0	0
289	12.042	0	16.1723	2.0084	12.3918	54.3071	8.7517	6.3687	0	0
313	13.042	0	16.1723	2.0159	13.1426	52.9508	9.3497	6.3687	0	0
337	14.042	0	16.1723	1.2359	14.6351	51.663	9.9251	6.3687	0	0
385	16.042	0	16.1723	1.6695	15.4742	49.2755	11.0398	6.3687	0	0
433	18.042	0	16.1723	1.4267	16.815	47.1127	12.1046	6.3687	0	0
481	20.042	0	16.1723	1.3051	17.8882	45.1472	13.1185	6.3687	0	0
601	25.042	0	16.1723	1.2876	19.7439	40.946	15.4814	6.3687	0	0
721	30.042	0	16.1723	0.5071	21.8256	37.5383	17.5879	6.3687	0	0
841	35.042	0	16.1723	0.4454	22.7912	34.7138	19.5086	6.3687	0	0
1081	45.042	0	16.1723	0.4346	23.8612	30.2617	22.9016	6.3687	0	0
1201	50.042	0	16.1723	0.2649	24.3254	28.4524	24.4163	6.3687	0	0
1321	55.042	0	16.1723	0.13	24.6655	26.8415	25.822	6.3687	0	0

Table XXIX.B-11 Grays Harbor - Bunker C, WA state mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7681	0.1852	0	0	0	0.0468	0	0	99.7681
4	0.167	99.6138	0.2978	0.0001	0	0	0.0883	0	0	99.6138
6	0.25	99.3005	0.5283	0.0001	0	0	0.1712	0	0	99.3005
8	0.333	98.8657	0.7664	0	0	0	0.2537	0.1141	0	98.8657
10	0.417	93.3266	1.7859	0	0	4.0841	0.3357	0.4676	0	93.3266
12	0.5	84.5789	3.2885	0.2531	0	10.5175	0.416	0.9459	0	84.5789
14	0.583	24.0545	12.9743	0.1986	0.0506	60.155	0.4932	2.0738	0	24.0545
16	0.667	12.9062	14.6047	0.1351	0.1084	68.5913	0.5676	3.0867	0	12.9062
18	0.75	12.0421	14.6375	0.0893	0.1484	68.5443	0.6409	3.8975	0	12.0421
20	0.833	9.8932	14.8854	0.0586	0.1733	69.6888	0.7135	4.5872	0	9.8932
22	0.917	6.6604	15.2952	0.04	0.1859	71.7838	0.7853	5.2494	0	6.6604
24	1	5.9929	15.3111	0.8896	0.1922	70.8714	0.8563	5.8865	0	5.9929
28	1.167	2.7556	15.3712	0.6732	0.3955	71.0251	0.995	8.7845	0	2.7556
32	1.333	0	15.4342	0.4127	0.6432	71.2388	1.1285	11.1427	0	0
36	1.5	0	15.4342	1.137	0.7565	70.2703	1.2594	11.1427	0	0
40	1.667	0	15.4342	0.8501	1.03	70.1534	1.3896	11.1427	0	0
44	1.833	0	15.4342	0.5673	1.3001	70.0367	1.5191	11.1427	0	0
48	2	0	15.4342	1.1894	1.4864	69.0994	1.6479	11.1427	0	0
55	2.292	0	15.4342	0.7366	1.9166	68.8985	1.8715	11.1427	0	0
61	2.542	0	15.4342	1.38	2.1119	67.8695	2.0618	11.1427	0	0
67	2.792	0	15.4342	1.172	2.3	67.7004	2.2508	11.1427	0	0
73	3.042	0	15.4342	1.6916	2.5243	66.7685	2.4388	11.1427	0	0
79	3.292	0	15.4342	1.2497	2.9461	66.6022	2.6251	11.1427	0	0
85	3.542	0	15.4342	1.5445	3.3696	65.6993	2.8097	11.1427	0	0
91	3.792	0	15.4342	0.9931	3.9018	65.5358	2.9924	11.1427	0	0

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
103	4.292	0	15.4342	0.9469	4.6235	64.5001	3.3527	11.1427	0	0
115	4.792	0	15.4342	1.0888	5.1328	63.4939	3.7076	11.1427	0	0
127	5.292	0	15.4342	0.9532	5.8969	62.5164	4.0567	11.1427	0	0
139	5.792	0	15.4342	0.9242	6.5323	61.5666	4.4001	11.1427	0	0
151	6.292	0	15.4342	1.1635	6.8774	60.6435	4.7388	11.1427	0	0
163	6.792	0	15.4342	1.3999	7.2035	59.7462	5.0736	11.1427	0	0
193	8.042	0	15.4342	2.0836	8.1062	57.3431	5.8903	11.1427	0	0
217	9.042	0	15.4342	2.5643	8.5747	55.7564	6.5278	11.1427	0	0
241	10.042	0	15.4342	2.1922	9.8324	54.2542	7.1443	11.1427	0	0
265	11.042	0	15.4342	2.0371	10.812	52.8311	7.7429	11.1427	0	0
289	12.042	0	15.4342	1.8911	11.7257	51.4819	8.3244	11.1427	0	0
313	13.042	0	15.4342	1.8978	12.4323	50.2018	8.8913	11.1427	0	0
337	14.042	0	15.4342	1.1631	13.837	48.9863	9.4367	11.1427	0	0
385	16.042	0	15.4342	1.5707	14.626	46.7329	10.4935	11.1427	0	0
433	18.042	0	15.4342	1.3417	15.8866	44.6917	11.5032	11.1427	0	0
481	20.042	0	15.4342	1.2268	16.895	42.8365	12.4649	11.1427	0	0
601	25.042	0	15.4342	1.2091	18.6367	38.8707	14.7067	11.1427	0	0
721	30.042	0	15.4342	0.4754	20.5884	35.6528	16.7065	11.1427	0	0
841	35.042	0	15.4342	0.4171	21.4909	32.9844	18.5307	11.1427	0	0
1081	45.042	0	15.4342	0.4059	22.4872	28.7746	21.7554	11.1427	0	0
1201	50.042	0	15.4342	0.2472	22.9183	27.062	23.1956	11.1427	0	0
1321	55.042	0	15.4342	0.1212	23.2331	25.5361	24.5328	11.1427	0	0

Table XXIX.B-12 Grays Harbor - Bunker C, 3rd alternative mechanical removal: Mass balance of oil over time (percent of spilled oil) for the worst run for the GRPs.

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	0.083	99.7681	0.1852	0	0	0	0.0468	0	0	99.7681
4	0.167	99.6138	0.2978	0.0001	0	0	0.0883	0	0	99.6138
6	0.25	99.1198	0.5283	0.0001	0	0	0.1711	0.1807	0	99.1198
8	0.333	98.6771	0.7662	0	0	0	0.2535	0.303	0	98.6771
10	0.417	92.6507	1.7788	0	0	4.0484	0.3352	1.1868	0	92.6507
12	0.5	83.6897	3.2006	0.2588	0	10.0538	0.4147	2.3824	0	83.6897
14	0.583	19.6226	13.0998	0.203	0.0517	60.7669	0.4898	5.7662	0	19.6226
16	0.667	7.1172	14.6629	0.1381	0.1109	68.8284	0.5603	8.5822	0	7.1172
18	0.75	4.5279	14.7013	0.0912	0.1519	68.8847	0.6284	11.0145	0	4.5279
20	0.833	2.4145	14.7173	0.0599	0.1775	68.8525	0.6946	13.0838	0	2.4145
22	0.917	0.4174	14.7227	0.0409	0.1907	68.7992	0.759	15.0702	0	0.4174
24	1	0	14.7232	0.8031	0.1948	67.9702	0.8221	15.4866	0	0
28	1.167	0	14.7232	0.6682	0.3172	67.8571	0.9477	15.4866	0	0
32	1.333	0	14.7232	0.558	0.4151	67.7442	1.073	15.4866	0	0
36	1.5	0	14.7232	1.1454	0.5612	66.8859	1.1977	15.4866	0	0
40	1.667	0	14.7232	0.8458	0.8481	66.7746	1.3217	15.4866	0	0
44	1.833	0	14.7232	0.5631	1.1186	66.6635	1.445	15.4866	0	0
48	2	0	14.7232	1.0857	1.3042	65.8327	1.5676	15.4866	0	0
55	2.292	0	14.7232	0.6706	1.6979	65.6412	1.7805	15.4866	0	0
61	2.542	0	14.7232	1.2279	1.875	64.7256	1.9617	15.4866	0	0
67	2.792	0	14.7232	1.0418	2.0422	64.5643	2.1418	15.4866	0	0
73	3.042	0	14.7232	1.4946	2.2408	63.7339	2.3209	15.4866	0	0
79	3.292	0	14.7232	1.1038	2.6127	63.5752	2.4985	15.4866	0	0
85	3.542	0	14.7232	1.3598	2.9856	62.7702	2.6746	15.4866	0	0
91	3.792	0	14.7232	0.8743	3.453	62.614	2.8489	15.4866	0	0

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
103	4.292	0	14.7232	0.8321	4.0853	61.6798	3.193	15.4866	0	0
115	4.792	0	14.7232	0.956	4.5303	60.7718	3.5322	15.4866	0	0
127	5.292	0	14.7232	0.8367	5.1986	59.8889	3.8661	15.4866	0	0
139	5.792	0	14.7232	0.8111	5.7538	59.0304	4.1948	15.4866	0	0
151	6.292	0	14.7232	1.0211	6.0541	58.1955	4.5194	15.4866	0	0
163	6.792	0	14.7232	1.2286	6.3379	57.3834	4.8403	15.4866	0	0
193	8.042	0	14.7232	1.8288	7.1241	55.2131	5.6242	15.4866	0	0
217	9.042	0	14.7232	2.2509	7.5305	53.7721	6.2368	15.4866	0	0
241	10.042	0	14.7232	1.9245	8.6298	52.4057	6.8303	15.4866	0	0
265	11.042	0	14.7232	1.7886	9.4851	51.1091	7.4075	15.4866	0	0
289	12.042	0	14.7232	1.6607	10.2826	49.8778	7.9692	15.4866	0	0
313	13.042	0	14.7232	1.6667	10.8985	48.7076	8.5174	15.4866	0	0
337	14.042	0	14.7232	1.0217	12.1277	47.5945	9.0462	15.4866	0	0
385	16.042	0	14.7232	1.3802	12.812	45.5256	10.0724	15.4866	0	0
433	18.042	0	14.7232	1.1794	13.9111	43.6446	11.0551	15.4866	0	0
481	20.042	0	14.7232	1.0789	14.7893	41.9286	11.9935	15.4866	0	0
601	25.042	0	14.7232	1.0645	16.3015	38.2363	14.1879	15.4866	0	0
721	30.042	0	14.7232	0.4195	18.0021	35.2112	16.1574	15.4866	0	0
841	35.042	0	14.7232	0.3687	18.7816	32.6788	17.9611	15.4866	0	0
1081	45.042	0	14.7232	0.3609	19.633	28.6328	21.1636	15.4866	0	0
1201	50.042	0	14.7232	0.2207	20.0029	26.9682	22.5985	15.4866	0	0
1321	55.042	0	14.7232	0.1088	20.2719	25.4761	23.9334	15.4866	0	0

Table XXIX.B-13 Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	59	121	46
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	59	121	46
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	2,027	1,198	1,394
Shoreline length (km) oiled by > 100 g/m^2	1,988	1,156	1,276
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	1,101,200	712,040	795,000
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	925,720	486,180	598,550
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	217.9	115.5	138.8

Table XXIX.B-14 Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	57	120	32
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	57	120	32
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,948	942	1,201
Shoreline length (km) oiled by > 100 g/m^2	1,948	903	1,122
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	1,140,500	317,440	592,740
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	807,930	624,770	608,100
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	202.4	107.9	128.8

Table XXIX.B-15 Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	55	117	27
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	55	117	27
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,588	1,026	878
Shoreline length (km) oiled by > 100 g/m^2	1,548	948	878
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	867,850	519,700	238,780
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	719,900	506,590	639,370
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	169.7	106.3	109.4

Table XXIX.B-16 Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Water surface area (km^2) oiled by > 0.01 g/m^2 (sheen or thicker oil) at some time after the spill	51	112	27
Water surface area (km^2) oiled by > 10.0 g/m^2 at some time after the spill	51	111	27
Shoreline length (km) oiled by > 0.01 g/m^2 (where cleanup would occur)	1,070	979	868
Shoreline length (km) oiled by > 100 g/m^2	1,070	898	868
Shoreline area (m^2) oiled by up to 1000 g/m^2 (where low cleanup effort would occur)	511,270	483,180	278,110
Shoreline area (m^2) oiled by > 1000 g/m^2 (where high cleanup effort would occur)	559,030	496,100	589,930
Cost (in millions of 2003$) for shoreline cleanup (per area costs only)	120.5	102.7	105.2

XXIX.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 XXIX.C-1 Grays Harbor - Bunker C, 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)	-	1,835	222	14,141	-	-	2	1	16,200	16,197	2
Worst run for Willapa Bay	4,658	3,071	125	8,027	-	0	2	1	15,885	15,881	4
Worst run for the GRPs	-	1,561	139	8,905	-	0	2	0	10,608	10,606	2

Table XXIX.C-2 Grays Harbor - Bunker C, 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)	-	1,789	217	13,853	-	-	2	1	15,862	15,859	2
Worst run for Willapa Bay	4,543	3,047	96	6,165	-	0	2	1	13,855	13,851	4
Worst run for the GRPs	-	1,271	122	7,778	-	-	1	0	9,172	9,170	2

Table XXIX.C-3 Grays Harbor - Bunker C, 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)	-	1,745	171	10,911	-	-	2	1	12,829	12,827	2
Worst run for Willapa Bay	4,230	2,981	101	6,494	-	0	2	1	13,810	13,806	3
Worst run for the GRPs	-	1,169	93	5,983	-	-	1	0	7,247	7,246	2

Table XXIX.C-4 Grays Harbor - Bunker C, 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)	-	1,664	116	7,396	-	-	2	1	9,178	9,176	2
Worst run for Willapa Bay	3,648	2,859	96	6,128	-	0	2	1	12,733	12,730	3
Worst run for the GRPs	-	1,163	92	5,909	-	-	1	0	7,165	7,164	2

XXIX.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 XXIX.D-1. Grays Harbor - Bunker C, 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)	-	9.50	2.29	-	-	20,168	20,180
Worst run for Willapa Bay	-	10.24	2.46	-	-	11,811	11,824
Worst run for the GRPs	-	12.70	3.05	-	-	13,030	13,045

Table XXIX.D-2. Grays Harbor - Bunker C, 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)	-	9.43	2.27	-	-	19,762	19,774
Worst run for Willapa Bay	-	10.39	2.50	-	-	9,228	9,241
Worst run for the GRPs	-	12.45	2.99	-	-	11,462	11,478

Table XXIX.D-3. Grays Harbor - Bunker C, 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)	-	9.17	2.21	-	-	15,671	15,682
Worst run for Willapa Bay	-	9.97	2.40	-	-	9,692	9,705
Worst run for the GRPs	-	12.21	2.94	-	-	8,967	8,982

Table XXIX.D-4. Grays Harbor - Bunker C, 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)	-	9.17	2.20	-	-	10,737	10,748
Worst run for Willapa Bay	-	9.95	2.39	-	-	9,228	9,240
Worst run for the GRPs	-	11.74	2.82	-	-	8,880	8,894

XXIX.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 XXIX.E-1. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	10	10	13
Large pelagic fish	2	2	3
Demersal fish	-	-	-
Decapods	20,168	11,811	13,030
Molluscs			
Birds:	-	5,221	-
Waterfowl (# * kg each)	995	1,666	847
Seabirds (# * kg each)	120	68	76
Waders (# * kg each)	7,671	4,355	4,831
Shorebirds (# * kg each)	-	-	-
Raptors (# * kg each)			
Other wildlife:	0	1	0
Sea otters, other mammals	1	1	1
Pinnipeds	-	0	0
Cetaceans			
Totals:	20,180	11,824	13,045
Subtotal fish and invertebrates	8,787	11,309	5,754
Subtotal birds	1	2	1
Subtotal other wildlife	28,968	23,135	18,800
Total all species	10	10	13

Table XXIX.E-2. Grays Harbor - Bunker C, no removal: Area and costs (in millions of 2004$) for compensatory restoration.

HEA Results	99th Percentile Run (based on shore cost)	Worst run for Willapa Bay	Worst run for the GRPs
Saltmarsh Area (ha)	18.5	23.5	13.1
Saltmarsh Area (acres)	45.7	58.2	32.3
Saltmarsh Cost (millions of 2004$)	8.5	10.9	6.0
Eelgrass Area (m2)	11.6	14.7	8.2
Eelgrass Area (acres)	28.6	36.3	20.2
Eelgrass Cost (millions of 2004$)	3.4	4.3	2.4

Table XXIX.E-3. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	9	10	12
Demersal fish	2	2	3
Decapods	-	-	-
Molluscs	19,762	9,228	11,462
Birds:			
Waterfowl (# * kg each)	-	5,092	-
Seabirds (# * kg each)	970	1,653	690
Waders (# * kg each)	118	52	66
Shorebirds (# * kg each)	7,515	3,344	4,219
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	0	1	0
Pinnipeds	1	1	1
Cetaceans	-	0	-
Totals:			
Subtotal fish and invertebrates	19,774	9,241	11,478
Subtotal birds	8,604	10,142	4,975
Subtotal other wildlife	1	2	1
Total all species	28,379	19,385	16,454

Table XXIX.E-4. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Saltmarsh Area (ha)	18.1	21.7	11.1
Saltmarsh Area (acres)	44.7	53.6	27.5
Saltmarsh Cost (millions of 2004$)	8.4	10.0	5.4
Eelgrass Area (m2)	11.3	13.5	6.9
Eelgrass Area (acres)	27.9	33.5	17.2
Eelgrass Cost (millions of 2004$)	3.3	4.0	2.0

Table XXIX.E-5. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	9	10	12
Demersal fish	2	2	3
Decapods	-	-	-
Molluscs	15,671	9,692	8,967
Birds:			
Waterfowl (# * kg each)	-	4,741	-
Seabirds (# * kg each)	946	1,617	634
Waders (# * kg each)	93	55	51
Shorebirds (# * kg each)	5,919	3,523	3,246
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	0	1	0
Pinnipeds	1	1	1
Cetaceans	-	0	-
Totals:			
Subtotal fish and invertebrates	15,682	9,705	8,982
Subtotal birds	6,959	9,936	3,931
Subtotal other wildlife	1	2	1
Total all species	22,642	19,643	12,914

Table XXIX.E-6. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Saltmarsh Area (ha)	15.4	21.3	9.2
Saltmarsh Area (acres)	38.0	52.7	22.8
Saltmarsh Cost (millions of 2004$)	7.1	9.8	4.3
Eelgrass Area (m2)	9.6	13.3	5.8
Eelgrass Area (acres)	23.7	32.9	14.2
Eelgrass Cost (millions of 2004$)	2.8	3.9	1.7

Table XXIX.E-7. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Fish and Invertebrates:			
Small pelagic fish	-	-	-
Large pelagic fish	9	10	12
Demersal fish	2	2	3
Decapods	-	-	-
Molluscs	10,737	9,228	8,880
Birds:			
Waterfowl (# * kg each)	-	4,089	-
Seabirds (# * kg each)	903	1,551	631
Waders (# * kg each)	63	52	50
Shorebirds (# * kg each)	4,012	3,324	3,205
Raptors (# * kg each)	-	-	-
Other wildlife:			
Sea otters, other mammals	0	1	0
Pinnipeds	1	1	1
Cetaceans	-	0	-
Totals:			
Subtotal fish and invertebrates	10,748	9,240	8,894
Subtotal birds	4,978	9,016	3,886
Subtotal other wildlife	1	2	1
Total all species	15,727	18,258	12,782

Table XXIX.E-8. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Saltmarsh Area (ha)	12.0	19.8	9.1
Saltmarsh Area (acres)	29.7	49.0	22.5
Saltmarsh Cost (millions of 2004$)	5.6	9.2	4.2
Eelgrass Area (m2)	7.5	12.4	5.7
Eelgrass Area (acres)	18.6	30.6	14.1
Eelgrass Cost (millions of 2004$)	2.2	3.6	1.7

XXIX.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 XXIX.E above) are more likely to be used for NRDA. However, we have included the Compensation Schedule results for comparison.

Table XXIX.F-1. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Vulnerability Score ($/gal.)	32.13	31.27	30.92
% Removed by 24 hours	0.00	0.00	0.00
Compensation (millions $)	33.7	32.8	32.5

Table XXIX.F-2. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Vulnerability Score ($/gal.)	32.15	31.26	30.60
% Removed by 24 hours	3.3	0.4	3.3
Compensation (millions $)	32.6	32.7	31.1

Table XXIX.F-3. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Vulnerability Score ($/gal.)	32.11	31.29	30.60
% Removed by 24 hours	6.7	0.9	5.9
Compensation (millions $)	31.5	32.6	30.2

Table XXIX.F-4. Grays Harbor - Bunker C, 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 Willapa Bay	Worst run for the GRPs
Vulnerability Score ($/gal.)	32.07	31.30	30.56
% Removed by 24 hours	20.7	2.6	15.5
Compensation (millions $)	26.7	32.0	27.1