MODELING IMPACTS OF RESPONSE METHOD AND CAPABILITY ON OIL SPILL COSTS AND DAMAGES FOR WASHINGTON STATE SPILL SCENARIOS

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ABSTRACT

The issues and results of modeling major crude oil spill scenarios in outer coast and sound locations in the state of Washington, USA, to determine relative costs and impacts are explored. Oil spill trajectory and fate and effects modeling were coupled with modeling of response operation strategies (conventional mechanical containment and recovery operations; dispersant application with concurrent mechanical containment and recovery; and in-situ burning with concurrent mechanical containment and recovery) to estimate oil spill response costs and socioeconomic and environmental impacts. The complex issues in modeling the impact of response capability and timing of initial response operations were also examined, comparing the US Coast Guard (USCG) federal response capability standards, proposed Washington State standards, and potential theoretical higher response capability standards.

Results of initial modeling showed little difference in costs and impacts between on-water response options and capability levels, with the exception of being significantly lower than the "no response" option, in which only protective shoreline response, but no on-water removal, were employed. The extremely high level of theoretical oil recovery (50 to 70%) that occurred in the modeling was adjusted in a second analysis to account for increasing inefficiencies in recovery capability with time, demonstrating that oil recovery under Washington State's earlier and more aggressive response standard was three times as high as under the federal response standard. Greater differences in costs and impacts were then realized. Increasing on-water oil removal through more efficient oil slick surveillance, training in strategic response, and more timely response can all contribute to reducing spill impacts and costs.

INTRODUCTION

It is conventional wisdom that prompt, effective, and efficient response operations can significantly reduce the socioeconomic and environmental damages related to a major oil spill. In addition, the response methodology and strategy employed can also significantly decrease costs and damages by reducing the amount of oil that impacts sensitive areas. Response preparedness and capability planning are based on these reasonable assumptions. Measurement of the exact degree to which damages can be reduced by increased response capability and different response strategy is a matter of conjecture, since it is not possible to "redo" a spill response operation for an actual spill to determine how damages might have been reduced. Nor is it possible to conduct sufficient experimentation on response impacts during an actual spill event. Alternatively, modeling can be used to replay a spill scenario with various spill response capabilities, timing, and response strategies to determine different outcomes.

This type of modeling is a complex task in that it necessitates making predictions of the physical and chemical behavior and fate of spilled oil, as well as the biological and ecological impacts of spilled oil, based on known properties of the relevant body of water, oil type, biological species, and ecosystems in relation to each other. Onto this background of oil fate and effect, it is then also necessary to superimpose the application of various response actions to remove oil or change its behavior. This requires predicting the effectiveness of mechanical equipment, chemical dispersants, and combustion based on past performance and testing. Included in the modeling of response operations must also be a prediction of human behavior and decision-making during a complex emergency response operation. The way in which a response is *actually conducted* within the framework of available resources, applicable regulations and response capability standards, and chance circumstances surrounding a particular spill scenario is instrumental in determining the outcome in terms of the effectiveness of oil removal and reduction of costs and impacts.

METHODOLOGY

The goal of this study was to examine differences in costs and effectiveness in reducing oil impacts of three levels of response capability and different response strategies. To accomplish this, the trajectory and fate of hypothetical tanker oil spill scenarios involving the spillage of 65,000 barrels of Alaskan North Slope crude oil on the outer Pacific coast of Washington, USA, near Duntz Rock, off Cape Flattery (48 24.781N/124 44.718W) and in the Rosario Straits/San Juan Islands shipping lanes in Puget Sound (48 25.124N/122 47.604W to 48 40.174N/122 43.047W and 48 40.174N/122 43.047W to 48 51.096N/122 45.806W) (Figure 1) were modeled using Applied Science Associates, Inc.'s modeling software, Spill Impact Model Application Package (SIMAP). In both of these locations, 100 stochastic variations (runs) using different randomly-selected wind, tide, and current patterns were modeled to determine the 5th, 50th, and 95th percentile situations[1] in terms of shoreline impact for further cost and impact analysis. Shoreline impacts were determined by the area of shoreline impacted weighted by factors related to the degree of work required to remove oil and the sensitivity of the shoreline type. [The use of SIMAP in this study is further detailed in French-McCay, *et al*., 2005.]

FIGURE 1: LOCATION OF HYPOTHETICAL CRUDE SPILL SCENARIOS.

Previous modeling efforts using SIMAP to predict oil fate and cost/impact consequences were presented in Etkin, *et al*. (2002, 2003) and French-McCay, *et al*. (2002, 2004).

In each of these two locations, the stochastic modeling was repeated for the different response capabilities shown in Tables 1 and 2. Protective shoreline booming, as pre-determined by geographic response plans to protect sensitive locations (Figure 2), were included in the modeling. Different response strategies were employed in the two locations as shown in Table 3. The "no response" strategy involved only protective shoreline booming without any on-water response. Dispersant and in-situ burning scenarios included concurrent mechanical response operations at the indicated response capability level (federal, state, and 3rd hypothetical).

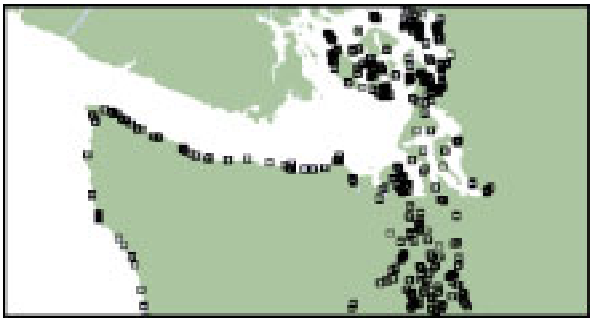

FIGURE 2: LOCATION OF PROTECTIVE SHORELINE BOOMS AS PER GEOGRAPHIC RESPONSE PLANS.

In initial mechanical recovery modeling, four response assumptions applied. (1) Mechanical containment and recovery 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 operating at the Effective Daily Recovery Capability (EDRC) rate ("recovery") and storage capacities as shown in the response capability tables (as 3–4) (USCG 1996, 2002). (2) SIMAP assumed that any oil on the water surface of sufficient thickness (set at 13 microns, based on API, *et al*. 2001) could be corralled with boom and recovered with removal equipment. 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. (3) Containment, deflection, and protective booms were 18 to 42 inches and capable of withstanding a significant wave heights up to three feet. Entrainment (oil escaping under or splashing over boom) occurred when wave heights exceeded three feet or current velocity exceeded one knot. Boom was properly deployed at angles to withstand currents up to one knot. Booms were placed to protect sensitive resources based on maps in the Geographic Response Plans associated with the 2003 Northwest Area Contingency Plan (ACP) (Figure 2).Only booms in the general vicinity of the expected spill trajectory were assumed deployed in the modeling runs. (4) Since it would be likely that a major oil spill in the waters of the Outer Coast and San

TABLE 1: Mechanical Spill Response Capabilities: Outer Coast Spill 65,000 bbl Crude

Hr	FEDERAL (Offshore) [1]			WASHINGTON STATE			3RD HYPOTHETICAL		
	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	40,000+	48,000	96,000	40,000	48,000	144,000
48	30,000	25,000	50,000	40,000+	60,000	180,000	40,000	60,000	180,000
72	30,000	50,000	100,000	40,000+	72,000	180,000+	-	-	-

bpd = barrels per day; ft = feet. Note: all response capabilities are cumulative. [1]USCG 1996, 2002.

TABLE 2: Mechanical Spill Response Capabilities: Outer Coast Spill 65,000 bbl Crude

Hr	FEDERAL (Offshore)[1]			WASHINGTON STATE			3RD HYPOTHETICAL		
	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	-	-	-	20,000	12,000	12,000	-	-	-
12	30,000	12,500	25,000	40,000	36,000	54,000	40,000	48,000	56,000
15	-	-	-	40,000+	48,000	96,000	40,000	60,000	180,000
24	30,000	25,000	50,000	-	-	-	-	-	-
48	-	-	-	40,000+	60,000	120,000	40,000	72,000	216,000
72	30,000	50,000	100,000	-	-	-	-	-	-

bpd = barrels per day; ft = feet. Note: all response capabilities are cumulative. [1]USCG 1996, 2002.

Table 3: WASHINGTON OIL SPILL SCENARIOS

Scenario No. [1]	Modeled Response							
		Mechanical[3]			Mechanical + Dispersant[4]			Mechanical + ISB[5] State
	No[2]	Fed	State	3rd	Fed	State	3rd	
OUTER COAST (CAPE FLATTERY)								
OC-Crud-N	M							
OC-Crud-R-Fed		M						
OC-Crud-R-ST			M					
OC-Crud-R-3				M				
OC-Crud-C-Fed					M			
OC-Crud-C-ST						M		
OC-Crud-C-3							M	
OC-Crud-R-ISB								M
SAN JUAN ISLANDS/ROSARIO STRAITS								
SI-Crud-N	M							
SI-Crud-R-Fed		M						
SI-Crud-R-ST			M					
SI-Crud-R-3				M				
SI-Crud-C-Fed					M			
SI-Crud-C-ST						M		
SI-Crud-C-3							M	

[1] Scenario numbers: location (OC = outer coast; SI = San Juan Islands); oil type (crud = crude); response type (R = "removal" for mechanical recovery or *in-situ* burning; C = chemical dispersion); and response level (N = no response; Fed = federal response capability; ST = state response capability; and 3 = hypothetical 3rd response capability). All responses include protective booming (based on response capability level), shoreline cleanup, and monitoring as required. [2] "No response" = no *on-water* recovery or dispersion. [3]On-water mechanical response using federal, state, or hypothetical 3rd response capability. [4]Dispersant applications where permitted by state guidelines with concurrent mechanical response using federal, state, or hypothetical 3rd response capability. [5]ISB = *in situ* burning according to state guidelines with concurrent mechanical response using *state* response capability.

Juan Islands area would involve an impact to British Columbia, Canada, it was assumed that a concurrent Canadian oil spill response would take place on Canadian waters and shorelines. To impose the largest theoretical stress on Washington 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.

For *in-situ* burning scenarios, four assumptions were applied. (1) Burning took place when wind speed was less than 25 knots (10.3 meters per second), wave height was less than three feet, and currents were not greater than one knot, as there can be no effective booming (NW ACP 2003; Fingas and Punt 2000; USCG 1999). (2) Burns occurred at least three nautical miles from any shoreline, and at least six nautical miles from any areas inhabited by more than 10,000 persons (Allen 2004; USCG 1999; NOAA 1997, 1998; NW ACP 2003). (See Figure 3.) (3) Oil thickness was a minimum of 2 mm thick for *ignition* and, once burning, was minimum of one mm (Fingas and Punt 2000; NOAA 1998). [This

Table 4: Schedule of Dispersant Applications

Hour	Gallons Dispersant Applied	Barrels Oil Dispersed Per Hour[a]
8[b]	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

[a] Schedule was delayed for darkness. [b]Hour 8 rather than USCG hour 7 due to planes coming from Alaska.

was interpreted in SIMAP as 13 microns averaged across the slick.] Burning continued until oil reached 50% emulsification and/or oil was too thin (NW ACP 2003). (4) Burning operations could be conducted during daylight hours at a rate of three 500-bbl/day burns daily — i.e., 1,500 bbl per day with each burn lasting one hour. Burning occurred at a rate of 5,000 liters/m^2 per day up to 1,500 bbl for a whole day with a maximum burn efficiency of 50% (Fingas and Punt 2000; NOAA 1998, Allen 2004).

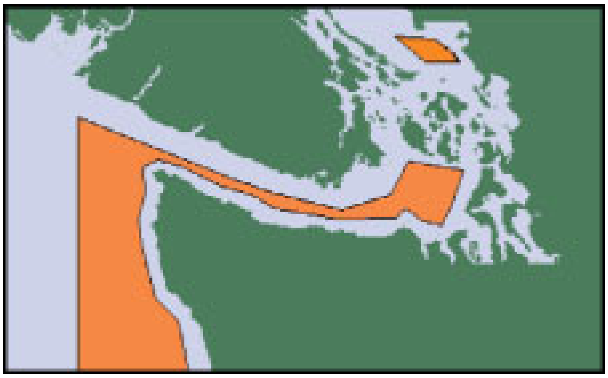

FIGURE 3: AREAS OF ASSUMED *IN-SITU* BURNING AND DISPERSANTS IN SIMAP MODELING.

For dispersant operations, three assumptions were applied. (1) Chemical dispersion only occurred under the following parameters: wind speed was between three and 27 knots; oil thickness was a minimum of 13 microns (French and Payne 2001); daylight hours; and at least three nautical miles from shoreline (API, *et al*. 2001; NOAA 1998) (Figure 3). (2) Dispersant removal efficiency was 45% based on minimum effectiveness of dispersants for listing in US EPA National Contingency Plan Product Schedule J (US EPA 2003). A previous study had shown that varying theoretical dispersant effectiveness from 45% to 80% did not appreciably change oil effectively dispersed when dispersants were applied eight hours after spill onset (French-McCay and Payne 2001). (3) Dispersants were applied according to the USCG existing planning factors (USCG 1999), applied in three tiers involving several C-130 aircraft sorties (flights without reloading), which were available and operational. Tier 1 involved delivery of 4,125 gallons of dispersant at hour 8 or at first daylight — 884 bbl oil removal per hour. Other applications occurred as per the Table 4 schedule. Corexit 9527 was available and applied at the dispersant-to-oil ratio of 1:20 (five gallons/acre). All necessary approvals and/or authorizations were in place. Weather conditions were suitable for air travel and conducting all other aspects of dispersant application safely and with sufficient precision to be successful.

Oil spill response costs applied were based on methodologies described in Etkin (2001, 2003), and Etkin, *et al*. (2002, 2003). Socioeconomic cost estimation (for impacts to tourism, recreation, commercial fishing, Tribal nations, ports, shipping, and other regional interests) was based on methods in Etkin, *et al*. (2002, 2003) applied to Washington and Canadian assets using costs derived from a variety of state, local, and federal sources. Natural resource damage costs were derived using methodologies in French-McCay, *et al*. (1996, 2002) and NOAA (1995).

RESULTS

Modeling results for 95th percentile runs (nearly the "worst case scenario" in terms of shoreline impact) for spill scenarios in the two locations are shown in Tables 5 and 6. A single model run was selected for comparison for each location in order to remove variables of chance wind, tide, and current factors that would determine the relative degree of impact. Costs for different stochastic model runs differed significantly due to the variations in shoreline impacts and spill trajectory. Selection of a single uniform spill scenario run (with the same baseline trajectory and shoreline impact) allowed for a more reasonable comparison between response options. The results showed extremely high levels of offshore oil removal (50 to 70%), which, though theoretically possible given the existence of oil on the water and the presence of sufficient resources for oil removal, are higher than generally seen in practice.

In order to more closely mimic the rates of removal seen in mechanical containment and recovery field operations, a second set of mechanical response San Juan Islands scenarios was modeled for which oil removal efficiency was systematically reduced with time (Figures 4–5), based on the work of Gregory, Allen, and Dale (1999). The oil removal under the federal response capability standard-based response reached 8.1%, while under the state response, which brings more equipment in at an earlier time, more than three times as much oil was recovered (24.8%) (Figure 6). These recovery rates were more in line with levels seen in actual practice in all but the most sheltered locations where oil recovery can be maximized.

Table 5: Washington Outer Coast 65,000-bbl Crude Oil Spill Scenario: 95th Percentile With Efficient Offshore Oil Removal

Scenario	Shoreline Impact (m^2)	% Offshore Oil Removal	Response Costs[1]	Impacts[1]	
				Socioeconomic[2]	NRDA
OC-Crud-N	237,000	0%	$73 million	$112 million	$998 million
OC-Crud-R-Fed	39,000	63%	$66 million	$24 million	$280 million
OC-Crud-R-ST	35,000	65%	$70 million	$24 million	$275 million
OC-Crud-R-3	37,000	66%	$78 million	$23 million	$264 million
OC-Crud-C-Fed	34,000	62%	$55 million	$25 million	$278 million
OC-Crud-C-ST	38,000	63%	$59 million	$23 million	$272 million
OC-Crud-C-3	36,000	66%	$59 million	$23 million	$266 million
OC-Crud-R-ISB	33,000	65%	$60 million	$23 million	$271 million

[1]2004 US $, [2]Impacts to tourism, port business, shipping, commercial fishing, Tribal subsistence fishing, recreation, *etc*.

Table 6: Washington San Juan Islands 65,000-bbl Crude Oil Spill Scenario: 95th Percentile With Efficient Offshore Oil Removal

Scenario	Shoreline Impact (m^2)	% Offshore Oil Removal	Response Costs[1]	Impacts[1]	
				Socioeconomic[2]	NRDA
SI-Crud-N	301,000	0%	$88 million	$18 million	$15.4 million
SI-Crud-R-Fed	140,000	54%	$78 million	$8 million	$6.2 million
SI-Crud-R-ST	122,000	65%	$76 million	$7 million	$5.3 million
SI-Crud-R-3	98,000	71%	$73 million	$8 million	$4.3 million
SI-Crud-C-Fed	142,000	54%	$75 million	$9 million	$6.8 million
SI-Crud-C-ST	120,000	65%	$72 million	$7 million	$6.4 million
SI-Crud-C-3	96,000	71%	$70 million	$11 million	$4.3 million

[1]2004 US $, [2]Impacts to tourism, port business, shipping, commercial fishing, Tribal subsistence fishing, recreation, *etc*.

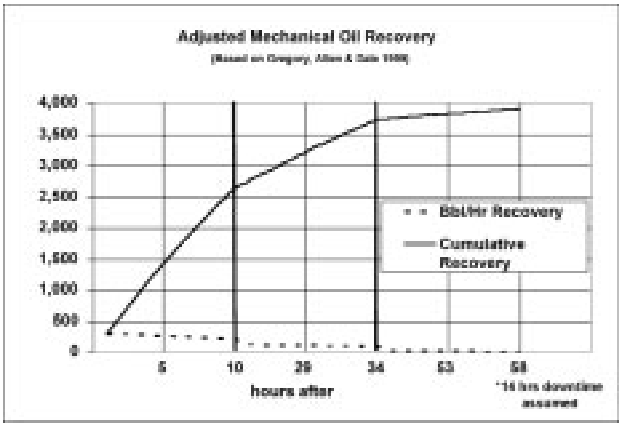

FIGURE 4: MECHANICAL OIL RECOVERY ADJUSTED FOR INCREASING INEFFICIENCY DUE TO SPREAD OF OIL ON WATER SURFACE, PERSONNEL SHIFT CHANGES AND DOWNTIMES, AND OFFLOADING AND STORAGE OF COLLECTED OIL, BASED ON GREGORY, ALLEN, AND DALE (1999).

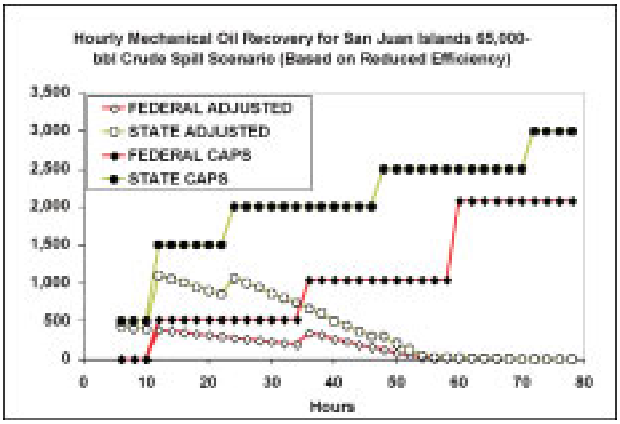

FIGURE 5: THEORETICAL HOURLY MECHANICAL OIL RECOVERY RATES FOR FEDERAL AND STATE RESPONSE CAPABILITY STANDARDS ADJUSTED TO ACCOUNT FOR INCREASING INEFFICIENCIES IN RECOVERY BASED ON GREGORY, ALLEN, AND DALE (1999).

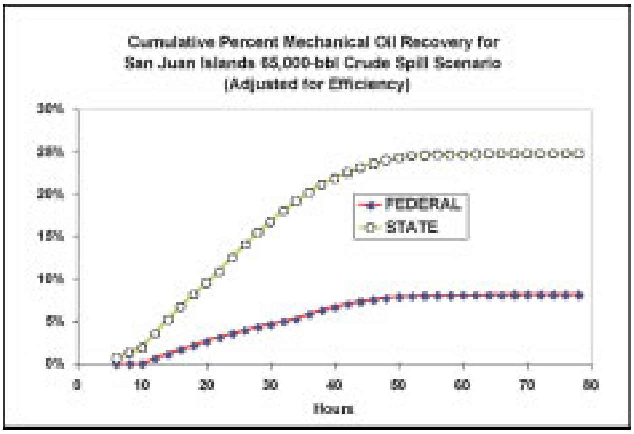

FIGURE 6: CUMULATIVE OIL RECOVERY UNDER STATE AND FEDERAL RECOVERY CAPABILITY STANDARDS AS ADJUSTED FOR INCREASING INEFFICIENCIES IN RECOVERY. STATE RECOVERY REACHES 25%, FEDERAL 8%.

Oil spill impacts to natural resources and socioeconomic assets, as well as shoreline-related response costs for the San Juan Islands scenarios are thus more likely to be closer to the “no response” scenario results, adjusted downward by 8% and 25%, respectively, for the federal and state mechanical response strategies. In other words, the on-water oil recovery would remove 8% or 25% of the oil before it impacted the shoreline. This could mean a difference in impacts of an estimated $3 million in socioeconomic costs and $2 million in natural resource damages under the federal response capability standard versus the state’s response standard in the San Juan Islands. For spills on the outer coast, where socioeconomic and natural resource damages were considerably higher in the modeling (due to more Tribal subsistence fishing and birds), the cost differences between the response levels would be considerably higher. The potential influence of increased oil removal through the earlier initiation of the state response (beginning at six hours rather than 12 hours after the spill occurs as in the federal response), now becomes more clear. Additional modeling and analysis is being conducted to evaluate the impacts of earlier and more aggressive response operations on these two spill locations, along with several others in Washington waters.

CONCLUSIONS

The modeling results indicate that, except for the “no response” scenarios where there was significantly greater shoreline oiling and cost impact, there was little difference between response options and response capabilities in terms of cost and impacts. The key to these results is that there was *extremely efficient offshore oil removal* (50 to 70%), which is rarely accomplished in actual spill response operations. Theoretically, this level of recovery is possible in that the modeling shows that there is still enough oil present for removal and sufficient equipment to accomplish this if the response operations are run with strategic precision, particularly with respect to locating and herding oil for removal, burning, or dispersant application. Indeed, the response capability standards, theoretically, require that these levels of oil removal (already “de-rated” to a reduced efficiency of oil encounter seen in the field) be present. When the factor of reducing oil removal efficiency that mimics actual field experience is incorporated into the modeling, the results become quite different. The increasing inefficiencies of mechanical containment and recovery operations over time due to the oil spreading, logistical issues (especially storage of recovered oil), and the shift of response operations from pro-active strategic response to reactively “chasing” oil dramatically increases the costs and impacts of a spill. Here it becomes clear that *timing* of response operations is paramount in reducing the impacts of a spill. Bringing the same or even greater amounts of offshore oil removal equipment on-scene at later hours and days into the spill response gives decreasingly effective results. It is also clear that with better preparedness and training, especially with greater emphasis on locating and strategically herding oil for mechanical removal, dispersion, or burning, the effectiveness of on-water response operations can be increased to dramatically reduce spill impacts and costs. The higher impacts and costs for “no response” scenarios show that effective on-water oil removal is essential for reducing impacts. The more effective offshore oil removal (or dispersion), the lower the costs and impacts.

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BIOGRAPHY

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1 The nth percentile run is that combination of wind, tide, and current for which the shoreline oil impact is greater in 100–n percent of cases, and the impact is less in n percent of cases. e.g., for the 95th percentile, only 5% of cases had greater impacts, and 95% had lesser impacts.