Modeling Inputs and Assumptions For Washington State Oil Spill Scenarios Phases I and II

Prepared for

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INTRODUCTION

The purpose of this study was to analyze a number of oil spill scenarios in major shipping lanes in Washington waters (Figures A and B) and to evaluate the way in which the state's proposed response planning guidelines might provide additional protection to the state's valuable natural and socioeconomic resources. A computer model was used to simulate hypothetical spills and responses to those spills in order to determine oil fates and impacts.

Two phases of the study involved different analyses. The first phase evaluated three different types of spill response. The second phase of modeling incorporated several modifications and additions to provide supplementary information to Ecology and to analyze different aspects of the spill scenarios and outcomes with a focus on mechanical containment and recovery.

Overall Purpose of Phase I and Phase II Studies

Washington Department of Ecology ("Ecology") is evaluating the potential benefits and costs of its proposed contingency planning rule and response planning standards. These standards generally exceed that required under federal US Coast Guard regulations by stipulating more response equipment on a more accelerated schedule, as shown in Tables A through C[1].

Ecology would like to measure the benefits that might be provided with this additional equipment and accelerated schedule in terms of reduction of shoreline oiling, damages to natural resources, and impacts to socioeconomic resources in the state. In addition, Ecology is evaluating the potential for additional benefits in terms of damage reduction with a response planning standard that requires even more equipment and a more accelerated schedule than the state's proposed standard (known as the "hypothetical 3rd alternative").

The two modeling studies simulate a variety of spill scenarios with subsequent responses under different actual or hypothetical response planning standards. The detailed analyses on the fate, effects, and impacts of the oil spills under different response regimes will provide Ecology with a means to objectively evaluate the potential benefits of increased spill response preparedness and response standards.

In each of the two modeling phases, a set of spill scenarios was developed for each of five or six general areas – Outer Coast (near Cape Flattery), Strait of Juan de Fuca, San Juan Islands, Inner Straits, lower Columbia River, and upper Columbia River. Three different oil types – Alaska North Slope crude, bunker fuel, and diesel fuel – in different amounts ranging from 25,000 barrels (bbl) from a hypothetical tank barge up to 250,000 bbl (an Exxon Valdez-sized spill) from a large tanker were included.

Since the impacts of a spill can vary tremendously depending on the movement of the oil, as influenced by winds, currents (tidal and other), and exact location of oil release, hundreds of random variations in these factors were incorporated into the modeling to determine the range of impacts that might be expected and to determine the situations in which the "worst" impacts might be realized. For each of the spill scenarios different responses were added to measure the reduction in impacts provided by different types and levels of response.

Additional information on this project can be found in French-McCay, *et al.* 2005a, 2005b).

[1] In some cases, the federal planning standard at a particular point in time is actually higher than the state planning standard. In these cases, the higher federal standard would take precedence as it would always be a requirement to meet the federal standard.

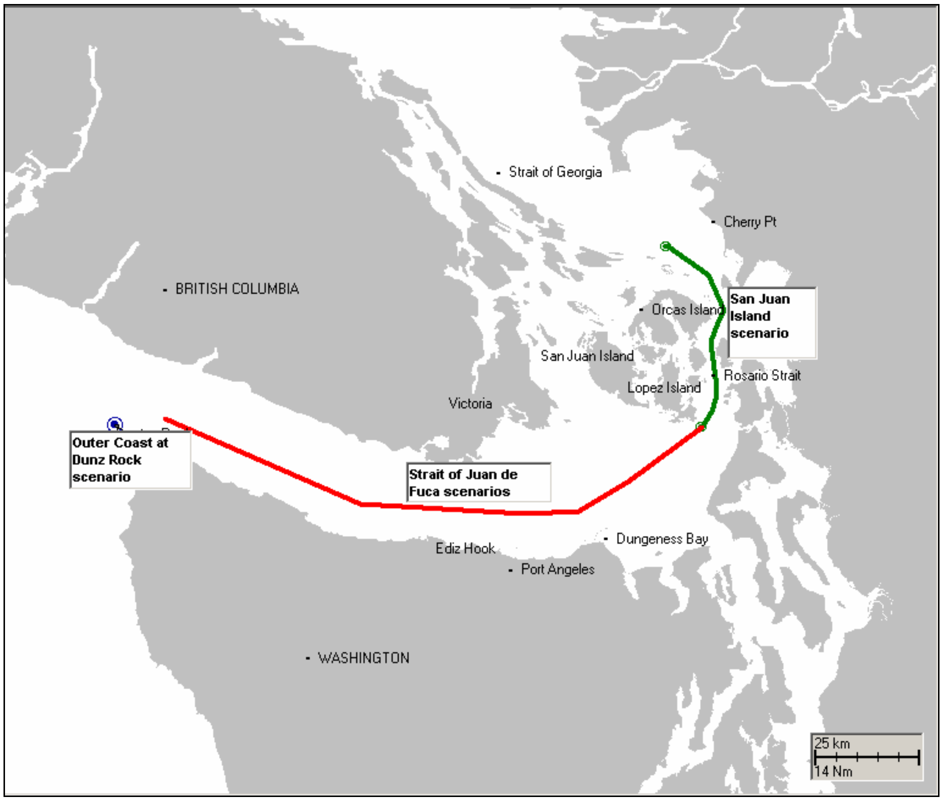

Figure A: Shipping route segments where the hypothetical spills are assumed to occur: Straits and outer coast scenarios.

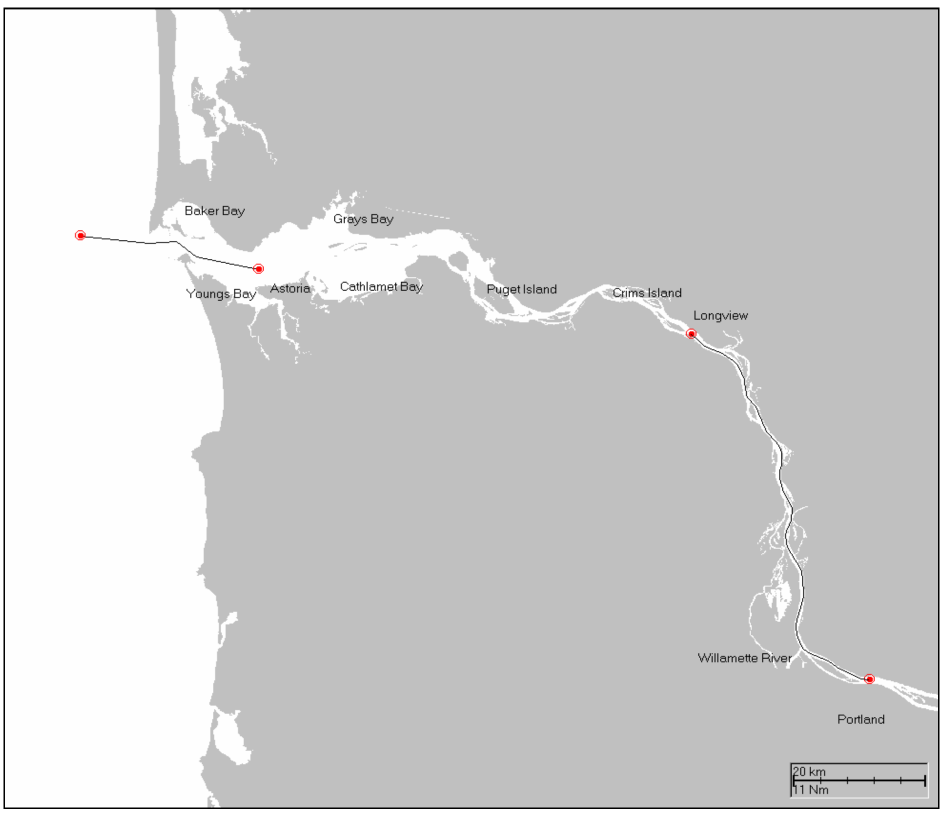

Figure B: Shipping route segments where the hypothetical spills are assumed to occur: Columbia River scenarios.

Table A: Vessel Planning Standards: Puget Sound						
Hr	**FEDERAL**			**STATE (WA)**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***[2]	***Recovery (bpd)***	***Storage (bpd)***
2				4 X vessel ft.		
6				20,000	2% WCD to 5,000 CAP	1 X Recovery
12	30,000	15% WCD to 12,500 CAP	2 X Recovery	40,000	5% WCD to 36,000 CAP	1.5 X Recovery
24				Boom as required	12% WCD to 48,000 CAP	2 X Recovery
36	30,000	25% WCD to 25,000 CAP	2 X Recovery			
48				Boom as required	17% WCD to 60,000 CAP	3 X Recovery
60	30,000	40% WCD to 50,000 CAP	2 X Recovery			
72				Boom as required	20% WCD to 72,000 CAP	Recovery as required

Table B: Vessel Planning Standards: Strait Juan deFuca, Grays Harbor/Willapa Bay, Columbia R.						
Hr	**FEDERAL**			**STATE (WA)**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***[1]	***Recovery (bpd)***	***Storage (bpd)***
2				4 X vessel ft.		
6				10,000	2% WCD to 12,000 CAP	1 X Recovery
12	30,000	15% WCD to 12,500 CAP	2 X Recovery	40,000	5% WCD to 36,000 CAP	1.5 X Recovery
24				Boom as required	12% WCD to 48,000 CAP	2 X Recovery
36	30,000	25% WCD to 25,000 CAP	2 X Recovery			
48				Boom as required	17% WCD to 60,000 CAP	3 X Recovery
60	30,000	40% WCD to 50,000 CAP	2 X Recovery			
72				Boom as required	20% WCD to 72,000 CAP	Recovery as required

Table C: Vessel Planning Standards: Outer Coast						
Hr	**FEDERAL (Not HVP)**			**STATE (WA)**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***[1]	***Recovery (bpd)***	***Storage (bpd)***
6				4 X vessel ft.		
18				40,000	3% WCD to 36,000 CAP	1 X Recovery
24	30,000	15% WCD to 12,500 CAP	2 X Recovery	Boom as required	8% WCD to 48,000 CAP	2 X Recovery
48	30,000	25% WCD to 25,000 CAP	2 X Recovery	Boom as required	14% WCD to 60,000 CAP	3 X Recovery
72	30,000	40% WCD to 50,000 CAP	2 X Recovery	Boom as required	17% WCD to 72,000 CAP	Recovery as required

[2] For state standards, boom must be added to previous amount required. *e.g.*, 10,000 at hour 6 and 40,000 at hour 12 means 50,000 required at hour 12.

PHASE I OIL SPILL SCENARIO MODELING

The spill scenarios investigated in Phase I are summarized in Table 1. For each location and oil type/amount combination the on-water response strategies indicated in the table were applied. The oil impacts for each scenario with the various spill response applied were analyzed to determine the spill runs (combinations of oil release location on the shipping routes, winds, and currents) that created the 5th, 50th (median), and 95th percentile[3] shoreline impacts based on stochastic[4] modeling results.

Shoreline impacts were determined based on the degree of oiling (oil thickness), as well as the amount and types of shorelines impacted. Shorelines that are more sensitive and more difficult to clean (*e.g.*, wetlands) were weighted more heavily in this analysis.

Table 1: Phase I Oil Spill Modeling Spill Scenarios

Location	**Oil**	**On-Water Response**							
		None[1]	**Mechanical[2]**			**Dispersant[3]**			**ISB[4]**
			Fed	**WA**	**3rd**	**Fed**	**WA**	**3rd**	**WA**
Outer Coast ***Cape Flattery***	**65,000 bbl crude**	●	●	●	●	●	●	●	●
Strait of Juan deFuca ***Neah Bay/Dungeness Spit***	**25,000 bbl bunker**	●	●	●	●				●
	65,000 bbl diesel	●	●	●	●				
Strait of Juan deFuca ***Neah Bay/Port Angeles***	**65,000 bbl crude**	●	●	●	●	●	●	●	●
San Juan Islands ***Rosario/Georgia Strait***	**65,000 bbl crude**	●	●	●	●	●	●	●	
Inner Straits ***Port Angeles/Lopez Island***	**65,000 bbl crude**	●	●	●	●	●	●	●	
Lower Columbia River (Western)	**25,000 bbl bunker**	●	●	●	●				
Upper Columbia River (Eastern)	**25,000 bbl bunker**	●	●	●	●				

[1] "No response" means no *on-water* recovery or dispersion attempted. Protective booming, shoreline cleanup, salvage, and spill management/monitoring conducted as required. [2] On-water mechanical response conducted using federal, state, or hypothetical 3rd alternative response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required. [3]Dispersant applications conducted where permitted by state guidelines with concurrent mechanical response using federal, state, or hypothetical 3rd alternative response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required. [4]ISB = *in situ* burning conducted according to state guidelines with concurrent mechanical response using *state* response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required.

For all response strategies employing on-water mechanical containment and recovery (*i.e.*, all responses except "no response"), the mechanical response capability was specified by one of three levels of response capability ("CAPS") according to the worst-case discharge of the vessel:

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[3] The 5th percentile is that variation of wind direction and speed, current, and tides that would cause shoreline impacts that are greater than 5 percent of the runs. 95 percent of the time the impacts would be greater. The 50th percentile is the median impact situation in which 50 percent of the runs are worse and 50 percent cause less impact. The 95th percentile run has worse impacts than 95 percent of cases. Only 5 percent are worse.

[4] Stochastic modeling (*i.e.*, modeling governed by a sequence of random variables) results were obtained by randomly varying spill locations along the shipping routes (as in Figures A and B), as well as date and time of the spill (which corresponds to a specific combination winds, tides, and currents) to develop a probability distribution function of shoreline impacts from the least impact (1st percentile) to the worst impact (100th percentile).

- ***Federal:*** US Coast Guard (USCG) Vessel and Facility Response Plans for Oil: 2003 Removal Equipment Requirements and Alternative Technology Revisions: Notice of Proposed Rulemaking. *Federal Register* Vol. 67 (198): pp. 63,331 – 63,452. 11 October 2002.
- ***State (WA):*** current state guidance (proposed planning standards in WAC 173-181)
- ***3rd alternative:*** hypothetical higher response capability alternative as determined by Contingency Plan Rule Advisory Committee

The actual required response capability for each level consists of specifications for amounts of and timing of arrival for booming equipment, oil removal equipment (skimmers, vacuum trucks, recovery vessels), and storage equipment, depending on the location and amount of oil spilled. The response capability levels applied in this modeling study are shown in Tables 2 – 7. (Note that for each scenario, the first table indicates the equipment required at different times during the response. The second table indicates the accumulating equipment – *i.e.*, the equipment that is required to be present at each point in time. Bold entries indicate new equipment arrivals.)

Table 2a: Mechanical Response Capability: Outer Coast Crude (Arrivals)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2							**3,500**		
4							**20,000**	**12,000**	**12,000**
6				**3,500**					
12									
15				**40,000**	**36,000**	**36,000**	**40,000**	**36,000**	**72,000**
24	**30,000**	**12,500**	**25,000**	***[5]**	**48,000**	**96,000**	*****	**48,000**	**144,000**
48		**25,000**	**50,000**	*****	**60,000**	**180,000**	*****	**60,000**	**180,000**

Table 2b: Mechanical Response Capability: Outer Coast Crude (Cumulative)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2							**3,500**		
4							**23,500**	**12,000**	**12,000**
6				**3,500**			23,500	12,000	12,000
12				3,500			23,500	12,000	12,000
15				**43,500**	**36,000**	**36,000**	**63,500**	**36,000**	**72,000**
24	**30,000**	**12,500**	**25,000**	43,500	**48,000**	**96,000**	**103,500**	**48,000**	**144,000**
48	30,000	**25,000**	**50,000**	43,500	**60,000**	**180,000**	103,500	**60,000**	**180,000**

Table 3a: Mechanical Response Capability: Strait Juan deFuca Bunker (Arrivals)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**1,392**			**1,392**		
4							**20,000**	**3,087**	**3,087**
6				**10,000**	**1,234.8**	**1,234.8**			
12	**30,000**	**6,483**	**12,966**	**40,000**	**3,087**	**4,630.5**	**30,000**	**9,261**	**18,722**
24				*****	**7,408.8**	**14,817.6**	**40,000**	**12,348**	**37,044**
36		**10,805**	**21,160**						
48				*****	**10,495.8**	**31,487.4**	*****	**15,435**	**46,305**

[5] * indicates equipment "as required" after this point in time, *i.e.*, as much boom or storage capacity as required based on the spill response.

Table 3b: Mechanical Response Capability: Strait Juan deFuca Bunker (Cumulative)									
Hr	**FEDERAL**			**STATE (WA)**			**3RD ALTERNATIVE**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**1,392**			**1,392**		
4				1,392			**21,392**	**3,087**	**3,087**
6				**11,392**	**1,234.8**	**1,234.8**	21,392	3,087	3,087
12	**30,000**	**6,483**	**12,966**	**51,392**	**3,087**	**4,630.5**	**51,392**	**9,261**	**18,722**
24	30,000	6,483	12,966	51,392	**7,408.8**	**14,817.6**	**91,392**	**12,348**	**37,044**
36	30,000	**10,805**	**21,160**	51,392	7,408.8	14,817.6	91,392	12,348	37,044
48	30,000	10,805	21,160	51,392	**10,495.8**	**31,487.4**	91,392	**15,435**	**46,305**

Table 4a: Mechanical Response Capability: Strait of Juan deFuca Diesel (Arrivals)									
Hr	**FEDERAL**			**STATE (WA)**			**3RD ALTERNATIVE**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**3,500**			**3,500**		
4							**20,000**	**36,000**	**36,000**
6				**10,000**	**12,000**	**12,000**			
12	**30,000**	**12,500**	**25,000**	**40,000**	**36,000**	**54,000**	**40,000**	**48,000**	**96,000**
24				*	**48,000**	**96,000**	**40,000**	**60,000**	**180,000**
36		**25,000**	**50,000**						
48				*	**60,000**	**180,000**		**72,000**	**216,000**

Table 4b: Mechanical Response Capability: Strait of Juan deFuca Diesel (Cumulative)									
Hr	**FEDERAL**			**STATE (WA)**			**3RD ALTERNATIVE**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**3,500**			**3,500**		
4				3,500			**23,500**	**36,000**	**36,000**
6				**13,500**	**12,000**	**12,000**	23,500	36,000	36,000
12	**30,000**	**12,500**	**25,000**	**53,500**	**36,000**	**54,000**	**63,500**	**48,000**	**96,000**
24	30,000	12,500	25,000	53,500	**48,000**	**96,000**	**103,500**	**60,000**	**180,000**
36	30,000	**25,000**	**50,000**	53,500	48,000	96,000	103,500	60,000	180,000
48	30,000	25,000	50,000	53,500	**60,000**	**180,000**	103,500	**72,000**	**216,000**

Table 5a: Mechanical Response Capability: Strait Juan deFuca/Inner Straits Crude (Arrivals)									
Hr	**FEDERAL**			**STATE (WA)**			**3RD ALTERNATIVE**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**3,500**			**3,500**		
4							**20,000**	**36,000**	**36,000**
6				**10,000**	**12,000**	**12,000**			
12	**30,000**	**12,500**	**25,000**	**40,000**	**36,000**	**54,000**	**40,000**	**48,000**	**96,000**
24				*	**48,000**	**96,000**	**40,000**	**60,000**	**180,000**
36		**25,000**	**50,000**						
48				*	**60,000**	**180,000**		**72,000**	**216,000**

Table 5b: Mechanical Response Capability: Strait Juan deFuca/Inner Straits Crude (Cumulative)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE		
	Boom (ft)	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*
2				**3,500**			**3,500**		
4				3,500			**23,500**	**36,000**	**36,000**
6				**13,500**	**12,000**	**12,000**	23,500	36,000	36,000
12	**30,000**	**12,500**	**25,000**	**53,500**	**36,000**	**54,000**	**63,500**	**48,000**	**96,000**
24	30,000	12,500	25,000	53,500	**48,000**	**96,000**	**103,500**	**60,000**	**180,000**
36	30,000	**25,000**	**50,000**	53,500	48,000	96,000	103,500	60,000	180,000
48	30,000	25,000	50,000	53,500	**60,000**	**180,000**	103,500	**72,000**	**216,000**

Table 6a: Mechanical Response Capability: San Juan Islands Crude (Arrivals)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE[6]		
	Boom (ft)	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*
2				**3,500**			**3,500**		
4									
6				**20,000**	**5,000**	**5,000**	**20,000**	**12,500**	**12,500**
12	**30,000**	**12,500**	**25,000**	**40,000**	**12,500**	**18,750**	**40,000**	**37,500**	**75,000**
24				*	**30,000**	**60,000**	**40,000**	**50,000**	**150,000**
36		**25,000**	**50,000**						
48				*	**42,500**	**127,500**	*	**62,500**	**187,500**

Table 6b: Mechanical Response Capability: San Juan Islands Crude (Cumulative)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE[6]		
	Boom (ft)	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*
2				**3,500**			**3,500**		
4				3,500			3,500		
6				**23,500**	**5,000**	**5,000**	**23,500**	**12,500**	**12,500**
12	**30,000**	**12,500**	**25,000**	**63,500**	**12,500**	**18,750**	**63,500**	**37,500**	**75,000**
24	30,000	12,500	25,000	63,500	**30,000**	**60,000**	**103,500**	**50,000**	**150,000**
36	30,000	**25,000**	**50,000**	63,500	30,000	60,000	103,500	50,000	150,000
48	30,000	25,000	50,000	63,500	**42,500**	**127,500**	103,500	**62,500**	**187,500**

Table 7a: Mechanical Response Capability: Columbia River Bunker (Arrivals)

Hr	FEDERAL			STATE (WA)			3RD ALTERNATIVE		
	Boom (ft)	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*	*Boom (ft)*	*Recovery (bpd)*	*Storage (bpd)*
2				**1,392**			**1,392**		
4							**20,000**	**3,087**	**3,087**
6				**10,000**	**1,234.8**	**1,234.8**			
12				**40,000**	**3,087**	**3,087**	**30,000**	**9,261**	**18,522**
24	**30,000**	**5,186**	**10,372**	*	**7,408.8**	**14,817.6**	**40,000**	**12,348**	**37,044**
36									
48		**6,915**	**13,830**	*	**10,495.8**	**20,991.6**	*	**15,345**	**46,305**

[6] The 3rd alternative response capability standard developed for the San Juan Islands scenarios by Ecology and the committee did not include a four-hour response requirement, in contrast to the other locations. This was due to an oversight. Response at four hours would enhance oil recovery and reduce impacts and damages of the oil, particularly in this area where shoreline impact would occur within a few hours due to the geography with many islands.

Table 7b: Mechanical Response Capability: Columbia River Bunker (Cumulative)									
Hr	**FEDERAL**			**STATE (WA)**			**3RD ALTERNATIVE**		
	Boom (ft)	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***	***Boom (ft)***	***Recovery (bpd)***	***Storage (bpd)***
2				**1,392**			**1,392**		
4				1,392			**21,392**	**3,087**	**3,087**
6				**11,392**	**1,234.8**	**1,234.8**	21,392	3,087	3,087
12				**51,392**	**3,087**	**3,087**	51,392	9,261	18,522
24	**30,000**	**5,186**	**10,372**	51,392	**7,408.8**	**14,817.6**	91,392	12,348	37,044
36	30,000	5,186	10,372	51,392	7,408.8	14,817.6	91,392	12,348	37,044
48	30,000	**6,915**	**13,830**	51,392	**10,495.8**	**20,991.6**	91,392	**15,345**	**46,305**

Important assumptions for the mechanical response portions of the response include:

- Booms are placed on sensitive areas as indicated in Geographic Response Plans (as in Figure 1) according to the schedule of booming in the appropriate standards. Containment, deflection, and protective booms were assumed to be of the type required for "inland" environments, as per US Coast Guard vessel response plan regulations in 33 CFR 155 (US Coast Guard 1996). Boom height was assumed to be 18 to 42 inches and capable of withstanding a significant wave height of up to 3 feet. Entrainment (oil escaping under or splashing over the boom) was assumed to occur when wave heights exceeded 3 feet or current velocity exceeded 1 knot. It was assumed that the booms would have been properly deployed at angles that would allow withstanding of currents up to 1 knot (Fingas 2001).

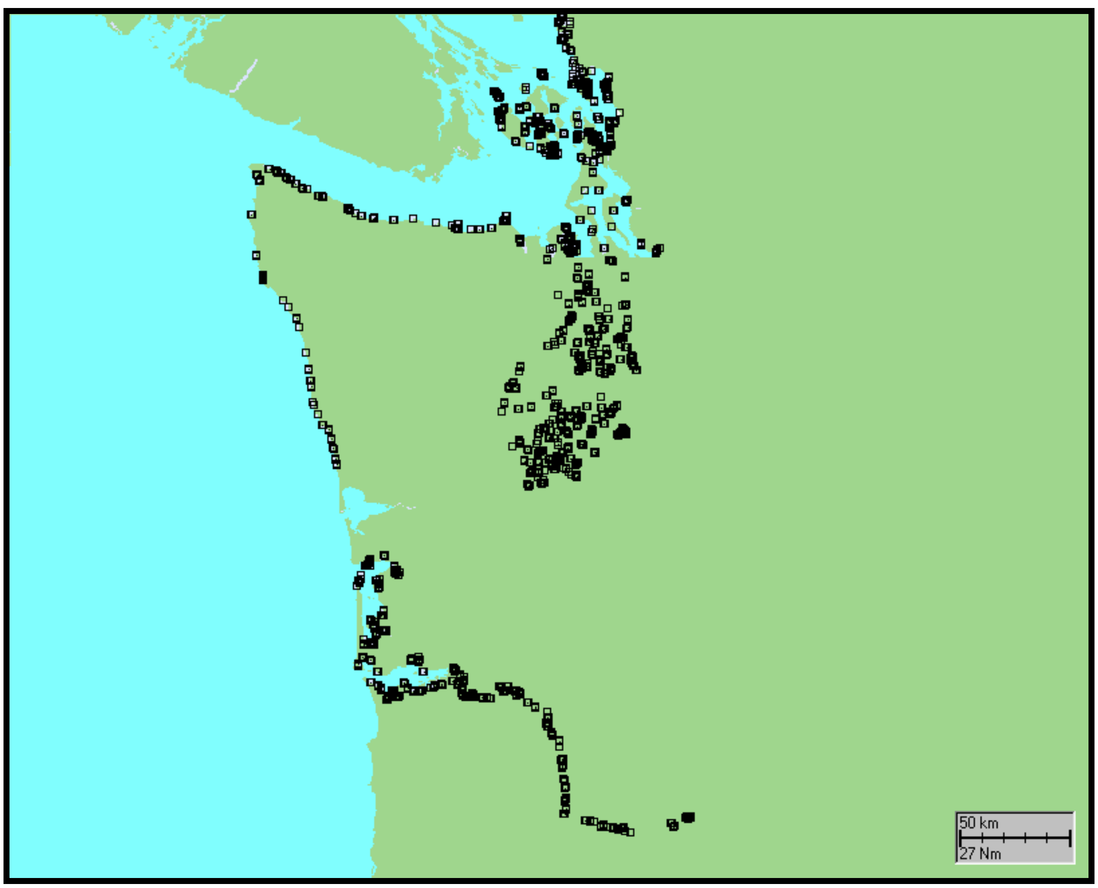

Figure 1: Location of protective booms as per Geographic Response Plans associated with the 2003 Northwest Area Contingency Plan. Note that only booms that were in the general vicinity of the expected spill trajectory would actually have been deployed and are assumed deployed in the modeling.

- All response equipment stipulated in the capability standards is available and in good working condition. All response equipment operators are familiar with the operations of the equipment.
- The equipment arrives on scene and is *deployed* at the time shown in the schedule.
- Canada and Oregon would respond in their respective waters and shorelines at the equivalent of the federal-level of response regardless of Washington's level of response (federal, state, or third).
- In the modeling, mechanical recovery and storage equipment was assumed to be operating at the Effective Daily Recovery Capability (EDRC) rate ("recovery") and storage capacities as shown in the response capability tables. The computer modeling used in this study assumes that any oil that is on the water surface of sufficient thickness (set at 13 microns or 0.0005 inches, based on guidance in API, *et al.* 2001) could be corralled with containment boom and recovered with oil removal equipment (skimmers, vacuum trucks, or oil recovery vessels). This would be the equivalent of responders being directed from observers in helicopters and small planes that could detect the presence of oil visually or with other aids.
- *In-situ* burning operations in relevant scenarios were assumed to occur only when the wind speed, wave heights, and currents were such that operations would be practicable and effective. Burning was assumed to take place only in those locations that were at least three nautical miles from any shoreline and at least six nautical miles from any areas inhabited by more than 10,000 persons (as in Figure 2), as per guidelines in the Northwest Area Contingency Plan 2003, as well as guidelines followed by the US Coast Guard (USCG) and National Oceanic and Atmospheric Administration (NOAA). Spill responses that involved in situ burning were assumed to have concurrent mechanical containment and recovery operations.

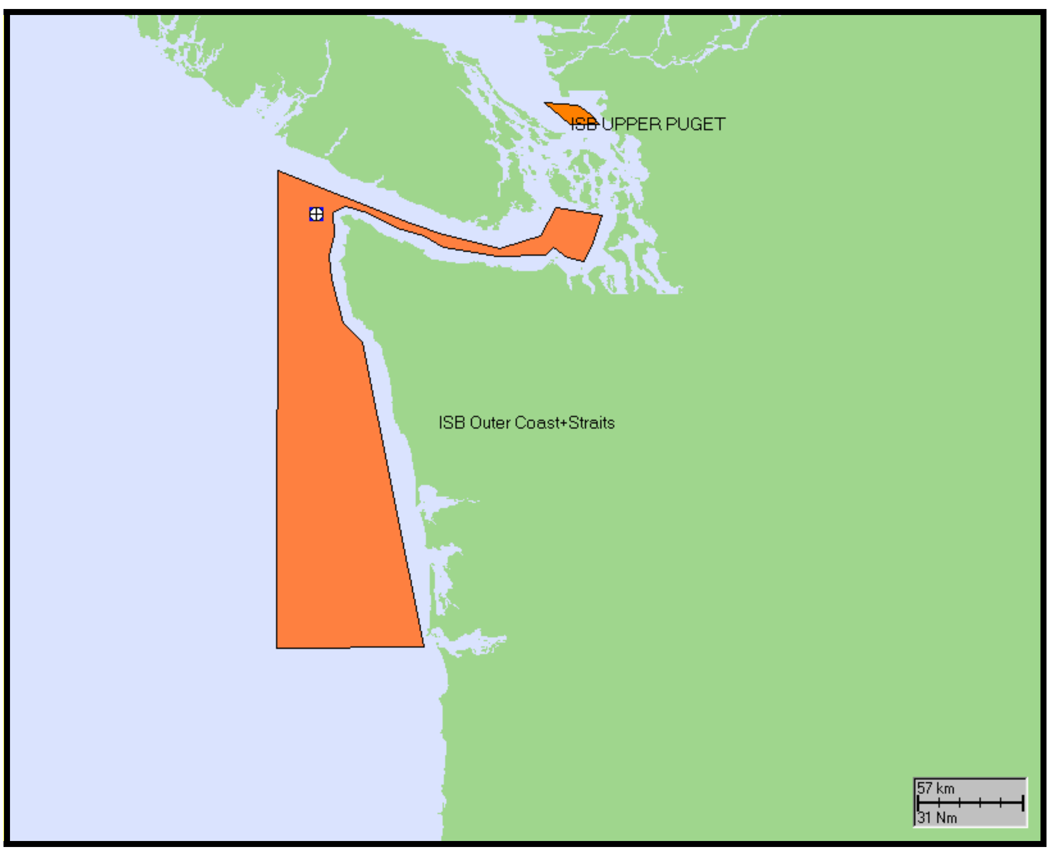

Figure 2: Areas of assumed *in-situ* burning application in SIMAP modeling.

- Modeling assumptions for *in-situ* burning operations in relevant scenarios were as follows:

- Wind speed was less than 25 knots (10.3 meters per second) (Allen 2004; Fingas and Punt 2000; US Coast Guard 1999);
- Wave height was less than three feet (Northwest Area Contingency Plan 2003; Fingas and Punt 2000; US Coast Guard 1999);
- When the current was greater than one knot, there can be no burning as there can be no effective booming (Northwest Area Contingency Plan 2003);
- Burns were at least three nautical miles from any shoreline (Allen 2004; US Coast Guard 1999; NOAA 1998);
- Burns were at least six nautical miles from any areas inhabited by more than 10,000 persons (Northwest Area Contingency Plan 2003; US Coast Guard 1999; NOAA 1997);
- Oil thickness was a minimum of 2 mm thick for *ignition* and, once burning, was minimum of 1 mm (Fingas and Punt 2000; ; NOAA 1998)) (Note: this is interpreted by the model as 13 microns averaged across the oil slick.);
- Burning operations could be conducted at a rate of three 500-bbl/day burns daily – *i.e.*, 1,500 bbl per day (Allen 2004);
- Each burn took one hour (Allen 2004);
- Burning occurred at a rate of 5,000 liters per m^s per day up to 1,500 bbl for a whole day (Allen 2004; Fingas and Punt 2000; NOAA 1998);
- Maximum burn efficiency was 50% (Allen 2004);
- Burns only took place during daylight hours (assume 8am to 6pm) (Allen 2004);
- Remaining oil was removed, as possible, with mechanical recovery at state mechanical response capabilities level; and
- Burning continues until oil reaches 50% emulsification (weathering) and/or oil was too thin (Northwest Area Contingency Plan 2003).

- For dispersant responses, operations were assumed to occur only in locations that were in sufficient water depths and at least three nautical miles from shore, as per the Northwest Area Contingency Plan 2003, as well as guidelines followed by the USCG and NOAA (as in Figure 7). Oil thickness, wind speed, daylight, and other factors that would affect dispersant effectiveness and application logistics were taken into account. Assumptions for the dispersant operations modeling were as follows:

- Wind speed was 3 and 27 knots (1.3 to 11.1 meters per second) (API, *et al.* 2001; NOAA 1998);
- Dispersant application occurred at least 3 n miles from shoreline (API, *et al.* 2001; ; NOAA 1998);
- Oil thickness was minimum of 13 microns (API, *et al.* 2001);
- Dispersants were applied during daylight hours (8am to 6pm) (API, *et al.* 2001);
- Undispersed oil was removed, as possible, with mechanical recovery at state, federal, or hypothetical 3rd alternative response capability levels;
- Mechanical recovery operations were initiated as per state, federal, or hypothetical 3rd alternative response capability levels regardless of the timing of the arrival of dispersant plane sorties;
- Dispersant removal efficiency was 45% based on minimum effectiveness of dispersants for listing in US EPA National Contingency Plan Product Schedule J (Pond, Aurand, and Kraley 2000; US Environmental Protection Agency 2003). A previous study had shown that varying theoretical dispersant effectiveness from 45% to 80% did not appreciably change the oil effectively dispersed when the dispersants were applied after 8 hours after the spill onset (French-McCay, *et al.* 2004).
- Dispersants were applied according to the US Coast Guard CAPS report (USCG 1999) existing planning factors, applied in three tiers involving several C-130 aircraft sorties (flights without reloading). Tier 1 would require delivery of 4,125 gallons of dispersant at hour 8 or at first daylight – 884 bbl oil removal per hour. In this modeling study, hour 8 was considered more practicable than the US Coast Guard's hour 7 due to the planes needing to come from Alaska (personal communication, Richard Wright, Clean Sound Cooperative). The other dispersant applications occurred as per the schedule shown in Table 8.

Table 8: Schedule of Dispersant Applications		
Hour	**Gallons Dispersant Applied**	**Barrels Oil Dispersed Per Hour[1]**
8	4,125	884
14	5,495	1,178
16	5,495	1,178
18	5,495	1,178
20	5,495	1,178
22	1,395	299
27	5,495	1,178
29	5,495	1,178
31	5,495	1,178
33	5,495	1,178
35	1,395	299
[1]The schedule was delayed for darkness.		

- Dispersants were assumed to be applied in the areas shown in Figure 3. These areas are based on the dispersant application criteria in the Northwest Area Contingency Plan 2003 of distances of at least three nautical miles from shore.
- All necessary dispersant approvals and/or authorizations were in place.
- All airplanes equipped with dispersant application equipment (ADDSPACK-equipped C-130 aircraft) were available for deployment from Alaska.
- Weather conditions were suitable for flying airplanes and conducting all other aspects of dispersant application safely and with sufficient precision to be successful.
- The dispersant-to-oil ratio used in all operations was 1:20 (5 gallons/acre).
- Corexit 9500 was applied to Bunker C and Corexit 9527 was applied to crude oil.
- Both Corexit 9500 and Corexit 9527 were available within the time period required.
- Hourly charges for the C-130 aircraft (including field operational support, administrative support, and depreciation) would follow US Coast Guard standard rates for non-government operations.
- Two additional hours of C-130 aircraft usage costs are factored in to allow for transit to and from spill site.

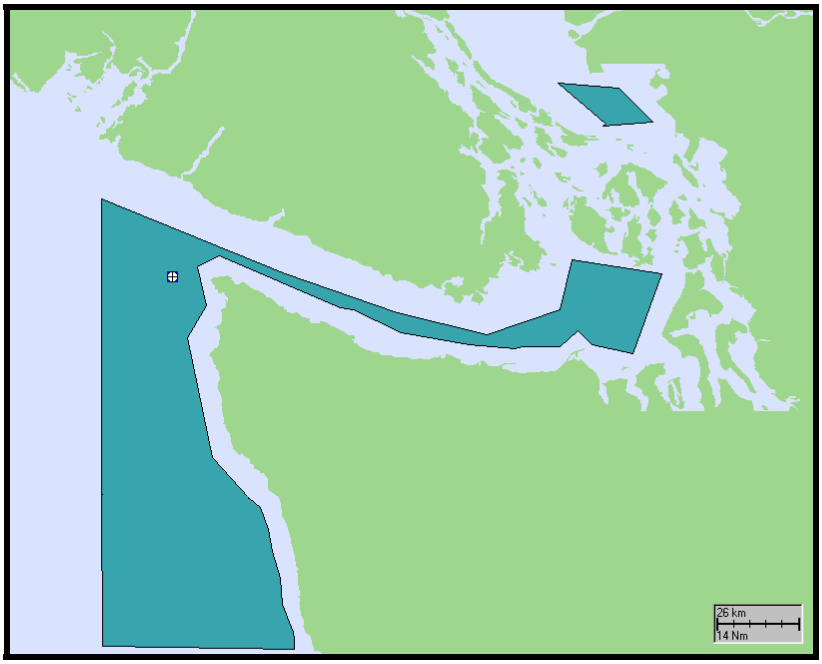

Figure 3: Areas assumed for dispersant operations in modeling.

PHASE II OIL SPILL SCENARIO MODELING

Modifications to Scenario Characteristics Incorporated into Phase II

A number of adjustments and modifications to development of scenarios and the selection of runs for further analysis were incorporated into this second phase of modeling to allow the analysis of "worst case" spills, as per the statutory requirement. The worst cases were incorporated in terms of spill size and magnitude of impacts. These modifications included developing some different scenarios, incorporating different in response assumptions and model inputs, and adding new analyses and focusing on different aspects of the results. On-water spill responses were limited to mechanical containment and recovery (with shoreline cleaning). No dispersant or in situ burning scenarios were included.

- ***Modifications to Spill Volume***

In this phase of modeling spill volumes (250,000 bbl crude) that would "cap" the planning standards were added. This spill volume is the equivalent of an Exxon Valdez-sized spill in Washington waters. The scenarios modeled and analyzed in Phase II are shown in Table 9.

Table 9: Phase II Oil Spill Modeling Spill Scenarios

Location	Oil	On-Water Response							
		None[1]	Mechanical[2]			Dispersant[3]			ISB[4]
			Fed	WA	3rd	Fed	WA	3rd	WA
Outer Coast *Cape Flattery*	250,000 bbl crude	●	●	●	●				
Strait of Juan deFuca *Neah Bay/Dungeness Spit*	25,000 bbl bunker	●	●	●	●				
	65,000 bbl diesel	●	●	●	●				
	250,000 bbl crude	●	●	●	●				
San Juan Islands *Rosario/Georgia Strait*	250,000 bbl crude	●	●	●	●				
Lower Columbia River (Western)	25,000 bbl bunker	●	●	●	●				
Upper Columbia River (Eastern)	25,000 bbl bunker	●	●	●	●				

[1] "No response" means no *on-water* recovery or dispersion attempted. Protective booming, shoreline cleanup, salvage, and spill management/monitoring conducted as required. [2] On-water mechanical response conducted using federal, state, or hypothetical 3rd alternative response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required. [3] Dispersant applications conducted where permitted by state guidelines with concurrent mechanical response using federal, state, or hypothetical 3rd alternative response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required. [4] ISB = *in situ* burning conducted according to state guidelines with concurrent mechanical response using *state* response capabilities. Protective booming, shoreline cleanup, salvage, disposal, and spill management/monitoring conducted as required.

- ***Modifications to Scenario Impact Run Selection***

In the second phase, the selection of runs was modified to incorporate Ecology's need to model "the worst case" for spill impacts. The worst case was defined as the greatest degree of shoreline oiling[2], as well as the most and fastest impact with thick oil to sites within each scenario area (Strait of Juan deFuca, Outer Coast, *etc.*). This gives Ecology different ways to define "worst case" for the purposes of measuring the effectiveness of different spill responses for these types of spills. The basis for selection of runs is shown in Table 10.

Table 10: Phase II Oil Spill Modeling Basis Selection of Worst Case Runs

Scenario Location	*Worst Impact Runs for Analysis*	*Scenario Location*	*Worst Impact Runs for Analysis*
Strait of Juan deFuca	Worst shoreline oiling	***Outer Coast (Cape Flattery)***	Worst shoreline oiling
	Dungeness Spit[1]		Olympic National Marine Sanctuary[1]
	Protection Island[1]		Tatoosh Island[1]
San Juan Islands/Rosario Straits	Worst shoreline oiling	***Western Columbia River***	Worst shoreline oiling
	Lopez Island[1]		Baker Bay[1]
	Orcas Island[1]		Columbia National Wildlife Sanctuary[1]
	Median shoreline oiling	***Eastern Columbia River***	Worst shoreline oiling
	Lummi Island[1]		Ridgefield National Wildlife Refuge #1[2]
	Padilla Bay[1]		Ridgefield National Wildlife Refuge #2[2]

[1]Worst impacts to sensitive site based on fastest oiling with most oil. [2]Two worst impacts to refuge were selected.

Modifications to Response Assumptions and Model Inputs Incorporated into Phase II

A number of adjustments and modifications to assumptions and model inputs related to the spill responses were made in this second phase of modeling that differ from the first phase. These changes were made to better replicate actual spill response outcomes based on experience in the field and current research, as well as to provide Ecology and the Contingency Planning Rule Subcommittee with additional information for the evaluation of the Rule.

- ***Modifications to Booming Response Assumptions***

In Phase I, the "no response" scenarios were assumed to exclude all *on-water* response efforts (mechanical containment and recovery, in situ burning, or dispersants) while still including protective booming at sites designated in Geographic Response Plans (GRPs) according to the schedule in the state-level response guidelines. This gave an assessment of the impacts of on-water recovery but did not provide a baseline for predicting where the oil would go and what impacts would ensue given shoreline protection. In Phase II, the "no response" was redefined to be a complete absence of any response both on-water and protective shoreline booming. In addition, in Phase II, protective booms were assumed to have an effectiveness (*i.e.*, keeping oil out) of 80% as opposed to 100%, assuming that there would be some errors in deployment and boom condition, as would be seen in many actual applications in the field.

- ***Modification of Assumptions about Responses in Canadian and Oregon Waters***

Since it could be expected that because of the geography of Washington and its waters, it would be likely that most major oil spills that occurred in the waters of the Outer Coast, Inner Straits of Puget Sound, Strait of Juan de Fuca, and San Juan Islands area would involve an impact on British Columbia, Canada, it was assumed that a Canadian oil spill response would take place. Based on information on Canadian response capabilities, it was assumed that the Canadian response would always be at a level equal to the US federal response capability regardless of Washington's response level. In Phase I, it was assumed that the Canadian response would be limited to Canadian nearshore areas and Canadian waters. The state response would be limited to Washington's jurisdiction. In Phase II, it was assumed that Canadian and Washington resources would work *jointly and cooperatively* in areas in the middle of the Straits of Juan deFuca and other locations in the San Juan Islands area that were of joint concern. Nearshore resources would be based on each jurisdiction's response capability. Twenty-five percent of Canadian and Washington resources would operate jointly in offshore locations. The remaining 75 percent would operate in nearshore areas. For spills in the Columbia River that would likely affect Oregon waters and initiate a response from Oregon's response system, it was assumed that Oregon's response would be the equivalent of Washington's response based on cooperative agreements between the two states. The response from Oregon would duplicate the response from Washington and at the same level. In Phase I, it had been assumed that Oregon's response would always be at a level equivalent to the federal response capability standard.

- ***Modification of Assumptions on Mechanical Recovery Effectiveness***

In the Phase I modeling, it was assumed that mechanical recovery and storage equipment were capable of operating at the Effective Daily Recovery Capability (EDRC) rate ("recovery") and storage capacities as stipulated by the response capability standard used (either federal, state, or hypothetical third alternative). Note that these recovery rates are already "de-rated" to 20% of the recovery rates this equipment would exhibit in testing facilities. Achieving this level of recovery assumes accurate and efficient tracking of spill slicks and no logistical issues regarding tracking, storage, offloading, *etc*.

The results of Phase I showed recovery rates of as high as 70%. This indicated that with very effective aerial monitoring and tracking of the location of oil slicks, effective day and night oil recovery methodologies, and with intensive training of response crews to foster rapid response and effective recovery operations under the conditions present in the waters of the state, it may be possible to recover this much oil. The model indicated that the oil was on the surface albeit moving about with winds, tides, and currents. But the results would have underestimated the likely costs and damages associated with a spill that might occur by overestimating the ability of on-water recovery.

In Phase II, 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 (*e.g.*, Figures 8 – 15).[7] The modeling in Phase II assumed that any oil that is on the water surface of sufficient thickness could be corralled with containment boom and recovered with oil removal equipment at a rate that decreased progressively over time due to the spreading of the oil on the water surface and decreasing opportunities to effectively corral and remove oil. These adjustments to mechanical recovery rates better simulated real-life recovery operations as are likely possible at present.

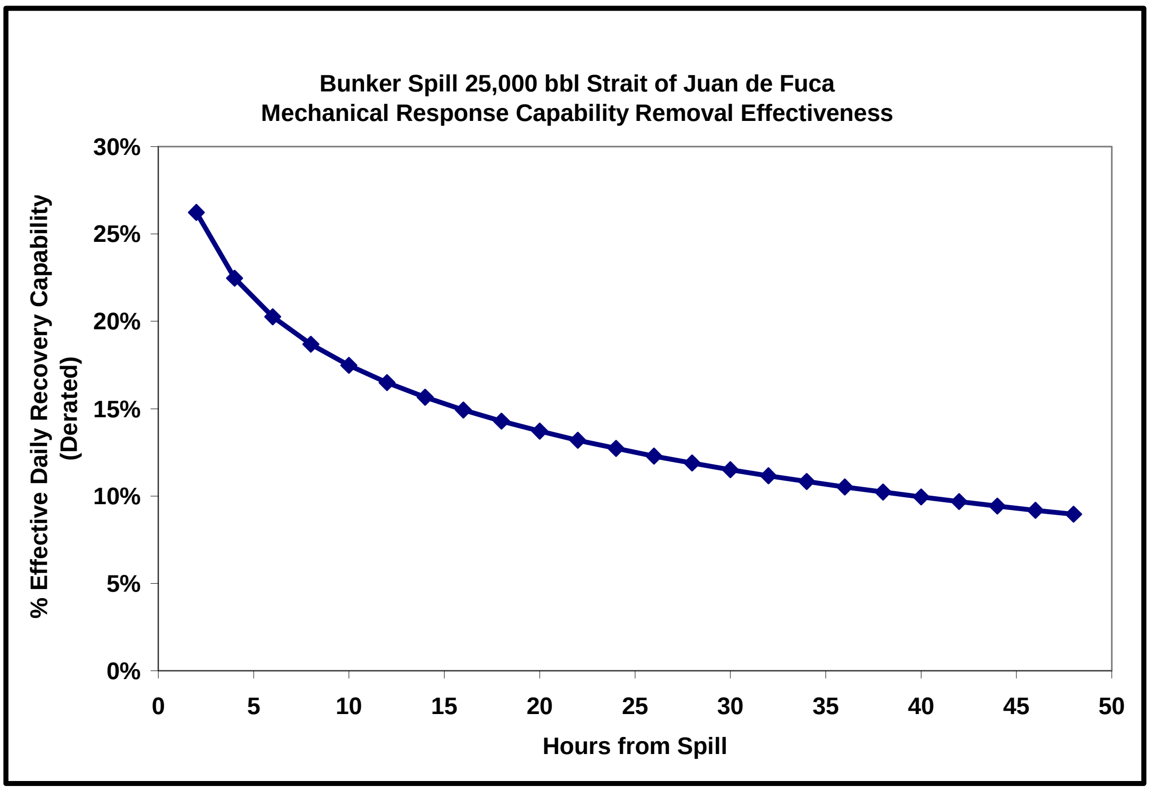

Figure 8: Decreasing oil removal capability with time for bunker spill scenarios.

[7] Reports of higher mechanical response efficiencies (*e.g.*, DeCola, undated) are known by ERC to be based on misinformation and incorrect data (see Etkin 2004 memo to National Academy of Sciences, Committee on Understanding Oil Spill Dispersants: Efficacy and Effects)

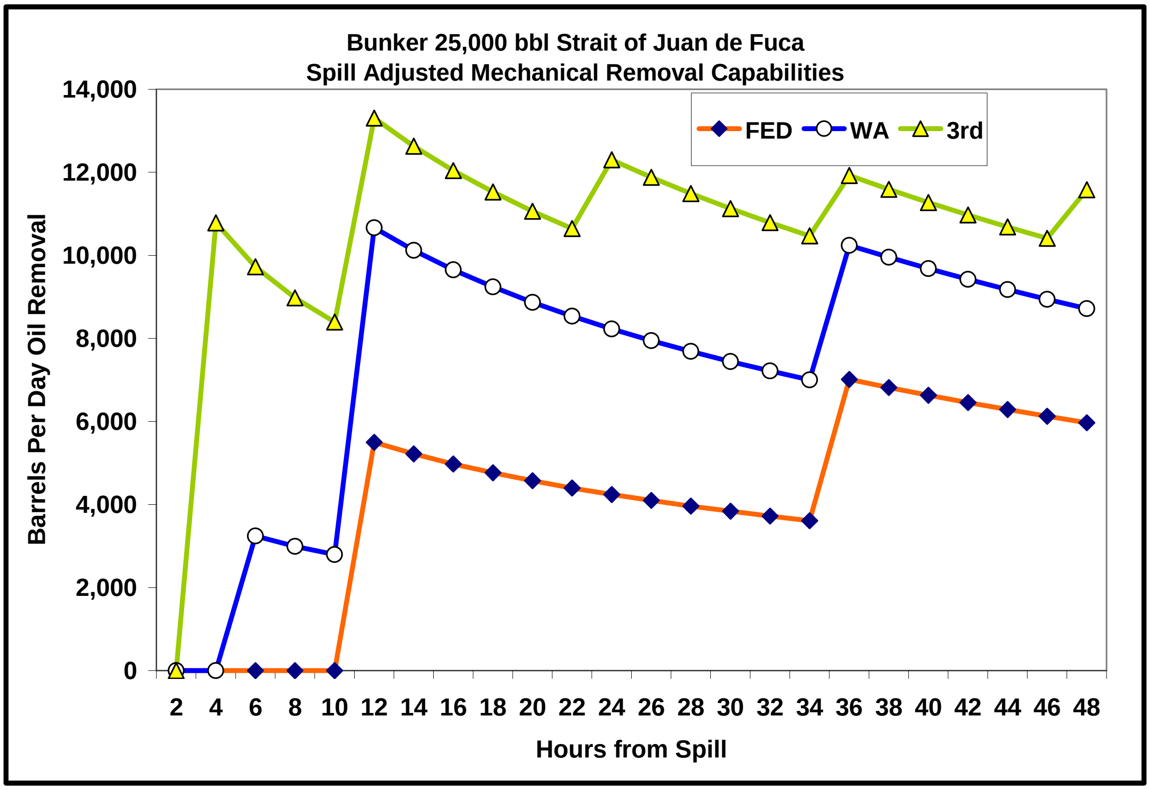

Figure 9: Realized oil removal capabilities by response CAPS for bunker spill scenarios.

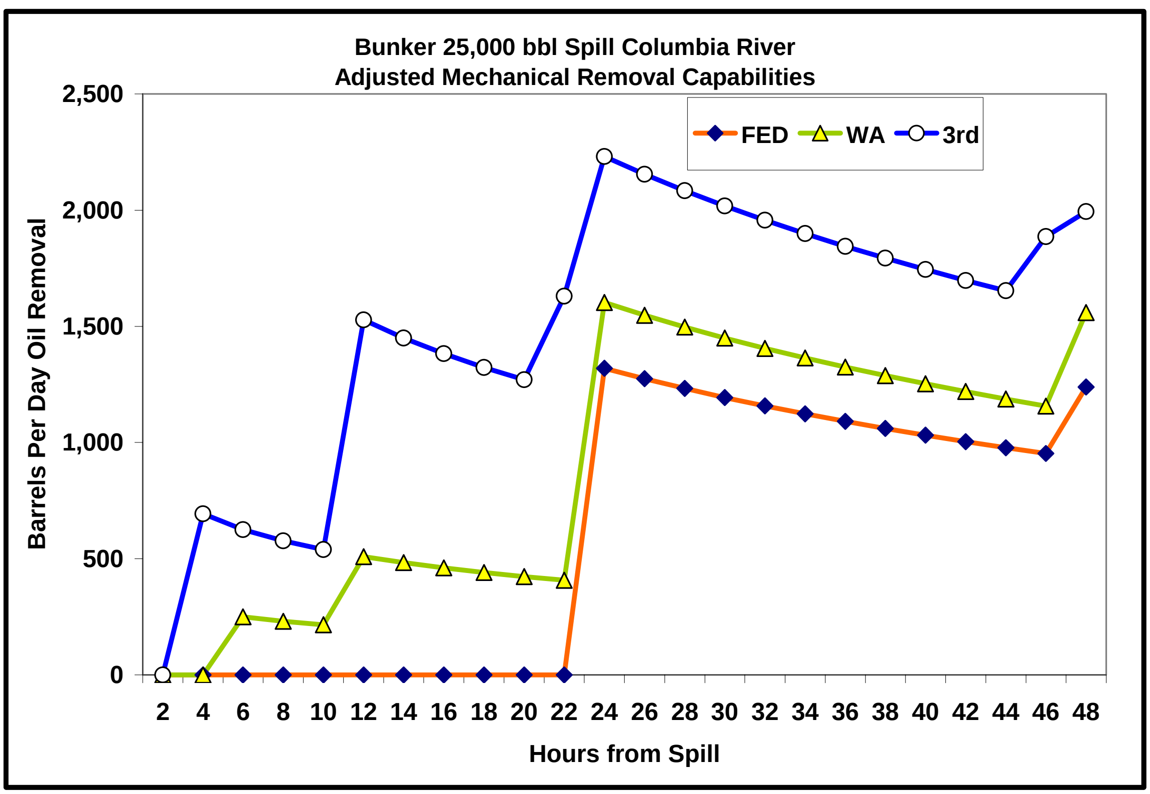

Figure 10: Realized oil removal capabilities by response CAPS for bunker spill scenarios.

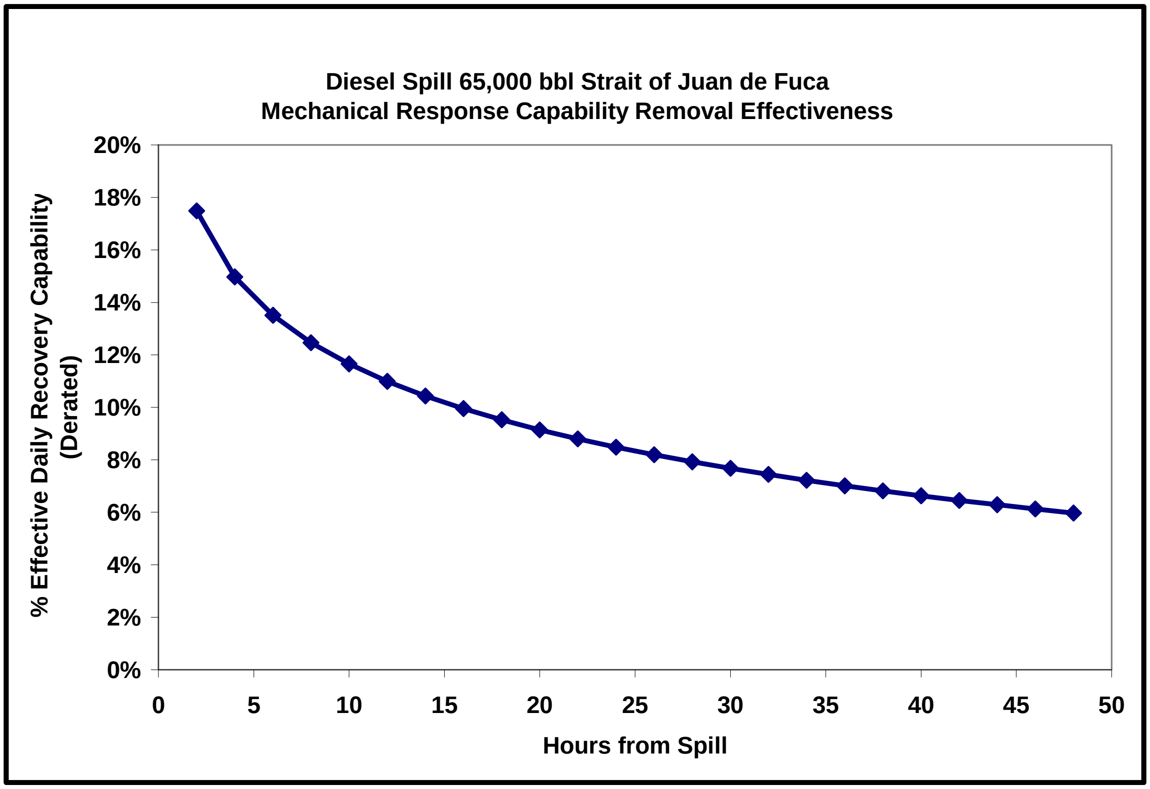

Figure 11: Decreasing oil removal capability with time for diesel spill scenarios.

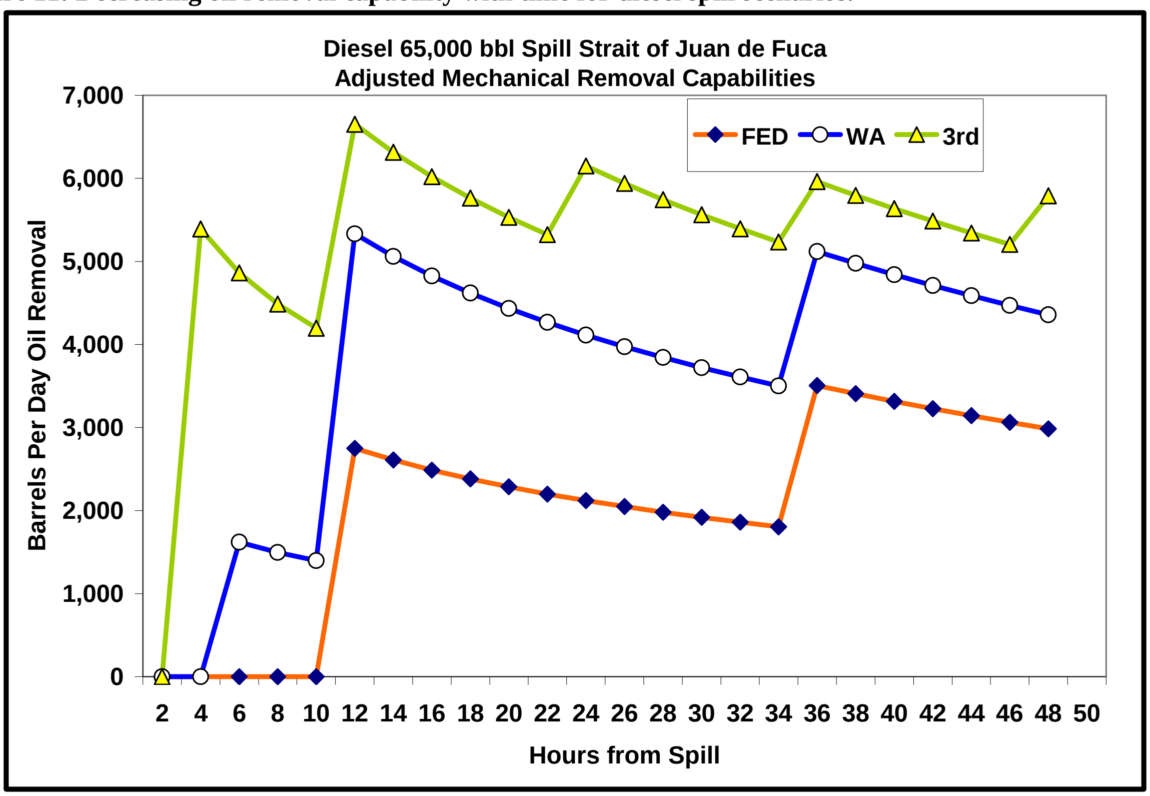

Figure 12: Realized oil removal capabilities by response CAPS for diesel spill scenarios.

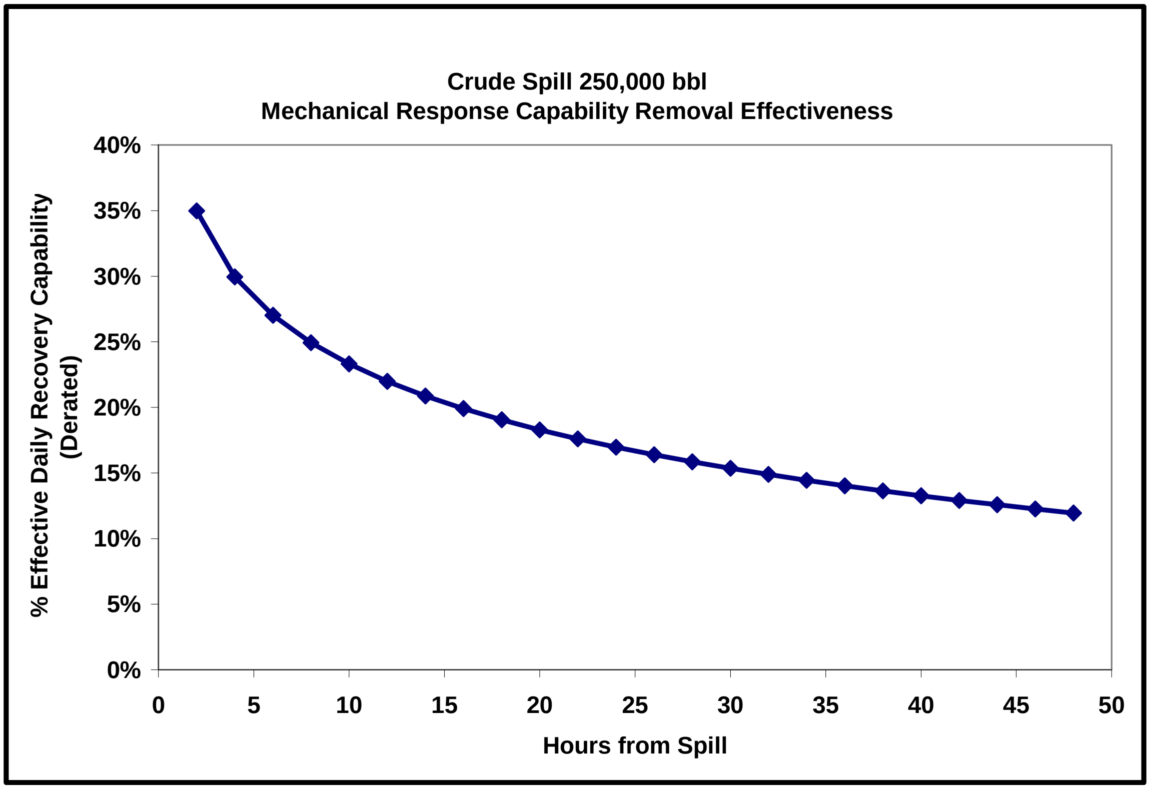

Figure 13: Decreasing oil removal capability with time for crude spill scenarios.

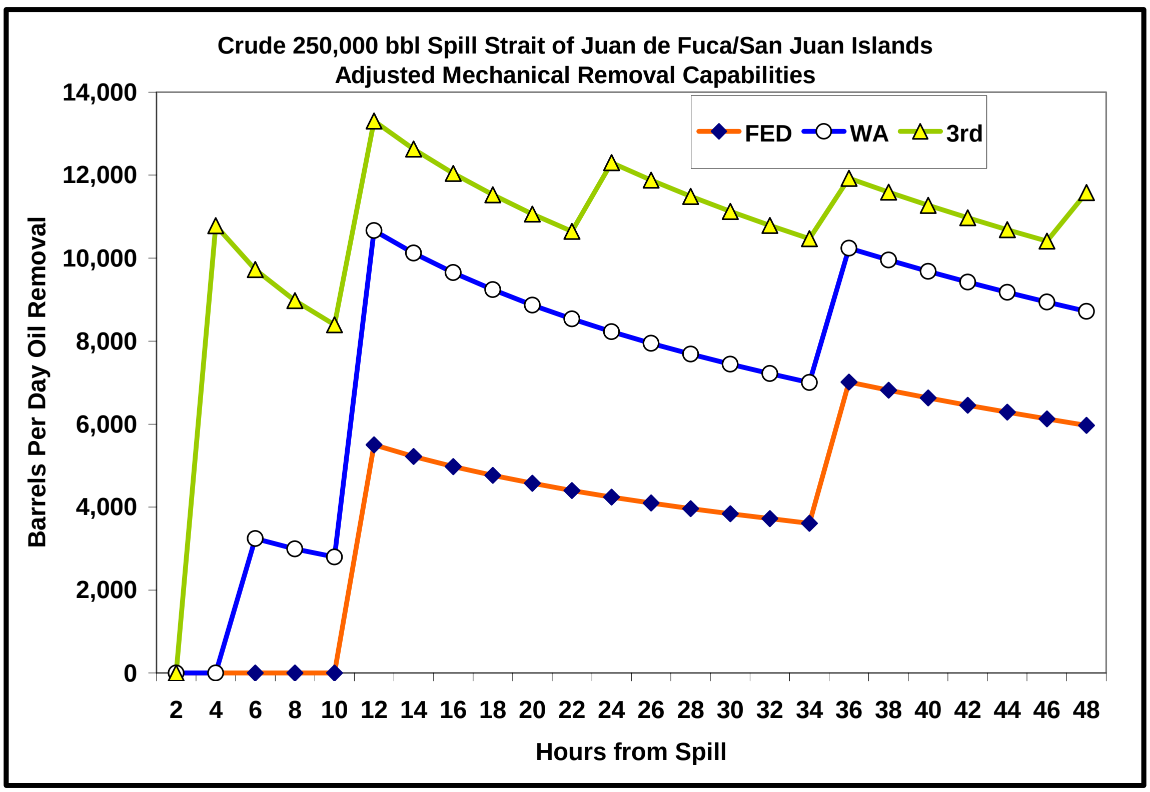

Figure 14: Realized oil removal capabilities by response CAPS for crude spill scenarios in San Juan Islands.

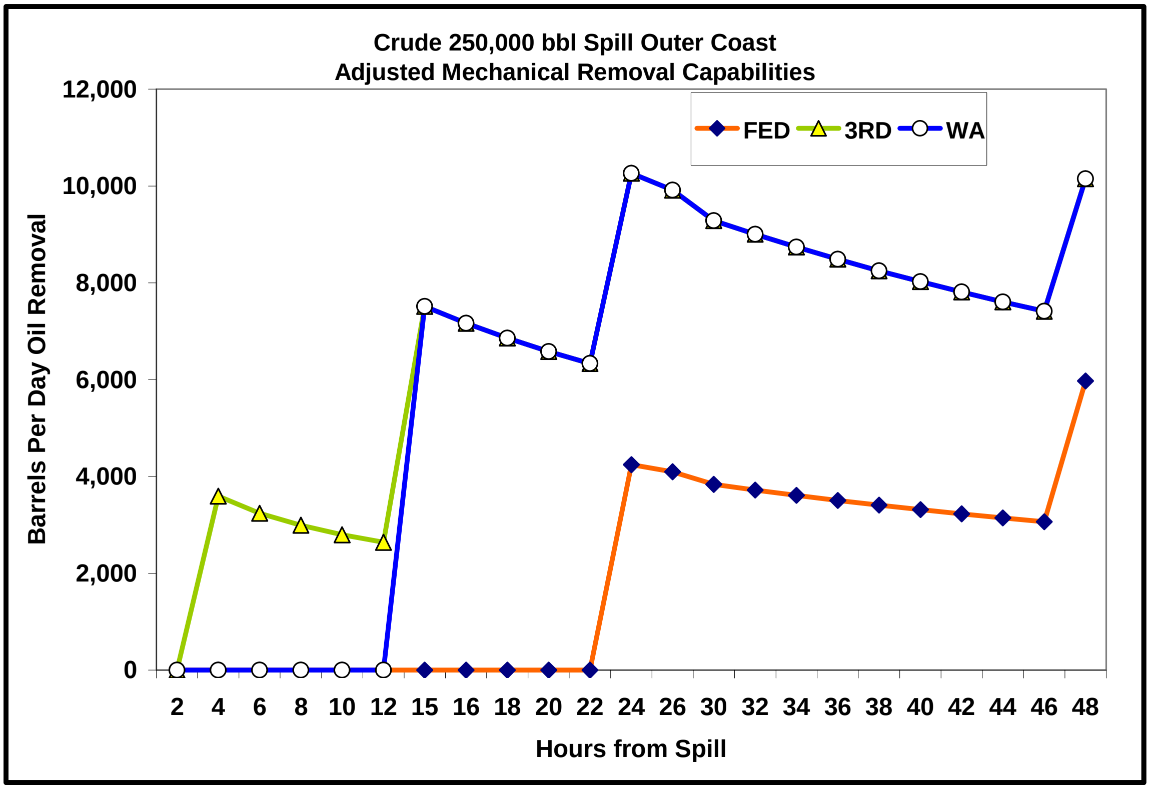

Figure 15: Realized oil removal capabilities by response CAPS for crude spill scenarios on outer coast.

The decreasing rate of oil recovery capability with time is based on a study conducted by Gregory, Allen, and Dale (1999) (Figure 16), as discussed in Etkin, *et al.* (2005).

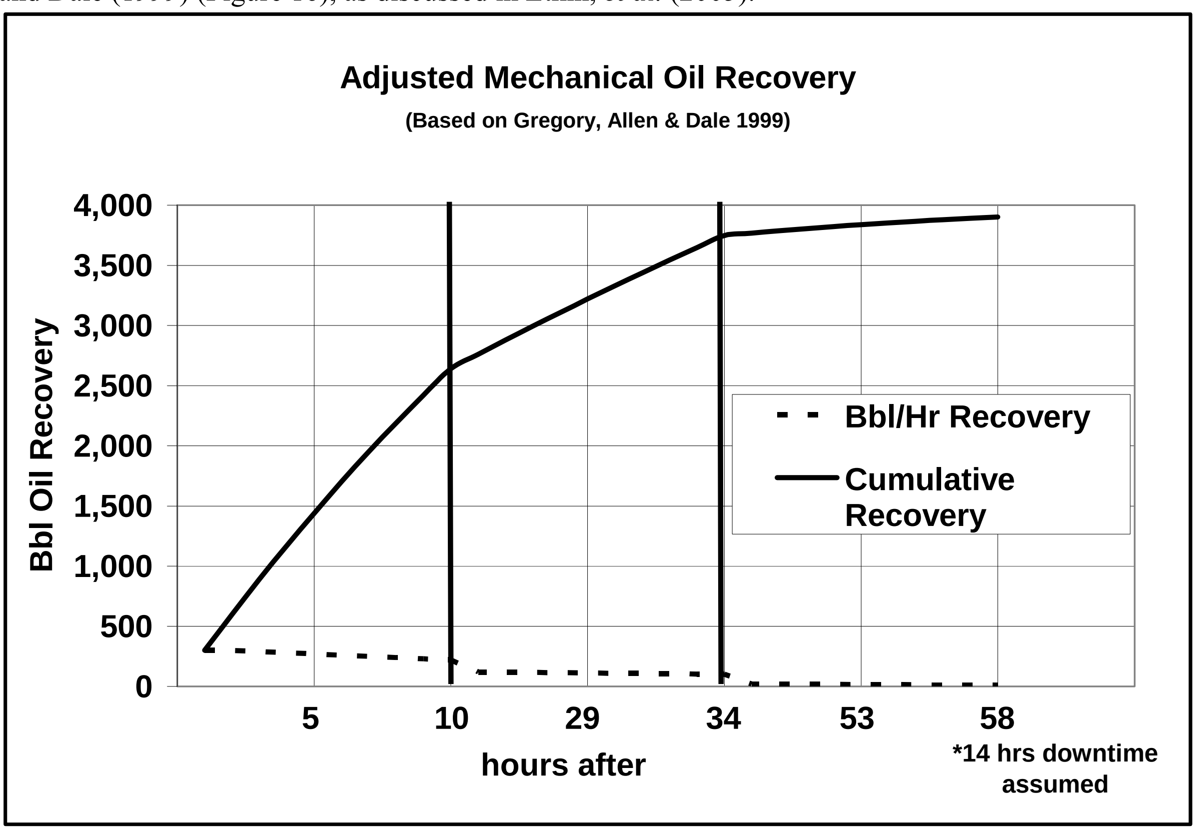

Figure 16: Adjustments to mechanical recovery rates due to spread of oil and reduced encounter rate.

Modifications to Analysis
Some modifications and additions to the analyses conducted in Phase I were included in Phase II. This was to provide additional information to Ecology to better evaluate the effectiveness of the state's proposed standard relative to the required federal planning standard and the hypothetical third standard.

- ***Modification in Geographic Impacts Analyzed***

In the first phase of modeling, the impacts to Washington waters and shorelines were the basis of run selection for degree of impacts. In the second phase, the impacts to both Washington and Canada (British Columbia) in the spill scenarios in San Juan Islands, Strait of Juan deFuca, and the Outer Coast were considered. The impacts to Oregon were included in the scenarios in the Columbia River.

- ***Focus on Differences in Oil Impacts Early in Spill Aftermath***

In Phase I, the analysis emphasized cumulative effects of the oil and shoreline and other impacts as they would be at the end of the response. In Phase II, the focus has shifted to the differences seen in the three response regimes (federal, state, and hypothetical third) as seen early in the response when the first tiers of response would be operative. A real response to a large oil spill of 25,000 to as much as 250,000 bbl would likely not be limited to the quantity of equipment stipulated by the response capability standards. Additional equipment would likely be brought in from other parts of the country. The modeling was aimed at analyzing the impacts of the earliest response efforts on reducing impacts to sensitive sites. While the final analysis contains estimates of costs, damages, and impacts at the end of the response, assuming only the equipment listed in the three response standards is available, a closer evaluation of differences between the response regimes in the early days of the spill aftermath is also included. For example, the time in which the shoreline and sensitive sites are impacted are analyzed for different locations. This will allow Ecology to ascertain the potential influence of earlier response with more equipment.

- ***Use of Federal Response Standard as Comparative Baseline Rather Than No Response***

In Phase I, the results of the three spill responses were compared with "no response". In Phase II, the baseline has been shifted to the federal standard response with the reasoning that this level of compliance is required. The modeling and analysis are measuring how much the state and the third higher standard might provide in terms of additional protection of resources and reduction of damages and costs above the baseline. The federal standards are integrated into state response guidelines where federal standard exceeds state requirements. In some cases, the state's standards are lower than the federal standards (for example, a non-capped vessel in the Strait). The federal standards are requiring smaller vessels to recover more oil earlier.

- ***Additional Analyses Incorporated Into Phase II Modeling***

Recognizing that the prevailing conditions and geography of different parts of the state's waters vary significantly to the point that spill response challenges differ by location, additional analyses have been incorporated into Phase II. These analyses will examine each of the scenario locations for conditions such as proximity to shore, currents, tides, winds, and other factors that could hamper or enhance containment and recovery operations. A summary of each geographic area's conditions that need to be taken into consideration for response planning will be developed. For example, in some areas, the wave heights and currents are such that ocean boom and fast-water booming strategies need to be employed for oil recovery operations.

VARIABILITY AND RANDOMNESS IN MODELING RESULTS

In both Phases I and II of this study, the use of modeling to simulate hypothetical spill scenarios introduces certain degrees of inherent variability and "randomness" that may impact the results and outcomes. In many respects, this "randomness" is analogous to what happens in actual spills and is not necessarily a sign of "incorrect" or "inaccurate" outcomes from the modeling.

For example, because the oil transport model in SIMAP[8] 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[9] 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 randomization 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, protective 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 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 between the three response regimes are small in the Phase II simulations, the differences between runs[10] 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 installation of shoreline protective boom along shorelines changes the impacts to various sensitive sites and to the area as a whole. These differences are the most important for evaluating the benefits of various response planning standards.

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[8] 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). (The use of SIMAP is described in greater detail in French-McCay, *et al.* 2005 Volume I)

[9] 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 or discrete smaller volumes of oil that in total make up the entire amount of oil spilled.

[10] Random combinations of oil release location on the shipping routes, winds, and currents.

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