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**US COAST GUARD RESEARCH AND DEVELOPMENT CENTER
LASER FLUOROSENSOR COST/BENEFIT ANALYSIS**

DELIVERABLE 1: OPPORTUNITY ANALYSIS

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Summary of Oil Spillage¹ Into US Navigable² Waters 1995 – 2004

An analysis of oil spillage into navigable waters of the US for the last decade (1995 – 2004) reveals that a total of nearly 25 million gallons of have been spilled in over 2,000 incidents involving at least 500 gallons³. (See Figure 1 and Table 1). There is an overall downward trend in both annual spill numbers and volume. During the first half of the last decade (1995 – 1999), an average of 3.5 million gallons spilled annually in 259 incidents involving at least 500 gallons. During the latter half (2000 – 2004), annual spillage averaged 1.5 million gallons per year in 156 incidents involving at least 500 gallons.

The most common types of oil spilled fall into the category of “light fuels”⁴, encompassing a total of 29% of all spillage. A total of 7.1 million gallons of light fuels have spilled in the last decade. Crude oils follow with a total of 6.3 million gallons spilled, 25% of the total spillage in the last ten years. Spills of volatile organic distillates⁵ totaled 6.3 million gallons or 16% of total spillage. Tables 2 and 3 give a breakdown of annual spillage by oil categories. An analysis by size class is shown in Table 4 and Figure 2. Tables 5 and 6 show total oil spillage for 1995 – 2004 by oil category.

Heavy oils⁶ are the fourth largest category of oils spilled with 2.3 million gallons or 10% of the total oil spilled in the last decade. There have been 115 heavy oil spills of at least 500 gallons in US navigable waters in this time period, with an average spill size of just over 20,000 gallons. (See Figures 3 and 4). With heavy oil spills as with all spills, the average annual volume of spillage has decreased since the first half of the decade, from an average of 348,000 gallons annually to 123,000 gallons. Spill number for heavy oil spills has decreased as well, from an average of 16 spills of at least 500 gallons during 1995 – 1999 to an average of 7 spills of this magnitude during 2000 – 2004.

¹ Only spills of 500 gallons or more were considered in this analysis.

² “Navigable” is defined as “navigable in fact”.

³ There are many spills under 500 gallons that are not being considered in this analysis. These spills make up at least 90% of all reported spills. The total volume of these smaller spills amounts to less than 1% of the total spillage in any year, however, based on analyses of Environmental Research Consulting’s databases. The pattern of spillage represented by an analysis of spills of 500 gallons or more is representative of overall spillage patterns. Spills of less than 500 gallons, and, in particular spills, of less than 100 gallons have been reported on an increasing basis since the early 1980s in large part due to spill reporting requirements at the federal and state levels.

⁴ Includes diesel, No. 2 fuel oils, naphtha, and other light fuels.

⁵ Includes jet fuel, gasoline, and No. 1 fuel oil.

⁶ Includes No. 5 fuel, No. 6 fuel, heavy fuels, bunker fuels, and heavy crude.

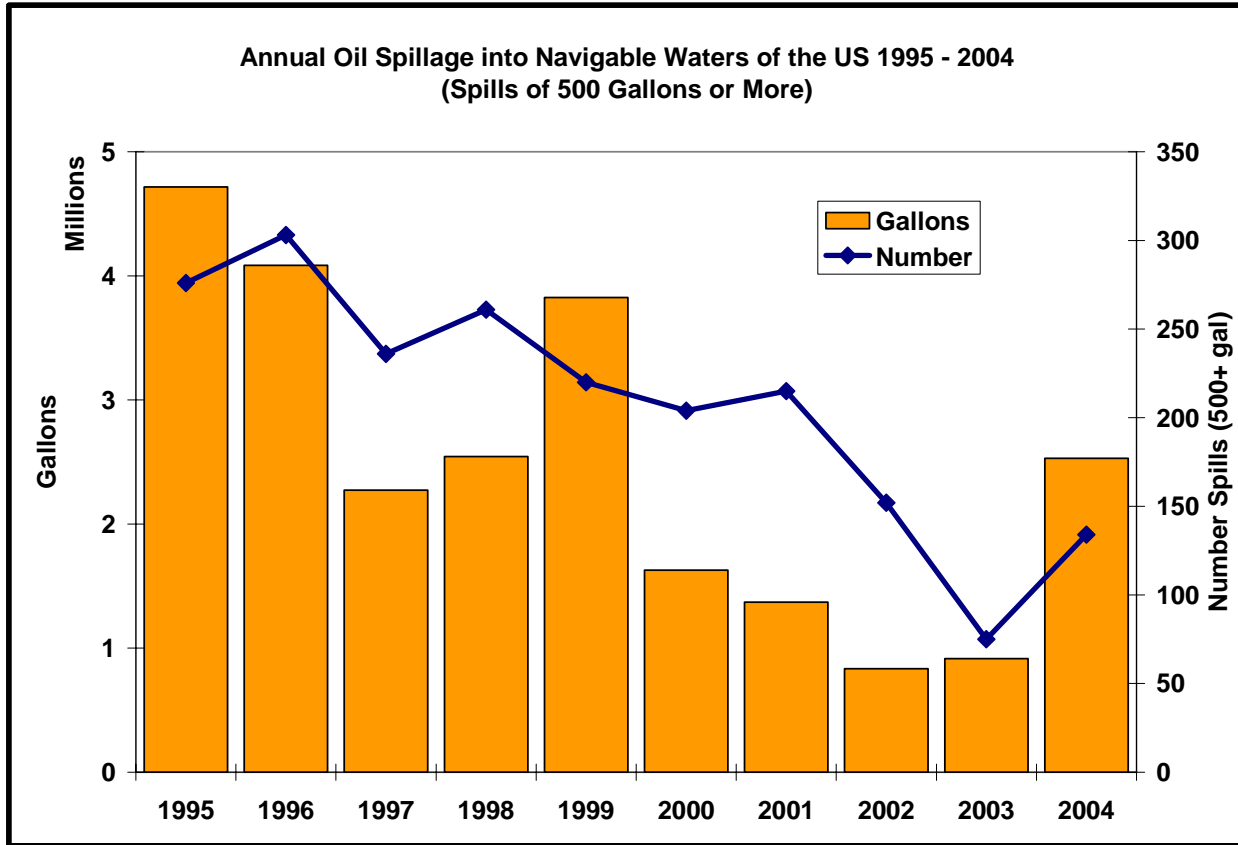


Figure 1: Annual Oil Spillage into US Navigable Waters 1995 – 2004 (Spills of 500 Gallons or More)⁷

Year	Number	Gallons
1995	276	4,716,443
1996	303	4,084,449
1997	236	2,273,488
1998	261	2,544,263
1999	220	3,825,911
2000	204	1,628,577
2001	215	1,370,041
2002	152	834,172
2003	75	915,733
2004	134	2,530,812
TOTAL	2,076	24,723,890

⁷ Source: Environmental Research Consulting Databases

⁸ “Navigable” is defined as “navigable in fact”.

⁹ Source: Environmental Research Consulting Databases

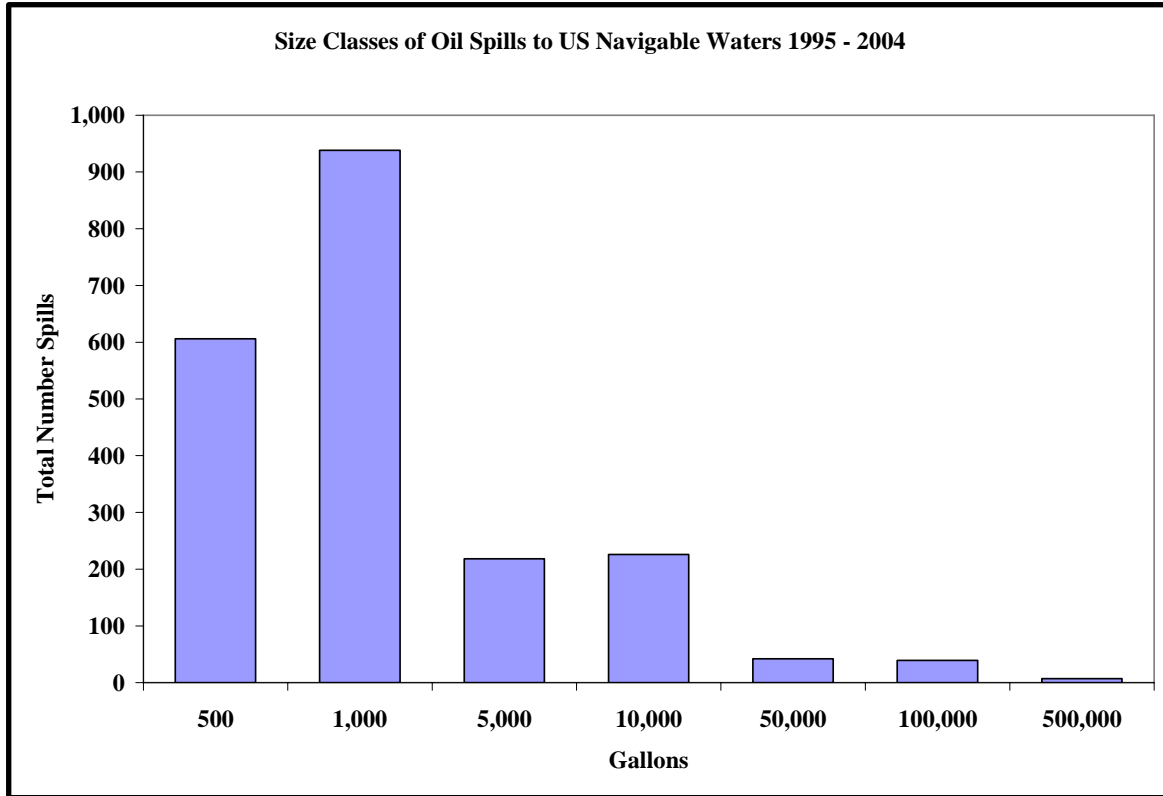


Figure 2: Oil Spills to US Navigable Waters 1995 – 2004 By Size Class¹⁰

Size Class	All Oil Spills		Heavy Oil Spills	
	Number	% Total	Number	% Total
500 – 999 gallons	606	29.2%	22	19.1%
1,000 – 4,999 gallons	938	45.2%	53	46.1%
5,000 – 9,999 gallons	218	10.5%	10	8.7%
10,000 – 49,999 gallons	226	10.9%	19	16.5%
50,000 – 99,999 gallons	42	2.0%	8	7.0%
100,000 – 499,999 gallons	39	1.9%	2	1.7%
500,000 – 999,999 gallons	7	0.3%	1	0.9%

¹⁰ Source: Environmental Research Consulting Databases

Table 3: Annual Amount Spilled into Navigable US Waters In Incidents Involving 500 Gallons or More (In Gallons)¹¹												
OIL CATEGORY¹²	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL	% TOTAL
ANF	0	1,000	0	6,000	2,000	0	1,000	500	0	0	10,500	0.04%
CRD	2,143,209	312,142	934,499	618,188	616,400	367,757	503,631	335,788	420,668	95,952	6,348,234	25.68%
EDO	23,460	1,000	11,200	206,947	810	1,000	1,600	18,000	0	26,000	290,017	1.17%
HVO	266,991	272,907	176,117	208,488	817,320	186,926	19,070	29,708	108,814	268,200	2,354,541	9.52%
IFO	13,500	75,200	14,055	0	72,000	130,796	3,500	0	34,930	10,700	354,681	1.43%
LTC	84,000	0	115,000	336,000	700	840	0	0	0	0	536,540	2.17%
LTF	460,692	2,446,307	536,991	795,117	690,681	494,530	310,035	214,725	238,095	920,402	7,107,575	28.75%
LTO	210,000	142,055	1,100	8,450	5,800	2,200	500	0	3,232	5,600	378,937	1.53%
LUB	48,227	30,459	65,500	36,287	23,585	22,861	37,958	8,288	6,446	3,930	283,541	1.15%
MIN	9,500	20,050	4,900	34,100	3,000	7,100	14,300	6,500	5,600	1,346	106,396	0.43%
NEV	0	1,000	0	0	0	0	0	0	0	1,000	2,000	0.01%
OTR	222,404	116,966	8,399	18,020	7,248	26,295	87,041	53,965	1,218	0	541,556	2.19%
TAR	3,800	121,184	71,575	9,540	504	9,290	0	10,300	15,600	81,000	322,793	1.31%
UNK	16,210	6,470	95,222	48,200	14,040	12,815	31,281	4,900	3,000	58,310	290,448	1.17%
VOD	202,052	490,565	231,465	160,016	1,078,863	327,719	303,925	29,038	72,130	1,045,473	3,941,246	15.94%
WAX	5,000	0	0	51,000	0	1,848	8,000	0	0	0	65,848	0.27%
WTO	1,007,398	47,144	7,465	7,910	492,960	36,600	48,200	122,460	6,000	12,900	1,789,037	7.24%
TOTAL	4,716,443	4,084,449	2,273,488	2,544,263	3,825,911	1,628,577	1,370,041	834,172	915,733	2,530,813	24,723,890	100.00%

¹¹ Source: Environmental Research Consulting Databases

¹² ANF = animal fat; CRD = crude oil; EDO = edible oil; HVO = heavy oil; IFO = intermediate fuel oil; LTC = light crude oil; LTF = light fuel; LTO = light oils; LUB = lubricating oil; MIN = mineral oil; NEV = non-edible vegetable oil; OTR = other oils not included in other categories; TAR = tar/asphalt; UNK = unknown or unidentified oil; VOD = volatile organic distillate; WAX = wax; WTO = waste oil. Oils included in each category are shown in Table A-1 in the Appendix.

Table 4: Numbers of Oil Spill Incident Involving 500 Gallons or More into Navigable US Waters¹³												
OIL CATEGORY¹⁴	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	TOTAL	% TOTAL
ANF	0	1	0	1	1	0	1	1	0	0	5	0.24%
CRD	69	57	57	53	44	36	52	34	19	28	449	21.63%
EDO	5	1	5	6	1	1	1	2	0	1	23	1.11%
HVO	23	14	11	15	15	13	9	6	5	4	115	5.54%
IFO	3	6	3	0	3	2	2	0	4	4	27	1.30%
LTC	1	0	1	3	1	1	0	0	0	0	7	0.34%
LTF	95	130	88	96	86	87	75	67	21	59	804	38.73%
LTO	1	6	2	4	2	2	1	0	3	3	24	1.16%
LUB	4	13	8	20	12	9	6	8	4	4	88	4.24%
MIN	4	3	3	5	2	3	4	4	1	1	30	1.45%
NEV	0	1	0	0	0	0	0	0	0	1	2	0.10%
OTR	7	9	5	7	5	7	11	5	2	0	58	2.79%
TAR	1	11	7	4	1	3	0	4	2	2	35	1.69%
UNK	12	6	17	8	9	5	10	4	1	6	78	3.76%
VOD	33	35	23	30	29	29	34	14	11	18	256	12.33%
WAX	1	0	0	1	0	1	1	0	0	0	4	0.19%
WTO	17	10	6	8	9	5	8	3	2	3	71	3.42%
TOTAL	276	303	236	261	220	204	215	152	75	134	2,076	100.00%

¹³ Source: Environmental Research Consulting Databases

¹⁴ ANF = animal fat; CRD = crude oil; EDO = edible oil; HVO = heavy oil; IFO = intermediate fuel oil; LTC = light crude oil; LTF = light fuel; LTO = light oils; LUB = lubricating oil; MIN = mineral oil; NEV = non-edible vegetable oil; OTR = other oils not included in other categories; TAR = tar/asphalt; UNK = unknown or unidentified oil; VOD = volatile organic distillate; WAX = wax; WTO = waste oil. Oils included in each category are shown in Table A-1 in the Appendix.

**Table 5: Total Spillage and Average Spill Size for Oil Spills into Navigable US Waters 1995 – 2004
By Oil Category¹⁵**

OIL CATEGORY¹⁶	Total Number (Incidents 500 Gallons or More)	Total Gallons	Average Spill Size (Gallons)
ANF	5	10,500	2,100
CRD	449	6,348,234	14,139
EDO	23	290,017	12,609
HVO	115	2,354,541	20,474
IFO	27	354,681	13,136
LTC	7	536,540	76,649
LTF	804	7,107,575	8,840
LTO	24	378,937	15,789
LUB	88	283,541	3,222
MIN	30	106,396	3,547
NEV	2	2,000	1,000
OTR	58	541,556	9,337
TAR	35	322,793	9,223
UNK	78	290,448	3,724
VOD	256	3,941,246	15,395
WAX	4	65,848	16,462
WTO	71	1,789,037	25,198
TOTAL	2,076	24,723,890	11,909

**Table 6: Total Spillage by Oil Types into US Navigable Waters 1995 – 2004
(Spills of 500 Gallons or More)¹⁷**

OIL CATEGORY¹⁸	Total Gallons	% TOTAL
Light Fuels	7,107,575	28.75%
Crude Oils	6,348,234	25.68%
Volatile Organic Distillates	3,941,246	15.94%
Heavy Oils	2,354,541	9.52%
Waste Oils	1,789,037	7.24%
Other Petroleum Oils	541,556	2.19%
Light Crude	536,540	2.17%
Light Oils	378,937	1.53%
Intermediate Fuel Oils	354,681	1.43%
Tars/Asphalt	322,793	1.31%
Unknown Oils	290,448	1.17%
Edible Oils	290,017	1.17%
Lubricating Oils	283,541	1.15%
Mineral Oils	106,396	0.43%
Waxes	65,848	0.27%
Animal Fats	10,500	0.04%
Non-Edible Vegetable Oils	2,000	0.01%
TOTAL	24,723,890	100.00%

¹⁵ Source: Environmental Research Consulting Databases

¹⁶ ANF = animal fat; CRD = crude oil; EDO = edible oil; HVO = heavy oil; IFO = intermediate fuel oil; LTC = light crude oil; LTF = light fuel; LTO = light oils; LUB = lubricating oil; MIN = mineral oil; NEV = non-edible vegetable oil; OTR = other oils not included in other categories; TAR = tar/asphalt; UNK = unknown or unidentified oil; VOD = volatile organic distillate; WAX = wax; WTO = waste oil. Oils included in each category are shown in Table A-1 in the Appendix.

¹⁷ Source: Environmental Research Consulting Databases

¹⁸ Oils included in each category are shown in Table A-1 in the Appendix.

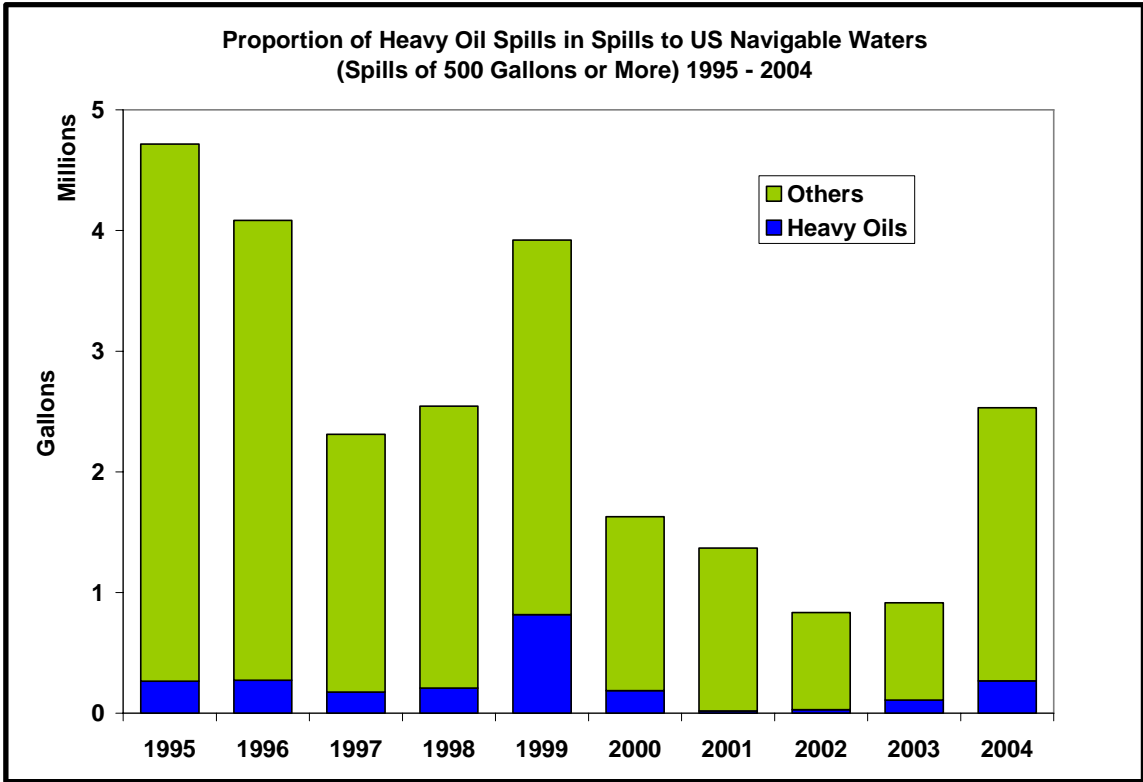


Figure 3: Proportion of Heavy Oil Spills to US Navigable Waters 1995 – 2004¹⁹

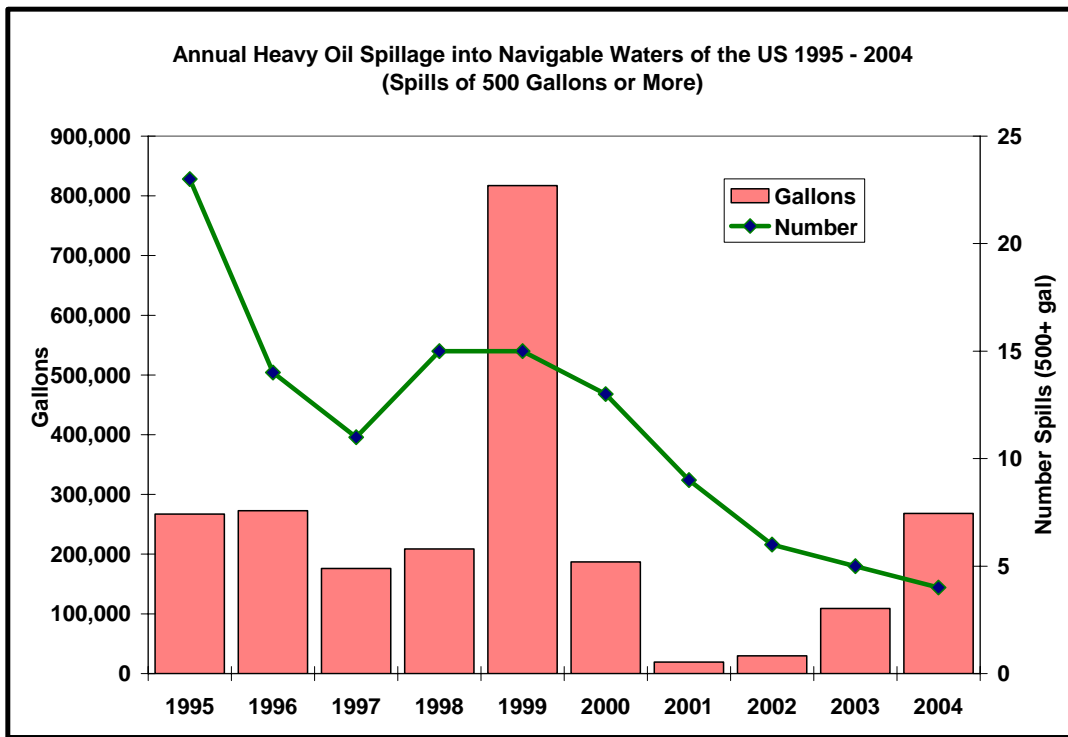


Figure 4: Annual Heavy Oil Spillage into US Navigable Waters 1995 - 2004¹¹

¹⁹ Source: Environmental Research Consulting Databases

Analysis of Oil Spill Costs for Oil Spillage into US Navigable Waters 1995 – 2004

An analysis of estimated costs and damages for all oil spills of at least 500 gallons into US navigable waters during 1995 – 2004 was conducted using the ERC Basic Oil Spill Cost Estimation Model (ERC BOSCEM)²⁰. This model *estimates* oil spill response costs, environmental damages, and socioeconomic damages based on characteristics of each spill (oil type, spill size, location characteristics, spill response methodology, and site sensitivity)²¹. Based on this methodology the estimated costs and damages for oil spills during the last decade are shown in the Table 7.

Table 7: Estimated Costs for Oil Spills of 500 Gallons or More into US Navigable Waters 1995 – 2004 Based on ERC BOSCEM				
Year	Response Costs²²	Socioeconomic Damages²²	Environmental Damages²²	Total Costs
1995	\$698 million	\$889 million	\$276 million	\$1,863 million
1996	\$420 million	\$711 million	\$203 million	\$1,334 million
1997	\$331 million	\$505 million	\$139 million	\$975 million
1998	\$341 million	\$522 million	\$159 million	\$1,022 million
1999	\$462 million	\$600 million	\$168 million	\$1,230 million
2000	\$226 million	\$355 million	\$96 million	\$678 million
2001	\$181 million	\$329 million	\$92 million	\$602 million
2002	\$129 million	\$203 million	\$69 million	\$401 million
2003	\$136 million	\$188 million	\$51 million	\$374 million
2004	\$204 million	\$448 million	\$137 million	\$789 million
Total	\$3,129 million	\$4,749 million	\$1,390 million	\$9,268 million
Average	\$313 million	\$475 million	\$139 million	\$927 million

Improving spill response effectiveness by responding to spills more quickly, locating and tracking oil more accurately (including during darkness, underwater, and in difficult locations, such as marshland), employing the most effective response strategies (such as fast-water strategies where applicable in high-current situations), and better training can reduce all of these costs.

Annual response costs for spills into US navigable waters amount to an estimated \$313 million. Environmental damages (roughly analogous to “natural resource damages”) amount to \$139 million annually. Socioeconomic damages are estimated at \$475 million annually. In the last ten years, over \$9 billion in costs and damages have resulted from oil spills into US navigable waters.

Spill response costs are reduced when oil spread is controlled and oil is kept out of sensitive locations, such as wetlands, and shoreline impacts are reduced. In general, it is advantageous from the perspective of minimizing spill impacts and costs to act strategically to “keep ahead of the oil” rather than “chasing oil” once it spreads rapidly through the environment through the actions of tides, currents, and winds. Deflecting oil away from sensitive socioeconomic features and reducing the overall time for the response can reduce socioeconomic damages. Likewise, environmental impacts (natural resource damages) can be significantly reduced by more effectively removing oil from the environment and controlling the spread of oil in a strategic fashion to minimize impacts to the most sensitive habitats and populations.

²⁰ See Appendix.

²¹ The estimation from this methodology is meant to provide a general picture of the magnitude and types of costs and damages that result from different types of oil spills rather than to accurately assess the costs for each spill. The algorithms for estimation are based on studies of past spills, as well as modeling of hypothetical spills.

²² Costs adjusted to 2004 dollars.

Analysis of Oil Spill Cost Reductions with Laser Fluorosensor Technology Use for Heavy Oil Spills

A cost analysis was conducted on only the heavy oil spills that occurred during 1995 – 2004²³ to determine the potential differences in spill response costs and environmental and socioeconomic damages for individual spills with a change in spill response timing and effectiveness as might be realized when the US Coast Guard’s laser fluorosensor technology was employed to detect oil. This technology allows for detection of submerged oil, oil in wetlands, and during hours of darkness. Oil spill costs were estimated based on the use of the laser fluorosensor in: a) the first 2 hours, b) within the first day, and c) more than 3 days after the onset of the spill. Results are summarized in Table 8.

Year	Response Costs ²⁴				Environmental Damages ²⁴				Socioeconomic Damages ²⁴			
	None ²⁵	2 hrs ²⁶	24 hrs ²⁷	3 days ²⁸	None ²⁵	2 hrs ²⁶	24 hrs ²⁷	3 days ²⁸	None ²⁵	2 hrs ²⁶	24 hrs ²⁷	3 days ²⁸
1995	\$97M	\$63M	\$82M	\$92M	\$23M	\$15M	\$20M	\$22M	\$146M	\$95M	\$124M	\$139M
1996	\$63M	\$41M	\$53M	\$59M	\$10M	\$6M	\$8M	\$9M	\$55M	\$35M	\$46M	\$52M
1997	\$64M	\$41M	\$54M	\$60M	\$15M	\$9M	\$12M	\$14M	\$104M	\$68M	\$89M	\$99M
1998	\$76M	\$49M	\$64M	\$72M	\$14M	\$9M	\$12M	\$14M	\$88M	\$57M	\$74M	\$83M
1999	\$153M	\$99M	\$130M	\$145M	\$19M	\$12M	\$16M	\$18M	\$91M	\$59M	\$77M	\$86M
2000	\$68M	\$44M	\$58M	\$64M	\$12M	\$8M	\$11M	\$12M	\$76M	\$49M	\$64M	\$72M
2001	\$7M	\$5M	\$6M	\$7M	\$2M	\$1M	\$2M	\$2M	\$11M	\$7M	\$9M	\$11M
2002	\$11M	\$7M	\$9M	\$10M	\$3M	\$2M	\$2M	\$3M	\$18M	\$11M	\$15M	\$17M
2003	\$39M	\$26M	\$33M	\$37M	\$6M	\$4M	\$5M	\$6M	\$63M	\$41M	\$53M	\$60M
2004	\$42M	\$27M	\$36M	\$40M	\$13M	\$9M	\$11M	\$12M	\$57M	\$37M	\$48M	\$54M
Total	\$620M	\$402M	\$525M	\$586M	\$117M	\$75M	\$99M	\$112M	\$709M	\$459M	\$599M	\$673M
AVG	\$62M	\$40M	\$53M	\$59M	\$12M	\$8M	\$10M	\$11M	\$71M	\$46M	\$60M	\$67M

In this analysis, it was assumed that there would be an increase in response effectiveness (oil removal capability) by being able to respond at night and being able to more accurately track the movement and location of oil²⁹. Oil spill responses without the benefit of the laser fluorosensor technology were assumed to have an oil removal efficiency averaging 10%. With the benefit of the technology at two hours, the response was assumed to have 45% effectiveness, at 24 hours 25%, and at three days 15%.

With these assumptions, an estimated \$22 million in spill response cost reduction (attributable to reduced spill response time overall and reduced shoreline cleanup operations) would likely be realized annually with the two-hour use of the technology. In addition, the reduced spread of the oil would likely result in reduced environmental damages of \$4 million annually, and reduced socioeconomic damages of \$25 million annually. Somewhat less would be saved with the later use of the laser fluorosensor.

²³ See Table A-2 in Appendix for list of spills included in the analysis.

²⁴ Costs adjusted to 2004 dollars.

²⁵ No laser fluorosensor technology employed.

²⁶ Laser fluorosensor technology employed in the first two hours.

²⁷ Laser fluorosensor technology employed in the first 24 hours.

²⁸ Laser fluorosensor technology employed in the after first three days.

²⁹ The estimated efficiency of oil removal was based on previous personal consultations with Al Allen, Spiltec, as well as work conducted for Washington Department of Ecology. See Etkin, D.S., D. French-McCay, J. Rowe, N. Whittier, S. Sankaranarayanan, and L. Pilkey-Jarvis. 2005. Modeling impacts of response method and capability on oil spill costs and damages for Washington State spill scenarios. *Proc. 2005 International Oil Spill Conference*: pp. 457 – 462.

A second analysis was conducted on these heavy oil spills using the ERC Oil Spill Response Cost Effectiveness Analytical Tool (OSRCEAT)³⁰. This analysis involves the use of ERC's Oil Spill Cost Effectiveness Analytical Tool (OSRCEAT). This tool, which can be used in the form of a software package, with calculations with a scientific calculator, or in Excel, was designed to estimate cost effectiveness of oil spill response operations. The estimation from this methodology is meant to provide a general picture of the magnitude and types of costs and damages that result from different responses to oil spills rather than to accurately assess the costs for each spill. The algorithms for estimation are based on studies of past spills, as well as modeling of hypothetical spills. It includes general information on oil types to anticipate oil behavior.

OSRCEAT estimates response costs, socioeconomic costs, and natural resource damage (environmental) costs based on various spill parameters, such as oil type, proximity to shore, volume spilled, on-water and shoreline response methodologies, timing of response deployment, waterbody type, shoreline type(s), and environmental and socioeconomic sensitivity. The algorithms calculate the degree to which the chosen on-water and responses will mitigate socioeconomic and environmental damage. The damage of the response itself is taken into account (*e.g.*, aggressive shoreline responses or on-water dispersant applications).

The final outcomes of the analysis are response cost-effectiveness and benefits to costs ratio. The purpose is to evaluate different response methods and applications in terms of costs and potential benefits. The calculation of response costs, environmental damages, and socioeconomic damages are merely part of the calculation steps in this process and are not intended to be the final outcome.

For this project, the OSRCEAT program was used to estimate response costs, environmental damages, and socioeconomic damages for 115 spills of heavy oils that occurred in US waters during 1995 and 2004. These spills are shown in Appendix 2³¹. The interim calculations for costs and damages were extracted from the series of calculations that form the algorithms for OSRCEAT.

To the extent possible information for each spill was inserted into the OSRCEAT program. When there was no definitive data available, default values were used for such variables as water temperature, wind speed and direction, shoreline types, and socioeconomic and natural resource features.

The important assumptions that were employed in these calculations are:

- “No Fluorosensor” responses were assumed to be 10 percent effective in removing oil.
- “Fluorosensor at 12 Hours” responses were assumed to be 33 percent effective, based on Figure 1.³²

³⁰ See Appendix for description of ERC OSRCEAT. The estimation from this methodology is meant to provide a general picture of the magnitude and types of costs and damages that result from different responses to oil spills rather than to accurately assess the costs for each spill. The algorithms for estimation are based on studies of past spills, as well as modeling of hypothetical spills. It includes general information on oil types to anticipate oil behavior.

³¹ This is the same table of spills that appeared in the original Deliverable 1 with a couple of corrections (missing states designations).

³² The effectiveness values in Figure 1 are based on the assumed effectiveness ratings used in the ERC BOSCEM modeling conducted previously for Deliverable 1. Using the same values would make the assumption for the two modeling approaches roughly equivalent.

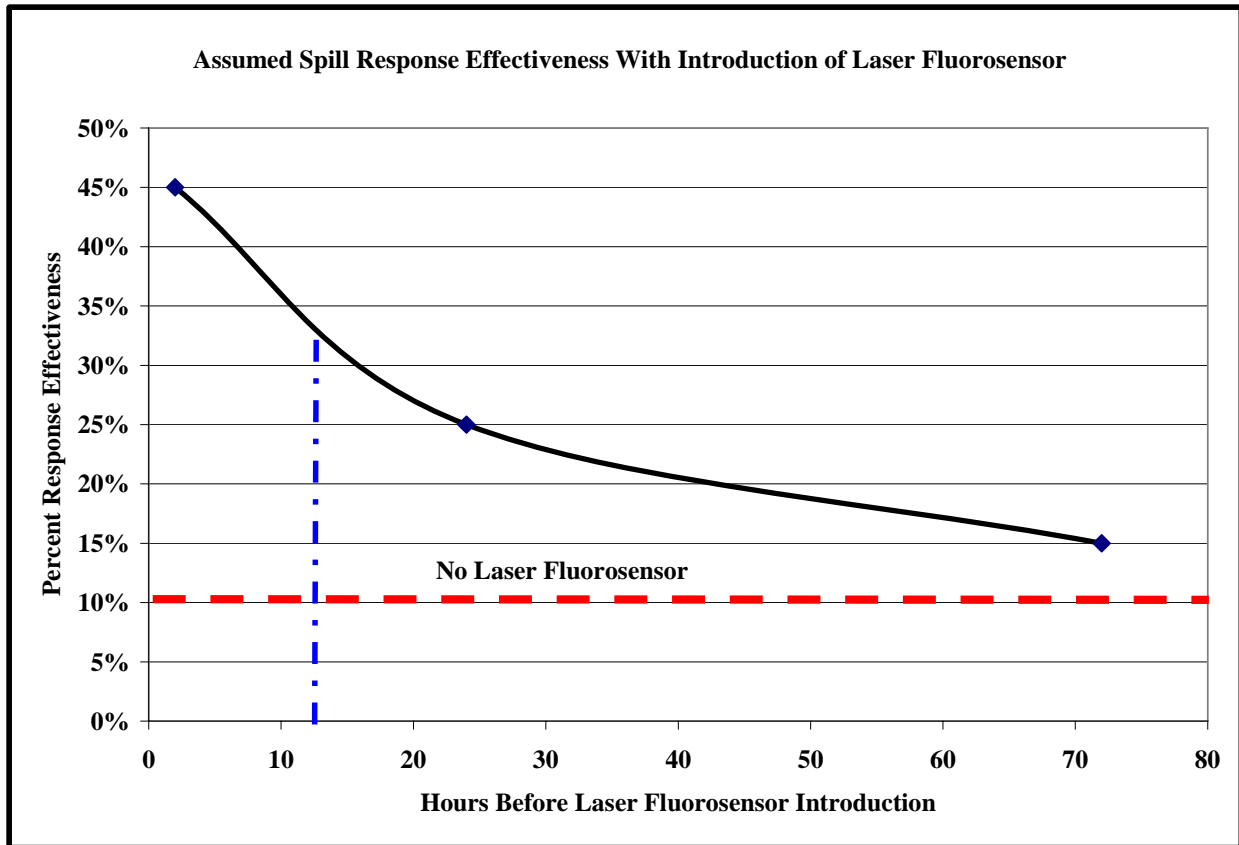


Figure 1: Assumed Spill Response Effectiveness with Introduction of Laser Fluorosensor. Points for two hours, 24 hours, and 72 hours were the assumed effectiveness percentages incorporated into the ERC BOSCEM modeling.

- Spill responses for both “No Fluorosensor” and “Fluorosensor at 12 Hours” were assumed to begin at 12 hours for coastal, nearshore, and river spills. Spill responses for offshore spills were assumed to begin at 24 hours, as per US Coast Guard response planning standards (see Appendix 3). For offshore spills, the fluorosensor was assumed to aid in locating spilled oil before response operations began.
- Spill responses were assumed to be limited to on-water mechanical containment and recovery with appropriate shoreline cleanup.

Modeling results are shown in Tables 9 – 10, and Figures 2 – 3 below.

Table 9: Estimated Costs for Heavy Oil Spills of 500 Gallons or More into US Navigable Waters 1995 – 2004 With Use of Laser Fluorosensor Technology Based on ERC OSRCEAT						
Year	Response Costs ³³		Environmental Damages ⁴		Socioeconomic Damages ⁴	
	No Fluorosensor	Fluorosensor at 12 hrs	No Fluorosensor	Fluorosensor at 12 hrs	No Fluorosensor	Fluorosensor at 12 hrs
1995	\$64,128,843	\$53,655,584	\$67,014,970	\$55,768,395	\$108,871,605	\$79,991,284
1996	\$62,470,619	\$51,361,327	\$61,879,079	\$51,400,163	\$92,667,329	\$67,798,885
1997	\$39,593,236	\$32,958,057	\$42,170,078	\$35,138,842	\$67,370,046	\$49,611,398
1998	\$49,579,133	\$41,243,879	\$51,758,977	\$43,035,245	\$82,496,238	\$60,497,460
1999	\$199,790,918	\$159,911,188	\$166,395,058	\$137,202,555	\$210,884,884	\$151,816,411
2000	\$47,071,523	\$38,933,086	\$49,262,465	\$40,808,950	\$77,692,525	\$56,507,845
2001	\$6,432,958	\$5,730,177	\$5,875,226	\$4,900,647	\$11,250,100	\$8,303,637
2002	\$8,198,948	\$7,099,078	\$8,599,580	\$7,170,990	\$15,611,480	\$11,514,106
2003	\$26,768,738	\$21,826,155	\$26,703,103	\$22,077,664	\$39,269,958	\$28,431,233
2004	\$58,460,460	\$47,060,916	\$52,981,365	\$43,909,519	\$69,800,279	\$50,778,462
Total	\$562,495,377	\$459,779,448	\$532,639,902	\$441,412,969	\$775,914,444	\$565,250,720
Average	\$56,249,538	\$45,977,945	\$53,263,990	\$44,141,297	\$77,591,444	\$56,525,072
SD	\$54,544,205	\$43,494,828	\$44,906,650	\$37,021,225	\$56,640,528	\$40,818,516

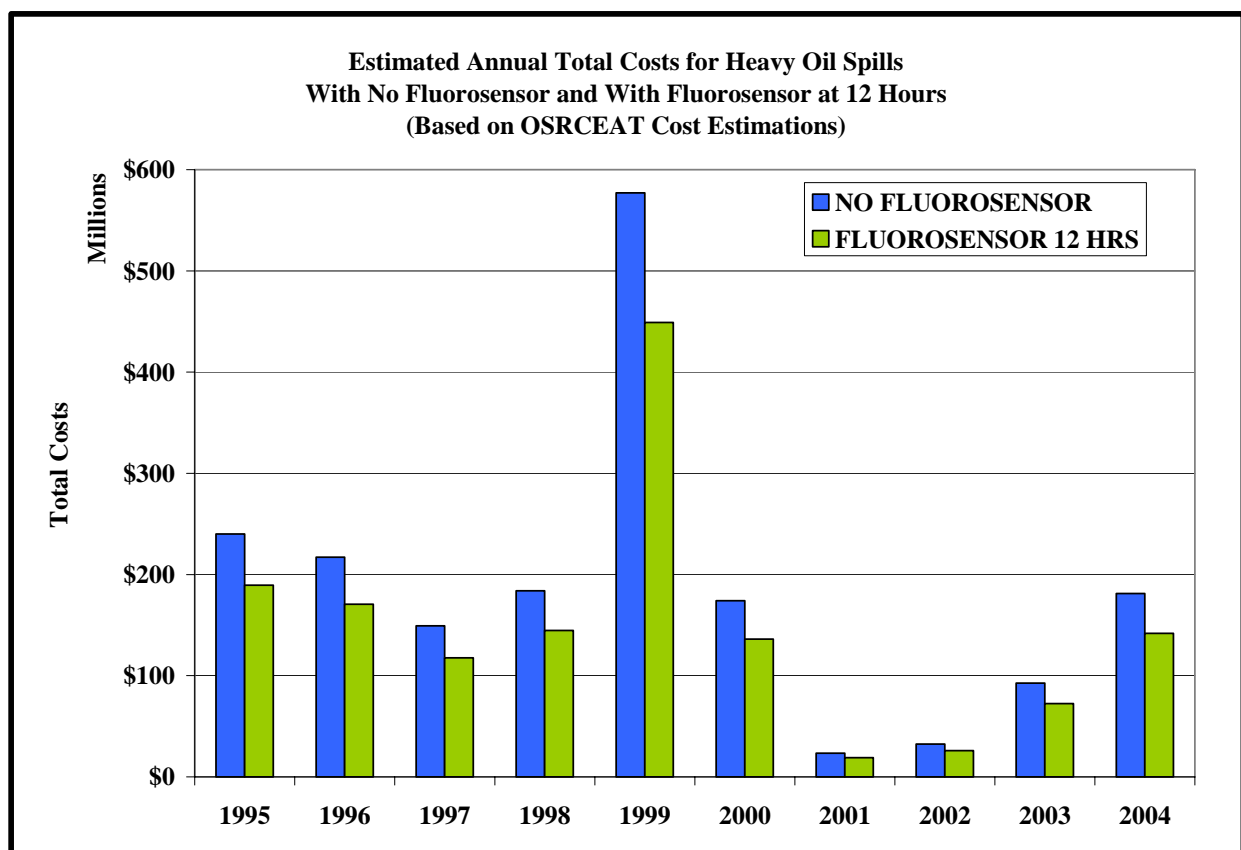


Figure 2: Estimated Total Costs for Heavy Oil Spills with No Fluorosensor in Response and With Fluorosensor at 12 Hours.

³³ Costs adjusted to 2004 dollars.

Table 10: Estimated Annual Savings with Laser Fluorosensor for Spill Response for Heavy Oil Spills (Based on OSRCEAT Cost Estimations)				
Year	Total Annual Costs (2004 Dollars)			
	Response	Environmental	Socioeconomic	Total
1995	\$10,473,259	\$11,246,575	\$28,880,321	\$50,600,155
1996	\$11,109,292	\$10,478,916	\$24,868,445	\$46,456,652
1997	\$6,635,179	\$7,031,237	\$17,758,648	\$31,425,064
1998	\$8,335,254	\$8,723,732	\$21,998,778	\$39,057,763
1999	\$39,879,729	\$29,192,503	\$59,068,473	\$128,140,705
2000	\$8,138,437	\$8,453,515	\$21,184,680	\$37,776,632
2001	\$702,782	\$974,579	\$2,946,463	\$4,623,824
2002	\$1,099,870	\$1,428,591	\$4,097,375	\$6,625,835
2003	\$4,942,583	\$4,625,440	\$10,838,726	\$20,406,749
2004	\$11,399,543	\$9,071,846	\$19,021,817	\$39,493,207
TOTAL	\$102,715,929	\$91,226,933	\$210,663,724	\$404,606,586
Average	\$10,271,593	\$9,122,693	\$21,066,372	\$40,460,659
SD	\$11,076,806	\$7,887,737	\$15,834,423	\$34,559,988

The estimated annual savings with the use of the laser fluorosensor at 12 hours is about \$40 million per year, including \$10 million in response costs, \$9 million in environmental damages, and \$21 million in socioeconomic damages.

APPENDIX

Table A-1: Oil Category Code Key		
Oil Category Code	Category Name	Included Oil Types
LTO	Light Oil	Absorption oil
		Light cycle oil
		Hydraulic oil
		Light oil
		Cutting oil
		Decant oil
		Catalytic feedstock
		Emulsion oil
		Spray oil
		Petroleum distillate
		Carbolic oil
		Gas oil
		Lean oil
		Clarified oil
		Produced oil
Process oil		
Petrolatum		
LTF	Light Fuel	No. 2 fuel oil
		Drill mud oil
		Naphtha
VOD	Volatile Distillate	Gasoline
		No. 1 fuel oil
		Crude condensate
IFO	Intermediate Fuel Oil	No. 3 fuel oil
		No. 4 fuel oil
		Transmix
HVO	Heavy Oil	Heavy fuel
		No. 6 fuel oil
		Residual oil
		Heavy oil
TAR	Tar	Tar
		Asphalt
		Creosote
		Wash oil
		Tack oil
WAX	Wax	Wax
		Paraffin
		Carnauba wax
WTO	Waste Oil	Waste Oil
ANF	Animal Fat	Tallow
		Sperm oil
		Lard
		Animal fat

Table A-1: Oil Category Code Key (continued)		
Oil Category Code	Category Name	Included Oil Types
OTR	Other Oil	Neatsfoot oil
		Dusting oil
		Dusting oil
		Penetrating oil
		Synthetic oil
		Road oil
		Resin oil
		Hot oil
NEV	Non-Edible Vegetable Oil	Tung oil
		Tanner oil
		Tall oil
		Pine oil
		Linseed oil
		Castor oil
MIN	Mineral Oil	Thermal oil
		Quench oil
		Mineral
		Insulating oil
		Heat transfer oil
		Transmission oil
LUB	Lube Oil	Spindle oil
		Lube oil
		Gear oil
		Machine oil
		Compressor oil
		Crankcase oil
		Cycle oil
		Crankcase oil
EDO	Edible Oil	Vegetable oil
		Soybean oil
		Seal oil
		Safflower oil
		Peanut oil
		Palm oil
		Fish oil
		Croton oil
		Cottonseed oil
		Corn oil
		Coconut oil
		Canola oil
CRD	Crude	Crude
HVC	Heavy Crude	Heavy crude
LTC	Light Crude	Light crude
UNO	Unknown Oil	Unknown oil

Table A-2: Heavy Oil Spills of At Least 500 Gallons into US Navigable Waters 1995 – 2004³⁴

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
1/27/95	Longview	WA	Columbia River	Weyrhauser	Facility	No. 6 Fuel	1,000
2/15/95	Port O Connor	TX	Gulf Of Mexico Coastal	Berge Banker	Tank Ship	No. 6 Fuel	37,716
2/24/95	Hamakua	HI	N Pacific Ocean	Hamakua Sugar Co.	Facility	No. 6 Fuel	11,000
2/27/95			Gulf Of Mexico 12-200 Miles	Florida Express	Tank Ship	No. 6 Fuel	8,400
2/28/95	Port Arthur	TX	Sabine/Neches River	Anthos	Freight Ship	No. 6 Fuel	840
3/7/95	Neah Bay	WA	Strait Of Juan De Fuca	Unknown Vessel	Unclassified Vess.	No. 6 Fuel	634
3/14/95	Long Beach	CA	Pacific Ocean	OOCL Flame	Other Vessel	No. 6 Fuel	29,000
3/31/95	Wilmington	CA	Port Los Angeles/Long Beach	WT. 30	Tank Barge	No. 5 Fuel	1,250
6/23/95	Staten Island	NY	Arthur Kill	Bloxom	Unclassified Vessel	No. 6 Fuel	4,500
7/1/95	Venice	LA	Gulf Of Mexico Contiguous	Enif	Freight Ship	No. 6 Fuel	92,610
7/19/95		AL	Theodore Industrial Canal		Facility	Heavy Fuel	1,200
7/19/95	Theodore	AL	Navigable Waters	Donald Duckling	Freight Ship	No. 6 Fuel	5,000
8/5/95	Portland	OR	Willamette River	Norton	Tank Barge	No. 6 Fuel	1,800
8/8/95	Grand Haven	MI	Grand River/Lake Michigan	Grand Haven Light & Power	Facility	No. 5 Fuel	551
8/8/95	Houston	TX	Houston Ship Channel	NMS-3100	Tank Barge	No. 6 Fuel	1,250
8/17/95	Rumford	ME	Androscoggin River	Boise Cascade Papermill	Facility	No. 6 Fuel	1,000
9/5/95	New Orleans	LA	Lower Mississippi River	M/V Galini	Freight Ship	No. 6 Fuel	3,190
9/10/95	Violet	LA	Lower Mississippi River	Golden Eagle	Freight Ship	No. 6 Fuel	3,350
9/28/95	Tampa	FL	Tampa Bay	Unknown Vessel	Unclassified Vessel	No. 6 Fuel	5,000
10/2/95	Everett	WA	Puget Sound	Mobile Oil Inc	Land Facility	No. 6 Fuel	27,000
10/25/95	Bayonne	NJ	Kill Van Kull	IMTT Bayonne	Facility	No. 6 Fuel	23,000
11/27/95	Manhattan	NY	East River	Con-Ed Generating Station	Waterfront Facility	No. 6 Fuel	5,200
12/12/95	Bayamon	PR	N Atlantic Ocean Coastal	Hospital De Bayamon	Facility	No. 5 Fuel	2,500
1/27/96	Staunton	IL	Sugar Camp Creek	Staunton Fuel Inc	Vehicle	No. 5 Fuel	2,000
2/16/96	Saint Paul	AK	Bering Sea	Citrus	Freight Ship	No. 6 Fuel	500
2/24/96	Corpus Christi	TX	Corpus Christi Ship Channel	Coastal Marketing & Refining	Transfer	No. 6 Fuel	1,460
3/7/96		AL	Black Warrior River		Facility	Heavy Fuel	1,400
3/14/96	Corpus Christi	TX	Corpus Christi Ship Channel	Coastal 2532-L	Tank Barge	No. 6 Fuel	5,250
3/18/96		TX	Houston Ship Channel	Buffalo 292	Tank Barge	No. 6 Fuel	176,400
5/14/96	Oahu Island	HI	Pearl Harbor	Chevron Pipeline	Pipeline	No. 6 Fuel	41,000
5/26/96	Houston	TX	Houston Ship Channel	Buffalo 286	Tank Barge	No. 6 Fuel	25,998
6/21/96	Myrtle Grove	La	Lower Mississippi River	MF 12	Tank Barge	No. 6 Fuel	3,534
9/8/96			Galveston Bay	Havglimt	Tank Ship	No. 6 Fuel	8,030

³⁴ Source: Environmental Research Consulting Databases

Table A-2: Heavy Oil Spills of At Least 500 Gallons into US Navigable Waters 1995 – 2004³⁵ (continued)

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
9/19/96	Chickasaw	Al	Navigable Waters	Babuyan	Freight Ship	No. 6 Fuel	2,000
10/17/96	Lewiston	ME	Androscoggin River	Pepperel And Associates	Facility	No. 6 Fuel	500
10/27/96	Los Angeles	CA	Port Los Angeles/Long Beach	Orenoco Reefer	Freight Ship	No. 5 Fuel	1,835
11/15/96	New York	NY	East River	Con-Ed Generating Station	Waterfront Facility	No. 6 Fuel	3,000
2/25/97	Ft Lauderdale	FL	Navigable Waters	Port Everglades	Waterfront Facility	No. 6 Fuel	2,600
2/25/97	Bayonne	NJ	New York Harbor Upper Bay	Bitlis	Freight Ship	No. 6 Fuel	3,500
3/19/97	Pago Pago	AS	South Pacific Ocean Coastal	Melone	Freight Ship	No. 6 Fuel	600
3/22/97		AS	South Pacific Ocean Coastal	Melone	Freight Ship	No. 6 Fuel	600
5/11/97	N Kingstown	RI	Narragansett Bay	RI Economic Development	Facility	No. 6 Fuel	800
5/15/97	Carteret	NJ	Arthur Kill	RTC No. 320	Tank Barge	No. 6 Fuel	52,000
6/20/97	Long Beach	CA	Port Los Angeles/Long Beach	Moana Pacific	Freight Ship	No. 5 Fuel	1,680
8/6/97	Ferndale	WA	Puget Sound	Tosco Refinery	Facility	No. 6 Fuel	16,800
11/5/97	Samoa	CA	N Pacific Ocean Coastal	Kure	Freight Ship	No. 5 Fuel	4,537
11/26/97	Unalaska	AK	Bering Sea	Kuroshima	Freight Ship	No. 6 Fuel	47,000
12/21/97	Catlettsburg	KY	Big Sandy River	AO 802	Barge	No. 5 Fuel	46,000
3/27/98	Middletown	CT	Connecticut River	Connecticut Valley Hospital	Facility	No. 6 Fuel	1,000
5/9/98	Linden	NJ	Arthur Kill	Wilma Yangtze	Tank Ship	No. 6 Fuel	600
6/24/98	Mobile	AL	Mobile River	USS Alabama	Unclassified Vess.	No. 5 Fuel	4,800
6/25/98	West Warwick	RI	Pawtucket River	Crompton Grain Company Inc	Facility	No. 6 Fuel	5,000
6/30/98	Honolulu	HI	Honolulu Harbor	State Of Hawaii DLNR	Facility	No. 5 Fuel	900
8/24/98	Honolulu	HI	N Pacific Ocean Coastal	Tesoro Hawaii Corp (SPM)	Waterfront Facility	No. 6 Fuel	4,914
9/15/98	None	NA	Navigable Waters	Mare Princess	Tank Ship	No. 6 Fuel	2,520
9/21/98	San Juan	PR	Caribbean Sea	Caribbean Petroleum Refining	Facility	No. 6 Fuel	16,800
9/27/98	Half Moon Bay	CA	N Pacific Ocean Coastal	Command	Tank Ship	No. 6 Fuel	30,000
9/28/98	Off San Francisco	CA	Pacific Ocean	Command	Tanker	No. 6 Fuel	51,450
10/14/98	Delaware City	DE	Delaware River	New Ideal	Tank Ship	No. 6 Fuel	2,300
10/26/98	Camden	NJ	Delaware River	Del Monte Consumer	Freight Ship	No. 6 Fuel	3,710
11/16/98	Honolulu	HI	N Pacific Ocean Coastal	Holo Kai	Tank Barge	No. 6 Fuel	2,352
11/27/98	Los Angeles	CA	Port Los Angeles/Long Beach	W.T. 25	Tank Barge	No. 5 Fuel	2,142
12/24/98	Charlestown	MA	Boston Harbor	Boston Edison Company	Land Fac/Non Marine	No. 6 Fuel	80,000
1/9/99	Pago Pago	AS	N Pacific Ocean Coastal	Unknown Vessel	Unclassified Vess.	No. 6 Fuel	1,050
1/13/99	Off Charleston	SC	Atlantic Ocean	Star Evviva	Other Vessel	No. 6 Fuel	24,000

³⁵ Source: Environmental Research Consulting Databases

Table A-2: Heavy Oil Spills of At Least 500 Gallons into US Navigable Waters 1995 – 2004³⁶ (continued)

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
2/14/99	Far Hills	NJ	N Branch Raritan River		Facility	No. 6 Fuel	2,000
3/4/99	Long Beach	CA	Port Los Angeles/Long Beach	Olympic L	Tank Barge	No. 6 Fuel	6,890
3/6/99	Port Allen	LA	Lower Mississippi River	Apex 3508	Tank Barge	No. 6 Fuel	3,970
3/14/99	Galveston	TX	Galveston Bay	Galveston Terminals Inc.	Waterfront Facility	No. 5 Fuel	3,780
5/13/99	Rosarito	CA	San Diego Harbor	Pemex Refinacion	Refining	No. 6 Fuel	60,000
6/19/99	Virginia Beach	VA	N Atlantic Ocean Coastal	Unknown Land Source	Shoreline Facility	No. 6 Fuel	1,200
7/31/99	Long Beach	CA	Port Los Angeles/Long Beach	Zim Israel	Freight Ship	No. 6 Fuel	900
8/12/99	New Orleans	LA	Lower Mississippi River	S.S. Unoin Faith	Unclassified Vess.	No. 6 Fuel	1,000
8/27/99	Galveston		Gulf Of Mexico	Blue Master	Freight Ship	No. 6 Fuel	18,900
9/6/99	Eureka	CA	N Pacific Ocean Coastal	Stuyvesant	Industrial Vessel	No. 5 Fuel	2,100
9/19/99	Brooklyn	NY	New York Harbor Lower Bay	Jonas Equities	Other	No. 6 Fuel	2,300
10/21/99	Jacksonville	FL	St. Johns River	Hmi Diamond Shoals	Tank Ship	No. 6 Fuel	1,000
11/8/99	Catlettsburg	KY	Big Sandy River	Marathon Ashland Petroleum	Facility	No. 5 Fuel	688,230
5/2/00	Corpus Christi	TX	Corpus Christi Ship Channel	Moc V	Tank Barge	No. 6 Fuel	2,420
5/31/00	Woonsocket	RI	Blackstone River		Facility	No. 6 Fuel	4,000
6/6/00	Brooklyn	NY	New York Harbor Upper Bay	Brooklyn Army Terminal	Municipal Facility	No. 6 Fuel	5,000
6/8/00	Boston	MA	Atlantic Ocean	Tosco Terminal	Vehicle	No. 6 Fuel	59,000
6/12/00	Baytown	TX	Houston Ship Channel	HMS 111	Tank Barge	No. 6 Fuel	70,130
7/5/00	Newport	RI	Narragansett Bay	Penn No. 460	Tank Barge	No. 6 Fuel	14,000
7/13/00	Ingleside	TX	Intracoastal Waterway-Gulf	Hollywood 213	Tank Barge	No. 6 Fuel	7,476
7/31/00	Pitusville	FL	Indian River		Facility	No. 6 Fuel	500
8/17/00	Charlestown	MA	Mystic River	Sithe Mystic Station	Facility	No. 6 Fuel	500
9/29/00	Philadelphia	PA	Schuylkill River	Sunoco Inc	Pipeline	No. 6 Fuel	14,700
10/5/00	Chesapeake	VA	Elizabeth River	VB40	Tank Barge	No. 6 Fuel	4,200
11/20/00	Belle Chase	LA	Lower Mississippi River	CT 2629	Tank Barge	No. 6 Fuel	2,000
12/16/00	Weirton	WV	Ohio River	Weirton Steel Facility	Facility	No. 6 Fuel	3,000
3/20/01	New Haven	CT	Long Island Sound	Rhode Island	Tank Barge	No. 6 Fuel	12,600
3/27/01	Queens	NY	Long Island Sound	Bay Terrace Coop. Inc.	Land Facility	No. 6 Fuel	600
4/20/01	Piti	GU	Navigable Waters	Shell Petroleum	Waterfront Facility	No. 6 Fuel	520
6/27/01	Wellsville	OH	Ohio River	Marathon Ashland Petroleum	Waterfront Facility	No. 6 Fuel	850

³⁶ Source: Environmental Research Consulting Databases

Table A-2: Heavy Oil Spills of At Least 500 Gallons into US Navigable Waters 1995 – 2004³⁷ (continued)

Date	City	State	Waterway	Source Name	Source Type	Oil Type	Total Gallons
7/16/01	Miami	FL	N Atlantic Ocean Coastal	Argentinean Reefer	Freight Ship	No. 6 Fuel	500
9/22/01	Baltimore	MD	Patapsco River	Unknown Vessel	Unclassified Vessel	No. 6 Fuel	500
11/7/01	Hicksville	NY	Long Island Sound	Keyspan Steam Station	Waterfront Facility	No. 6 Fuel	1,000
11/29/01	Camas	WA	Columbia Slough		Facility	No. 6 Fuel	500
12/18/01	Philadelphia	PA	Schuylkill River		Facility	No. 6 Fuel	2,000
1/28/02	Barlow Point	AK	Pacific Ocean	Pendrecht	Freight Ship	No. 6 Fuel	1,000
3/21/02		NJ	Atlantic Ocean	B. No. 195	Tank Barge	No. 6 Fuel	1,500
5/19/02	Port Angeles	WA	Puget Sound	Gaz Diamond	Tank Ship	No. 6 Fuel	512
9/30/02		SC	Cooper River	Ever Reach	Container Ship	No. 6 Fuel	12,500
12/5/02	Corpus Christi	TX	Corpus Christi Bay	Moc IV	Tank Barge	No. 6 Fuel	10,500
12/7/02		AL	Mobile River	Lorelay	Pipe Laying	No. 6 Fuel	3,696
3/1/03	Corpus Christi	TX	Corpus Christi Bay	Emerald Star	Tank Ship	No. 6 Fuel	714
4/1/03		MA	Buzzards Bay	Bouchard No. 120	Tank Barge	No. 6 Fuel	98,000
8/21/03	Pittsburg	CA	Willow Creek	Mirant	Facility	No. 6 Fuel	4,200
10/4/03			Lake Superior	Presque Isle	Towing Vessel	No. 6 Fuel	1,100
12/30/03		WA	Puget Sound	Foss 248 P2	Tank Barge	No. 6 Fuel	4,800
3/23/04		NC	Catawba River	Old Ford Finishing	Fixed	No. 6 Fuel	1,000
7/28/04	Honolulu	HI	Pacific Ocean Keehi Lagoon		Barge	No. 6 Fuel	700
10/14/2004	Dalco Passage	WA	Puget Sound	Polar Texas	Tanker	Heavy Fuel	1,500
11/26/04		PA	Delaware River	Athos I	Tanker	Heavy Crude	265,000

³⁷ Source: Environmental Research Consulting Databases

Database Employed For Analysis

Environmental Research Consulting utilized GFI 4.10 – 4.13, as well as its own set of proprietary oil spill databases³⁸ and spill case history archives in developing a custom comprehensive database of heavy oil spills in US waters over the last ten years³⁹ to compare to a larger database of all oil spills in US waters⁴⁰. Data will be limited to spills into bodies of water in which a laser laser fluorosensor system might reasonably be expected to be employed⁴¹. Minimum spill size for data included was 500 gallons⁴². “Heavy oils” were construed to include those oils that fall under the categories of Group IV (specific gravity between .95 to and including 1.0 [API° ≤17.5 and >10.0]) and Group V (specific gravity greater than 1.0 [API° ≤10.0])⁴³, the former of which are included due to the propensity of these oils to become non-floating when in contact with sand and other particulates⁴⁴. Analyses on trends in oil spillage (numbers of incidents and spill volumes) and percentage of oil spills and volume spillage involving heavy and potentially submerging oils were conducted to ascertain the extent of heavy oil spillage in relation to total oil spillage in US waters.

³⁸ ERC’s proprietary oil spill databases were developed (and are continually updated) from the merging, verification, and data quality checking of a large number of other spill databases, including those available from the US Coast Guard Marine Casualty and Pollution Database, National Response Center, Office of Pipeline Safety, Lloyd’s Casualty, the former International Oil Spill Database (Oil Spill Intelligence Report), the former EPA Emergency Response Notification System, state databases, and other media sources. ERC’s databases have been employed in developing EPA’s Facility Spill Database and EPA Jurisdiction Spill Database, as well as a number of key analyses and studies, including the National Academy of Sciences Oil in the Sea, UN/IMO GESAMP Oil in the Marine Environment, EPA Oil Program Cost Benefit Analysis, USCG Oil Spill Prevention, Preparedness, and Response Risk Assessment, Washington Department of Ecology studies (Contingency Planning Rule, Tug Escort Study, and Response Vessel Capabilities Study). Included in these databases is the one developed specifically for the June 2001 report, *Risk Assessment for the Coast Guard’s Oil Spill Prevention, Preparedness and Response (OSPPR) Program*, jointly prepared by PMG and ERC.

³⁹ Data will include the years 1994 through 2003 unless reasonably accurate updates to the data for 2004 have been made at the time of the commencement of the research project, in which case the dates will be shifted to 1995 through 2004. Data for the year 2005 will not be available in a sufficiently accurate state until mid-2006.

⁴⁰ ERC will develop the databases to conduct the analyses. The databases will remain the property of ERC.

⁴¹ This distinction is made due to the variable use of the term “navigable waters” in different contexts and by different agencies in distinct ways, particularly with regard to EPA’s use of the term in 40 CFR 112 to indicate locations in which water might potentially flow in heavy rains (e.g., dry ditches, washes, asphalt pavements) as opposed to waterways that are “navigable” by moderate-sized vessels.

⁴² Employing a minimum threshold of 500 gallons eliminates the smaller spills that would likely not require an extensive spill response.

⁴³ Title 33 Code of Federal Regulations, Volume 2, Part 155

⁴⁴ National Research Council Marine Board. 1999. *Spills of Nonfloating Oils: Risk and Response*. National Academy Press, Washington, DC. 75 pp.

In addition to this trends analysis, a brief cost damage analysis will be conducted to estimate the spill response costs, environmental (natural resource) damages, and socioeconomic impacts of heavy oil spills in relation to other types of oil spills will be conducted. The methodology employed in this will involve the use of ERC's Basic Oil Spill Cost Estimation Model (BOSCEM), versions of which have previously been employed in spill studies for the EPA Oil Program⁴⁵ and the USCG R&D Center⁴⁶ to determine the overall costs of spills taking into account differences in impacts based on oil type, spill size, and location factors. A diagrammatic representation of this model is shown in Figure A-1.

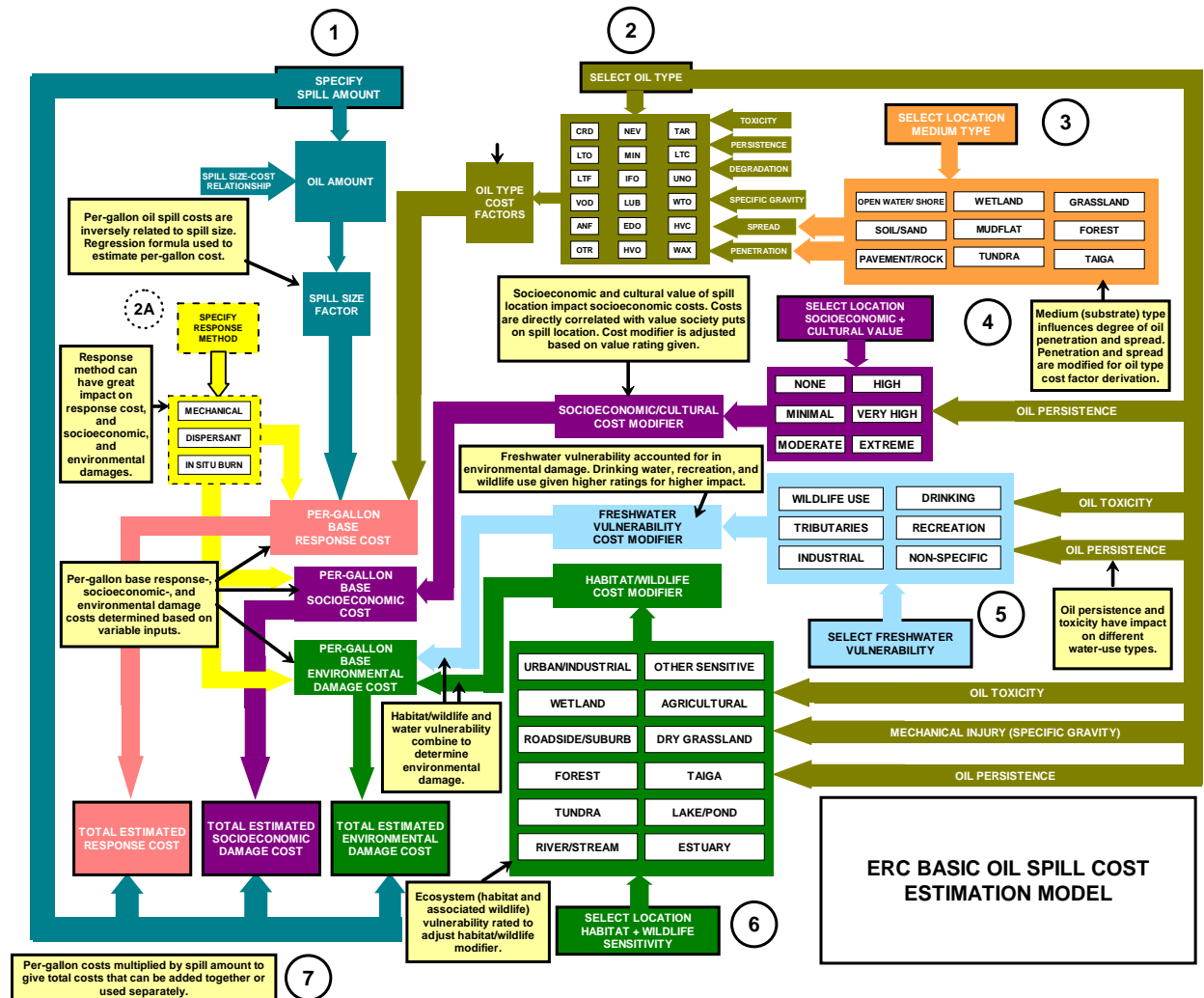


Figure A-1: ERC Basic Oil Spill Cost Estimation Model shown with explanation of inputs and relationships.

This analysis will enable a more reliable comparison of the impacts of heavy oil spills compared to other oil spillage by taking into account the different impact of heavy oil spills with respect to their greater persistence in the environment and greater propensity to involve prolonged and complex cleanup

⁴⁵Etkin, D.S. 2004. Modeling oil spill response and damage costs. *Proc. Fifth Biennial Freshwater Spills Symposium*.

⁴⁶Etkin, D.S. and P. Tebeau. 2003. Assessing progress and benefits of oil spill response technology development since Exxon Valdez. *Proc. 2003 International Oil Spill Conf.*: pp. 843 – 850.

ERC Project: Cost-Benefit Analysis of US Coast Guard Oil Spill Research & Development Program (USCG Office of Response as ERC subcontract to Potomac Management Group): 2002

responses and to cause socioeconomic impacts. The three categories of costs – response costs, environmental (natural resource) damages, and socioeconomic impacts will be presented separately and aggregated to allow for greater flexibility in applying these costs in future economic analyses as required.

From the selected ten-year database of heavy oil spills, ERC will identify those oil spills for which the use of a laser fluorosensor might have mitigated damages if employed within the first two hours, within the first day, and after more than three days. Cost analyses will be repeated for this subset of spills. Using another cost methodology, ERC’s Oil Spill Response Cost-Effectiveness Analytical Tool (OSRCEAT)⁴⁷ (diagrammed in Figure A-2) will be employed to estimate the overall impacts of responding to spills in a more timely fashion as aided by the laser fluorosensor technology.

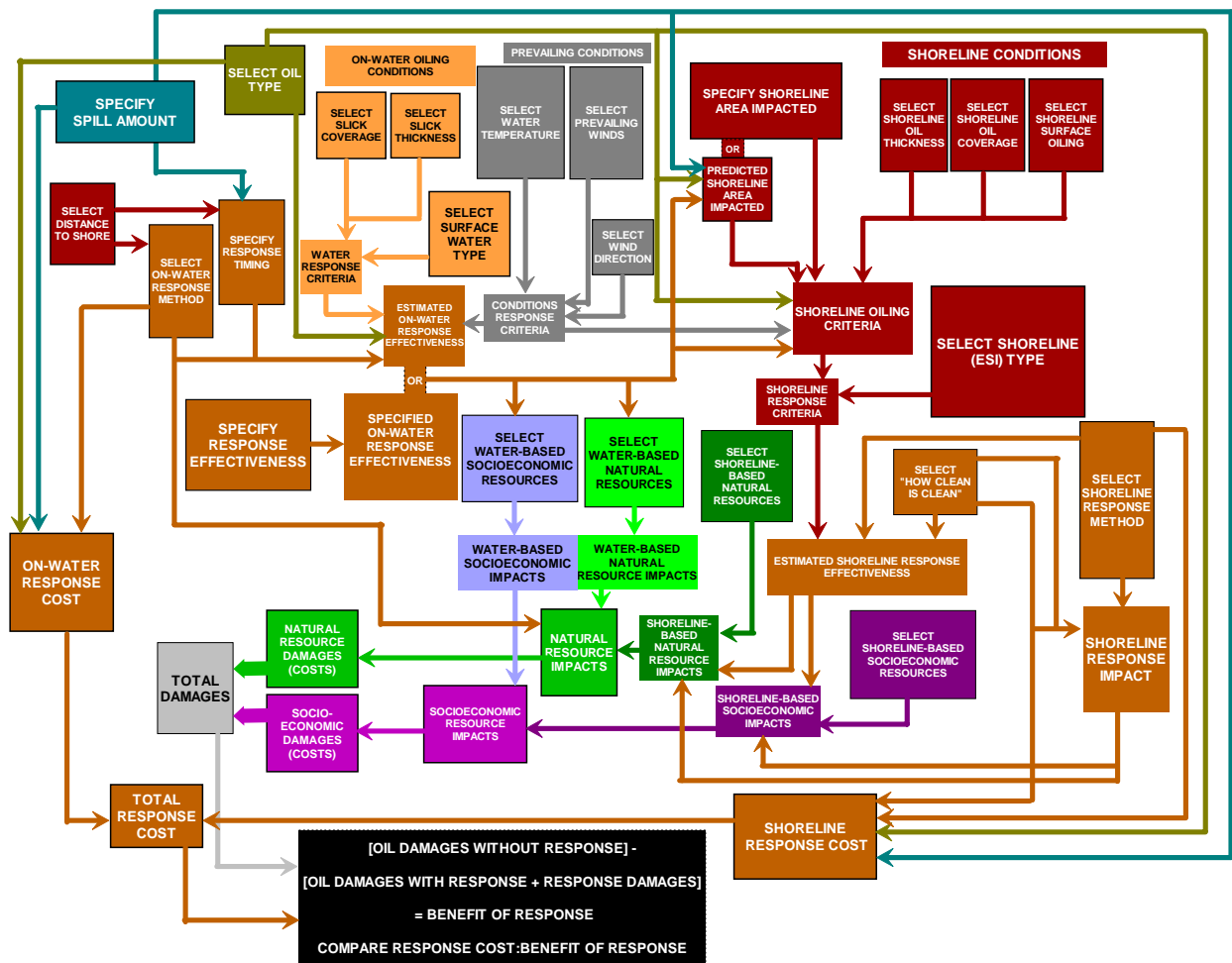


Figure A-2: ERC’s Oil Spill Response Cost-Effectiveness Analytical Tool (OSRCEAT)

This methodology will allow for a quick analysis of the overall benefits of decreasing response time by detecting spilled and submerged oil earlier. These estimates are based on averages of costs and impacts from past historical spills and modeled spills based on oil characteristics, location characteristics, and response strategies.

⁴⁷ Etkin, D.S. 2005. Development of an oil spill response cost-effectiveness analytical tool. *Proceedings of the 28th Arctic and Marine Oilspill Program Technical Seminar*: pp. 889 – 922.

MODELING OIL SPILL RESPONSE AND DAMAGE COSTS

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ABSTRACT

The EPA Basic Oil Spill Cost Estimation Model (BOSCEM) was developed to provide the US Environmental Protection Agency (EPA) Oil Program with a methodology for estimating oil spill costs, including response costs and environmental and socioeconomic damages, for actual or hypothetical spills. The model can quantify *relative* damage and cost for different spill types for regulatory impact evaluation, contingency planning, and assessing the value of spill prevention and reduction measures. EPA BOSCEM incorporates spill-specific factors that influence costs – spill amount; oil type; response methodology and effectiveness; impacted medium; location-specific socioeconomic value, freshwater vulnerability, habitat/wildlife sensitivity; and location type. Including these spill-specific factors to develop cost estimates provides greater accuracy in estimating oil spill costs than universal per-gallon figures used elsewhere. The model's basic structure allows for specification of response methodologies, including dispersants and *in situ* burning, which may have future applications in freshwater and inland settings. Response effectiveness can also be specified, allowing for analysis of potential benefits of response improvements.

INTRODUCTION

Regulatory analysis, cost-benefit analysis, resource planning, and impact analysis related to oil spills requires putting a value on the damages that oil spill cause. Use of a universal dollar-per-gallon (or dollar-per-barrel) cost for oil spill response, socioeconomic and environmental damage has been applied in many cases (*e.g.*, Office of Management and Budget, 2003), but this methodology overlooks the important factors in oil spill cases that can influence costs by orders of magnitude. The costs of a particular oil spill are related to a large number of factors, most notably: spill amount, oil type characteristics, response methodology and effectiveness, impacted medium or substrate type, location-specific socioeconomic and cultural value, location-specific freshwater vulnerability, location-specific habitat and wildlife sensitivity, year of spill (both in terms of inflation adjustments and probable response effectiveness for past and future cost projections), and the region or urban area impacted (Etkin 1999, 2000, 2001a, 2001b, 2003). To provide the EPA Oil Program Center with a simple, but sound methodology to estimate oil spill costs and damages, taking into account spill-specific factors for cost-benefit analyses and resource planning, the EPA Basic Oil Spill Cost Estimation Model (BOSCEM) was developed.

METHODOLOGY

EPA BOSCEM was developed as a custom modification to a proprietary cost modeling program, ERC BOSCEM, created by extensive analyses of oil spill response, socioeconomic, and environmental damage cost data from historical oil spill case studies and oil spill trajectory and impact analyses (Etkin, *et al.*, 2002; French-McCay, *et al.*, 2002; Etkin, *et al.*, 2003; Allen and Ferek, 1993). In addition, elements of habitat equivalency analysis as applied in Natural Resource Damage Assessment (NRDA) (NOAA, 1996, 1997; King, 1997) and other environmental damage estimation methods, such as Washington State's Damage Compensation Schedule (Geselbracht and Logan, 1993) and Florida's Pollutant Discharge Natural Resource Damage Assessment Compensation Schedule (Plante, *et al.*, 1993) were incorporated into the environmental damage estimation portion of ERC BOSCEM. Formulae, criteria, and cost modifier factors for estimating socioeconomic damages, including impacts to local and regional tourism, commercial fishing, lost-use of recreational facilities and parks, marinas, private property, and waterway and port closure, were derived from historical case studies of damage settlements and costs, as well as methods employed in other studies (Pulsipher, *et al.*, 1998; Dunford and Freeman, 2001; US Army Corps of Engineers, 2000a, 2000b, 2000c).

The model requires the specification of oil type and amount and primary response methodology and effectiveness to determine the base costs. Cost modifiers based on location medium type, location-specific relative socioeconomic/cultural value category, location-specific freshwater use, location-specific habitat and wildlife sensitivity category, and year of spill (in the case of future and past cost estimations), are then applied against the base costs. The base costs for response costs, socioeconomic costs, and environmental damages are shown in Tables 1 – 3. The modifier factors are shown in Tables 4 – 8. The basic model diagram for EPA BOSCEM depicting the interrelationships between cost factors is shown in Figure 1.

To apply EPA BOSCEM to estimate costs for a hypothetical spill, the following steps are taken:

Input of spill criteria:

1. Specify amount of oil spilled (in gallons);
2. Specify basic oil type category (as in Tables 1 – 3);
3. Specify primary response methodology and effectiveness (as in Table 1);
4. Specify medium type of spill location (as in Table 4);
5. Specify socioeconomic and cultural value of spill location (as in Table 5);
6. Specify freshwater vulnerability category of spill location (as in Table 7);
7. Specify habitat and wildlife sensitivity category of spill location (as in Table 8);

Note that if no specification is made for any of the input criteria, or if these factors are not known, the “default value” indicated in each table is used.

Determination of spill costs:

1. To calculate spill response cost, multiply the base per-gallon response cost based on oil type/volume/response method and effectiveness, as determined from Tables 1 or 2, by the medium modifier in Table 4 and by the spill amount:

$$\text{per-gallon response cost} \times \text{medium modifier} \times \text{spill amount} = \text{total response cost}$$
2. To calculate socioeconomic damages, multiply the base per-gallon socioeconomic cost based on oil type/volume, as determined from Table 3, by the appropriate socioeconomic and cultural damage cost modifier in Table 4 and by the spill amount:

$$\text{per-gallon socioeconomic cost} \times \text{socioeconomic cost modifier} \times \text{spill amount} = \text{total socioeconomic damage cost}$$
3. To calculate the environmental damages, multiply the base per-gallon environmental damage cost based on oil type/volume, as determined from Table 4, by the freshwater vulnerability modifier added to the habitat/wildlife sensitivity modifier and multiplied by 0.5, all multiplied by the spill amount:

$$\text{per-gallon environmental cost} \times 0.5(\text{freshwater modifier} + \text{wildlife modifier}) \times \text{spill amount} = \text{total environmental damage cost}$$

Note that in the use of cost modifiers, if there are spill situations in which the spill falls partly into one category and partly into another, estimate the *relative proportion* of the spill impact (by volume or area covered) in each of the categories and compute the weighted average of the modifiers to determine a combination modifier. For example, if impacted waters have a mixed use of 70% industrial and 30% wildlife use, the freshwater vulnerability would be computed as:

$$\text{freshwater vulnerability modifier} = 0.7(\text{industrial}) + 0.3(\text{wildlife}) = 0.7(0.4) + 0.3(1.7) = 0.79.$$

The costs can be added together for a total spill cost. All of the costs can be adjusted by regional/urban area- and year-specific consumer price index factors to adjust for regional differences in costs and inflationary changes in costs for past spills or future past projections.

RESULTS

EPA BOSCEM was used to estimate the costs of oil spills in navigable inland waterways in the EPA Jurisdiction Oil Spill Database, based on the characteristics of each spill. The data set included 42,860 spills of at least 50 gallons that occurred during the years 1980 through 2002. Each spill was classified by the input criteria of oil type and volume and general location-specific characteristics to determine the appropriate cost modifiers. The response, socioeconomic, environmental, and total costs were also adjusted for regional/urban area consumer price index and annual inflationary differences. All costs were adjusted to 2002 dollars. An assumption of increasing response effectiveness was also incorporated into the calculations. The costs for oil spills in inland navigable waterways for the years 1980 through 2002

are shown in Table 9. Over the 23-year period, estimated total costs for inland navigable waterway oil spills was \$63.2 billion, or, on average, \$2.7 billion annually. This is nearly the equivalent of an Exxon Valdez-magnitude spill event over the inland waterways each year.

DISCUSSION

Each oil spill is a *unique event* involving the spillage or discharge of a particular type of oil or combination of oils that may cause damage to the local and/or regional environment, wildlife, habitats, *etc.*, as well as to third parties. No modeling method can ever exactly determine or predict costs of an oil spill. Yet, there are patterns that emerge with respect to damages upon detailed analyses of oil spill case studies. For example, heavier oils are more persistent and present greater challenges – and thus costs – in oil removal operations than lighter oils, such as diesel fuel. Heavier oils, being more visible and persistent, have greater impacts on tourist beaches and private property. At the same time, lighter oils with their greater toxicity and solubility are more likely to cause impacts to groundwater and invertebrate populations. Greater effectiveness in oil removal tends to reduce environmental damages and socioeconomic impacts. Other factors, such as spill location, can also have significant impacts on spill costs and damages. A diesel fuel spill in an industrial area will likely have less impact and require a less expensive cleanup than one that occurs in or near a sensitive wetland. EPA BOSCEM incorporates these types of factors into a simple methodology for estimating the costs of “types of spills” that may be analyzed in a cost benefit analysis or for assessing which types of spills (oil type, location, *etc.*) that are causing the greatest impacts. It is important to note that with respect to “environmental damage” cost estimations, EPA BOSCEM is *not* a substitute for a federal- or state-level NRDA process. But, the model can provide a method for estimating *relative* differences in natural resource damage impacts from different types of spills.

The model allows for cost and damage estimation of different oil spill response methodologies, including different degrees of mechanical containment and recovery, as well as alternative response tools of dispersants and *in situ* burning that may have greater future applications in freshwater and inland settings. Response effectiveness can also be specified allowing for analysis of potential benefits of research and development into response improvements. Additionally, EPA BOSCEM is adaptable to future updates as research and development efforts on oil spill cost modeling provide even more reliable spill base costs and spill factor modifiers.

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BIOGRAPHY

Dagmar Schmidt Etkin received her B.A. in Biology from University of Rochester, and her A.M. and Ph.D. in Biology (specializing in population biology, ecology, and statistical analysis) from Harvard University. She has analyzed and modeled oil spill data and impacts for 15 years.

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Table 1: Per-Gallon Oil Spill Response Costs Applied in EPA BOSCEM¹

Oil Type	Volume (gallons)	Mechanical ^{2,4}				Dispersants ^{3,4}		In-Situ Burn ⁵	
		0%	10%	20%	50%	Low	High	50%	80%
Light Fuels ⁶	<500	\$100	\$85	\$70	\$57	\$36	\$25	\$26	\$13
	500 – 1,000	\$98	\$83	\$68	\$55	\$35	\$24	\$25	\$12
	1,000 – 10,000	\$97	\$82	\$67	\$54	\$34	\$23	\$24	\$11
	10,000 – 100,000	\$87	\$72	\$59	\$41	\$26	\$18	\$18	\$9
	100,000 – 1,000,000	\$74	\$62	\$49	\$26	\$17	\$10	\$10	\$5
	>1,000,000	\$31	\$26	\$17	\$12	\$11	\$6	\$7	\$3
Heavy Oils ⁷	<500	\$440	\$386	\$335	\$310	\$140	\$89	\$125	\$64
	500 – 1,000	\$438	\$385	\$334	\$309	\$139	\$88	\$124	\$63
	1,000 – 10,000	\$436	\$384	\$333	\$308	\$138	\$87	\$123	\$62
	10,000 – 100,000	\$410	\$359	\$308	\$267	\$103	\$62	\$103	\$51
	100,000 – 1,000,000	\$179	\$154	\$128	\$103	\$59	\$54	\$72	\$41
	>1,000,000	\$87	\$77	\$67	\$36	\$53	\$49	\$56	\$26
Crude Oil ⁸	<500	\$220	\$199	\$189	\$153	\$85	\$53	\$75	\$48
	500 – 1,000	\$218	\$197	\$187	\$151	\$84	\$52	\$74	\$47
	1,000 – 10,000	\$215	\$195	\$185	\$149	\$82	\$51	\$72	\$46
	10,000 – 100,000	\$195	\$185	\$174	\$138	\$74	\$31	\$62	\$31
	100,000 – 1,000,000	\$123	\$118	\$113	\$92	\$49	\$29	\$36	\$16
	>1,000,000	\$92	\$82	\$76	\$64	\$58	\$13	\$22	\$11
Volatile Distillates ⁹	<500	--	\$103	--	--	--	--	--	--
	500 – 1,000	--	\$102	--	--	--	--	--	--
	1,000 – 10,000	--	\$100	--	--	--	--	--	--
	10,000 – 100,000	--	\$55	--	--	--	--	--	--
	100,000 – 1,000,000	--	\$23	--	--	--	--	--	--
	>1,000,000	--	\$7	--	--	--	--	--	--

¹Per-gallon cost based on hypothetical modeling in Etkin *et al.* (2002, 2003) with shoreline oil removal costs adjusted by % reduction of oiling. Modeling included fate by oil type and trajectory (French-McCay *et al.* 2002). ²Per-gallon costs include on-water mechanical recovery, shoreline oil removal, mobilization, source control, protective booming. ³Per-gallon costs include on-water dispersant response, shoreline oil removal, mobilization, source control, protective booming. ⁴Removal assumed for on-water recovery or dispersants. Shoreline oiling assumed reduced by % on-water oil removal. Low/high removal by dispersants for light fuel/crude 40%/80%, for heavy oil 35%/70% (Pond *et al.* 2000). ⁵ISB costs based on per-gallon operations costs in Allen and Ferek (1993), plus costs of shoreline cleanup of unburned oil. ⁶Light fuels, light crude, and light oils; ⁷Heavy oils, heavy crude, lube oil, tars, and waste oil. ⁸Crude (except specifically-identified heavy- or light-crudes, intermediate fuel oils, waxes, animal fats, other oils, edible oils, non-edible vegetable oils, and mineral oils. Default values are shaded. ⁹Volatile distillates include gasoline, jet fuel, kerosene, No. 1 fuel oil, and crude condensate. Based on Etkin and Tebeau 2003.

Table 2: Socioeconomic Base Per-Gallon Costs For Use in EPA BOSCEM¹			
Oil Type	Volume (gallons)	Base Cost (\$/gallon)	
		Socioeconomic	Environmental
Volatile Distillates²	<500	\$65	\$48
	500 – 1,000	\$265	\$45
	1,000 – 10,000	\$400	\$35
	10,000 – 100,000	\$180	\$30
	100,000 – 1,000,000	\$90	\$15
	>1,000,000	\$70	\$10
Light Fuels³	<500	\$80	\$85
	500 – 1,000	\$330	\$80
	1,000 – 10,000	\$500	\$70
	10,000 – 100,000	\$200	\$65
	100,000 – 1,000,000	\$100	\$30
	>1,000,000	\$90	\$25
Heavy Oils⁴	<500	\$150	\$95
	500 – 1,000	\$600	\$90
	1,000 – 10,000	\$900	\$85
	10,000 – 100,000	\$500	\$75
	100,000 – 1,000,000	\$200	\$40
	>1,000,000	\$175	\$35
Crudes⁵	<500	\$50	\$90
	500 – 1,000	\$200	\$87
	1,000 – 10,000	\$300	\$80
	10,000 – 100,000	\$140	\$73
	100,000 – 1,000,000	\$70	\$35
	>1,000,000	\$60	\$30

¹Based on hypothetical spills in Etkin *et al.* (2002, 2003) with oil fate modeling as in French-McCay *et al.*, 2002, and historical cases with oil type impact based on characteristics as modeled by NOAA ADIOS 2. ²Volatile distillates include gasoline, No. 1 fuel oil, jet fuel, kerosene. ³Light fuels, light crude, light oils; ⁴Heavy oils, heavy crude, lube oil, tars, waste oil. ⁵Crude (except specifically-identified heavy- or light-crudes, intermediate fuel oils, waxes, animal fats, other oils, edible oils, non-edible vegetable oils, mineral oils. ¹Based on hypothetical spills in Etkin *et al.* (2002, 2003)

Table 3: Environmental Base Per-Gallon Costs For Use in Basic Oil Spill Cost Estimation Model¹		
Oil Type	Volume (gallons)	Base Environmental Cost (\$/gallon)
Volatile Distillates²	<500	\$48
	500 – 1,000	\$45
	1,000 – 10,000	\$35
	10,000 – 100,000	\$30
	100,000 – 1,000,000	\$15
	>1,000,000	\$10
Light Fuels³	<500	\$85
	500 – 1,000	\$80
	1,000 – 10,000	\$70
	10,000 – 100,000	\$65
	100,000 – 1,000,000	\$30
	>1,000,000	\$25
Heavy Oils⁴	<500	\$95
	500 – 1,000	\$90
	1,000 – 10,000	\$85
	10,000 – 100,000	\$75
	100,000 – 1,000,000	\$40
	>1,000,000	\$35
Crudes⁵	<500	\$90
	500 – 1,000	\$87
	1,000 – 10,000	\$80
	10,000 – 100,000	\$73
	100,000 – 1,000,000	\$35
	>1,000,000	\$30

¹Based on hypothetical spills in Etkin *et al.* (2002, 2003) with oil fate modeling by Applied Science Associates' SIMAP in French-McCay *et al.* 2002, and cases in Appendix Table L with oil type impact based on oil characteristics in Appendix Tables M and O. ²Volatile distillates: gasoline, No. 1 fuel oil, jet fuel, kerosene. ³Light fuels, light crude, and light oils as in Table 1; ⁴Heavy oils, heavy crude, lube oil, tars, and waste oil. ⁵Crude (except specifically-identified heavy- or light-crudes, intermediate fuel oils, waxes, animal fats, other oils, edible oils, non-edible vegetable oils, and mineral oils.

Table 4: EPA BOSCEM Response Cost Modifiers for Location Medium Type Categories¹	
Category	Cost Modifier Value²
Open Water/Shore*	1.0
Soil/Sand	0.6
Pavement/Rock	0.5
Wetland	1.6
Mudflat	1.4
Grassland	0.7
Forest	0.8
Taiga	0.9
Tundra	1.3

¹Category description in Table 2. ²Based on tendency for oil spread or deep penetration in area sensitive to impact of response equipment/personnel (higher values). *Default value.

Value Rank	Spill Impact Site(s) Description	Examples	Cost Modifier Value
Extreme	Predominated by areas with high socioeconomic value that may potentially experience a large degree of <i>long-term</i> ² impact if oiled.	Subsistence/commercial fishing, aquaculture areas	2.0
Very High	Predominated by areas with high socioeconomic value that may potentially experience some <i>long-term</i> ² impact if oiled.	National park/reserves for ecotourism/nature viewing; historic areas	1.7
High	Predominated by areas with medium socioeconomic value that may potentially experience some <i>long-term</i> ² impact if oiled.	Recreational areas, sport fishing, farm/ranchland	1.0
Moderate	Predominated by areas with medium socioeconomic value that may potentially experience <i>short-term</i> ² impact if oiling occurs.	Residential areas; urban/suburban parks; roadsides	0.7*
Minimal	Predominated by areas with a small amount of socioeconomic value that may potentially experience <i>short-term</i> ² impact if oiled.	Light industrial areas; commercial zones; urban areas	0.3
None	Predominated by areas already moderately to highly polluted or contaminated or of little socioeconomic or cultural import that would experience little short- or long-term impact if oiled.	Heavy industrial areas; designated dump sites	0.1

¹Default value is shaded. ²Long-term impacts are those impacts that are expected to last *months to years* after the spill or be relatively irreversible. ³Short-term impacts are those impacts that are expected to last *days to weeks* after the spill occurs and are generally considered to be reasonably reversible. *Default value.

Response Method	Oil Removal Effectiveness	Adjustment Factor¹
Mechanical Recovery	0%	1.15
	10%	1.00*
	20%	0.85
	50%	0.55
Dispersants	Light Oils/Crude/Light Fuels Low (40%) ²	0.45
	Heavy Oils Low (35%) ²	0.40
	Light Oils/Crude/Light Fuels High (80%) ²	0.25
	Heavy Oils High (70%) ²	0.35
In Situ Burning	50%	0.55
	80%	0.25

¹Adjustment factor based on percent reduction in oil spreading and shoreline oiling expected with response methodology. *Note that not all socioeconomic costs are directly related to the degree of oiling. Some impacts occur regardless of the amount of oiling. Thus the adjustment factors are slightly less than the percent oiling expected after response operations of certain removal effectiveness.* ²Low/high removal by dispersants for light fuel/crude 40%/80%, for heavy oil 35%/70% (Pond *et al.* 2000) *Default value.

Category	Cost Modifier Value
Wildlife Use	1.7
Drinking	1.6
Recreation	1.0
Industrial	0.4
Tributaries to Drinking/Recreation	1.2
Non-Specific*	0.9

*Default value shaded.

Table 8: EPA BOSCEM Habitat and Wildlife Sensitivity Categories¹	
Category	Cost Modifier Value^{1, 2}
Urban/Industrial	0.4
Roadside/Suburb	0.7
River/Stream*	1.5
Wetland	4.0
Agricultural	2.2
Dry Grassland	0.5
Lake/Pond	3.8
Estuary	1.2
Forest	2.9
Taiga	3.0
Tundra	2.5
Other Sensitive	3.2

¹Values based on relative time to recovery (based on Fingas 2001) ²If more than one category is relevant, the one that most closely represents the majority of the area, or, if there is a relatively even distribution of categories, the category that represents the greater sensitivity or vulnerability (*i.e.*, with the higher modifier value) should be chosen. Alternatively, a weighted average of different categories can be used in these cases. *Default value shaded.

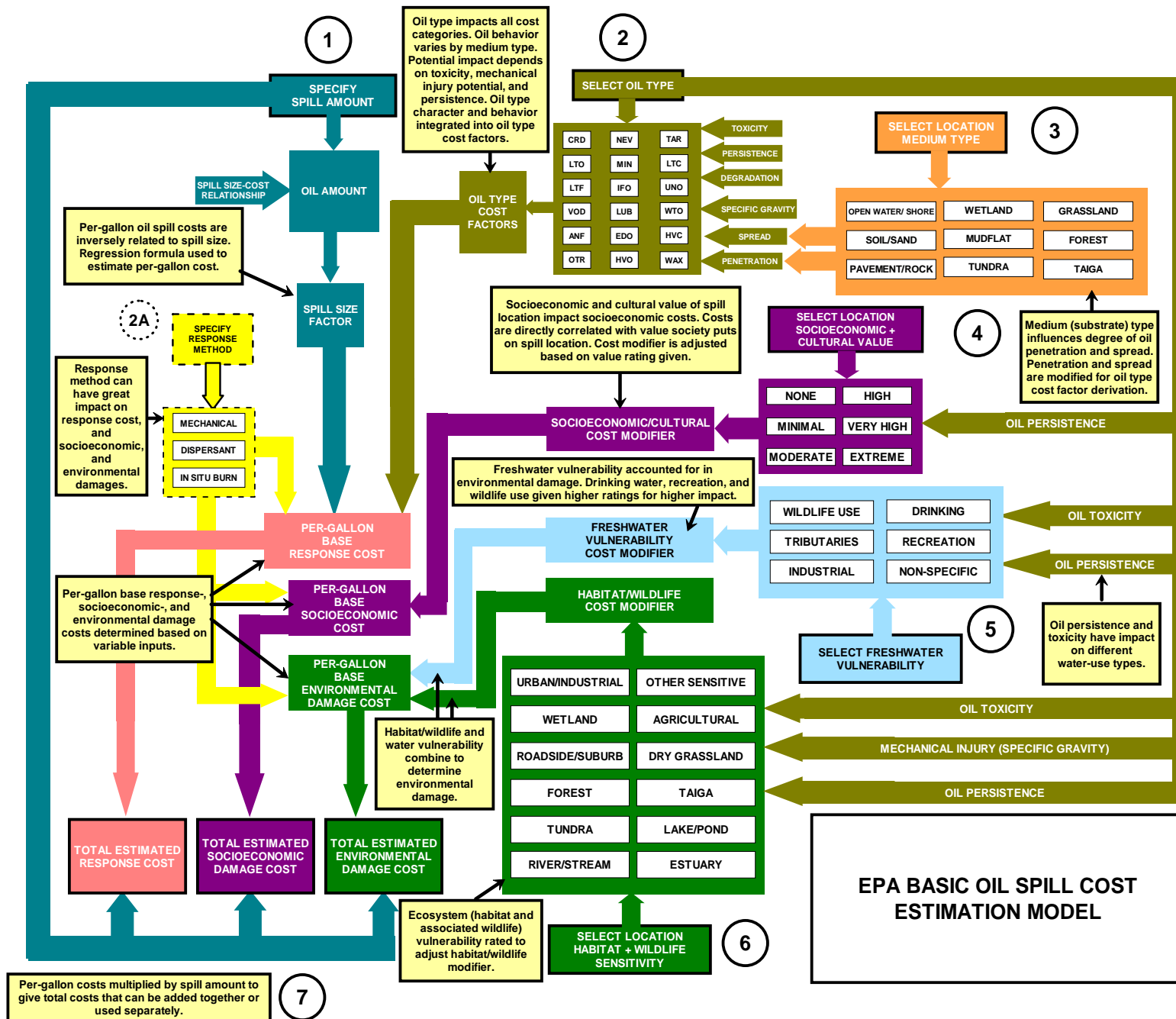


Figure 1: EPA BOSCEM basic interrelationships between oil spill base costs and modifiers. The circled numbers indicate steps of input by user.

Year	Estimated Costs ² (2002 \$ million)			Total
	Response	Socioeconomic Damage	Environmental Damage	
1980	\$1,665	\$2,019	\$701	\$4,386
1981	\$875	\$1,093	\$376	\$2,344
1982	\$2,025	\$2,209	\$791	\$5,025
1983	\$1,915	\$2,173	\$822	\$4,910
1984	\$1,008	\$1,268	\$443	\$2,719
1985	\$788	\$964	\$382	\$2,133
1986	\$838	\$1,278	\$416	\$2,531
1987	\$938	\$1,325	\$458	\$2,722
1988	\$844	\$1,273	\$438	\$2,555
1989	\$1,302	\$1,621	\$582	\$3,504
1990	\$1,293	\$1,898	\$619	\$3,810
1991	\$1,419	\$1,842	\$673	\$3,934
1992	\$586	\$897	\$317	\$1,801
1993	\$725	\$1,292	\$394	\$2,411
1994	\$547	\$961	\$325	\$1,833
1995	\$513	\$696	\$267	\$1,476
1996	\$422	\$637	\$229	\$1,288
1997	\$430	\$750	\$241	\$1,422
1998	\$449	\$603	\$260	\$1,312
1999	\$601	\$889	\$313	\$1,804
2000	\$482	\$1,002	\$289	\$1,773
2001 ³	\$1,382	\$2,224	\$763	\$4,369
2002 ³	\$977	\$1,678	\$488	\$3,143
TOTAL 1980 - 2002	\$22,025	\$30,592	\$10,588	\$63,205
TOTAL 1980 –1989	\$12,199	\$15,222	\$5,408	\$32,829
TOTAL 1990 - 1999	\$6,985	\$10,466	\$3,640	\$21,091
TOTAL 2000 - 2002	\$2,842	\$4,904	\$1,540	\$9,285
TOTAL 1998 - 2002	\$3,892	\$6,396	\$2,114	\$12,401
TOTAL 1993 - 2002	\$6,529	\$10,733	\$3,570	\$20,831

¹Non-marine waters *and adjoining shorelines*, including: i.) All waters currently used, used in the past, or may be used in interstate or foreign commerce, including all waters subject tidal ebb and flow; ii.) All interstate waters, including interstate wetlands; iii.) All other waters such as intrastate lakes, rivers, and streams (including intermittent streams), mudflats, sandflats, wetlands, prairie potholes, wet meadows, playa lakes, or natural ponds, the use, degradation, or destruction of which could affect interstate or foreign commerce including any such waters: (A) that are or could be used by interstate or foreign travelers for recreational or other purposes; or (B) from which fish or shellfish are or could be taken and sold in interstate or foreign commerce; or (C) that are or could be used for industrial purposes by industries in interstate commerce. iv.) All impoundments of waters otherwise defined as waters of the US under this section; v.) Tributaries of waters identified in (i) through (iv); and vi.) Wetlands adjacent to waters identified in (i) through (vii). ²Based on EPA Jurisdiction Oil Spill Database using EPA Basic Oil Spill Cost Estimation Model. Assumes mechanical recovery operations (plus shoreline) with 0% on-water effectiveness during 1980 – 1984, 10% during 1985 – 1992, and 20% during 1992 – 2002. ³Preliminary data (overestimates).

Development of the Oil Spill Response Cost-Effectiveness Analytical Tool

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Abstract

The Oil Spill Response Cost-Effectiveness Analytical Tool (OSRCEAT) was developed to compare *costs* of response to *benefits* of response for hypothetical or actual oil spills. The web-based analytical tool can assist spill responders and contingency planners in decision-making processes and act as a basis of discussion in for evaluating response options. With user input on spill parameters, location, and response options, OSRCEAT calculates response cost, costs of environmental and socioeconomic impacts of the oil, and response impacts. Oil damages *without* any response are contrasted to oil damages *with* response (improvements that response offers). Response damages are subtracted from difference in damages with and without response to derive the response benefit. Response cost can then be compared to response benefit. The user can test various response options to compare potential response benefits so as to maximizing response benefit. OSRCEAT is best used to compare and contrast the relative benefits and costs of various response options.

1 Introduction

Decision-making during oil spill response operations or contingency planning requires balancing the need to remove as much oil as possible from the environment with the desire to minimize impact of the response operations on the environment they are intending to protect. The decision-making analytical tool developed in this project will help incorporate factors of cost-effectiveness of response operations into net environmental benefit analysis (NEBA). By providing incident-specific (or hypothetical scenario-specific) information on response costs (by methodology), response efficiency, environmental impacts, socioeconomic impacts, and cost-effectiveness, the tools would help response and restoration officials make well-informed choices during actual response operations. The tool would also help in the evaluation of various response options for contingency planning or strategizing by understanding the potential costs involved for various response options and the potential effectiveness of those response strategies.

OSRCEAT allows the user to consider the following questions: How much oil remains after on-water oil removal? How much oil will hit the shoreline? What on-water natural and socioeconomic resources are impacted and to what degree, taking into account on-water oil removal? How is the shoreline oil distributed? What types and amounts of shoreline are impacted? What shoreline natural and socioeconomic resources are impacted and to what degree? What impact does the shoreline response have on shoreline natural resources? To what extent does the shoreline response mitigate damages of the oil? What is the total cost of response (on-water and shoreline)? What is the total cost of damages to natural resources (on-water and shoreline)? What is the total cost of damages to socioeconomic resources (on-water and shoreline)? What is the cost-benefit ratio of the response?

2 Methodology

There are two methods for applying OSRCEAT: through a web-based user interface and by manually (or with a calculator) going through a series of algorithms and calculations. The web-based user interface incorporates a series of algorithms developed from studies of previous spills and from spill modelling projects. This method allows the user to enter various parameters and variable values for actual or hypothetical spills. The functional user interface and rapid calculation makes it possible to estimate values for many different spill situations in a short period of time.

The manual calculations can be tedious, but this method allows the user to adjust algorithms and variables to better customize the calculation for a particular spill situation. This may be preferable when

there is better information available on some of the spill's parameters (such as socioeconomic resources at risk) than may be inherent in the built-in algorithms that are based on averages of other spill situations.

In either case, the basic premise of the calculations is that the baseline of oil damages *without* response (*i.e.*, the damage to natural and socioeconomic resources that would have occurred from the oil in the absence of any form of response) are compared to the oil damages remain despite response efforts and the damages that the response itself might cause, so that:

$$\begin{aligned} \text{Oil Damage Without Response} - \text{Oil Damage With Response} - \text{Response Damage} \\ = \text{Response Benefit} \end{aligned}$$

The point is to derive the *benefit*, if any, of the response. After calculating response cost, the user can then compare response cost to response benefit to derive a cost to benefit ratio of the response.

3 User Inputs

The user needs to select or specify inputs on spill location, resources at risk, oil type and amount, and various choices for response. User inputs, which are applicable for both the web-based user interface method and manual calculation, follow. (“Specify” indicates that the user enters variable values. “Select” indicates that there are limited choices from which the user must choose one alternative.)

- **Spill Amount**

- Specify: Spill Amount [No default] Note: Minimum spill size = 500 gallons.
- Select Units: Gallons/Barrels/Tonnes/Cubic Meters [No Default]

- **Oil Type**

- Select Oil Type: Gasoline/Jet Fuel/Diesel/Light Crude/Medium Crude/Heavy Crude/No. 6 Fuel/IFO/Lube Oil [Default = Medium Crude]

- **On-Water Response**

- Select On-Water Response: None/Mechan/Burn/Dispersant [Default = None]

- **Distance to Shore**

- Select Distance to Shore: Nearshore/<3 Miles (<5 km)/3 –10 Miles (5 – 16 km)/10 – 50 Miles (16 – 80 km) [No Default]

- **On-Water Response Efficiency**

The user can specify on-water response efficiency or allow OSRCEAT to estimate response efficiency based on oil type and selections made for oil slick coverage and thickness, response timing, distance to shore, and prevailing conditions.

- Specify Response Efficiency: % Removal [No Default], *or* select to allow program to estimate % Removal based on Response Timing, on-water oiling condition variables, and prevailing conditions variables.

- **Response Timing**

- Specify Response Timing: in hours (from 1 hour to 96 hours) [No Default]

- **On-Water Oiling Conditions**

- Select Slick Coverage: Continuous/Broken/Patchy/Sporadic [No Default]
 - Select Slick Thickness: Fresh/Rainbow Sheen/Silver Sheen/Mousse/Film [Default = Fresh]

- **Water Surface Type**

Select Water Surface Type: Open Marine/Open Fresh/Open Estuary/Large River/Small Stream/Small Lake [Default = Open Marine]

- **Prevailing Conditions**

- Select Water Temperature: 5°C (41°F)/10°C (50°F)/20°C (68°F)/30°C (86°F) [Default = 20°C]
- Select Prevailing Winds: Calm – Light (2 kts)/Moderate (15 kts)/Strong (25 kts)/Gale (35 kts) [Default = Moderate]
- Select Prevailing Wind Direction: To Shore/Offshore [Default = To Shore]

- **Shoreline Area Impacted**

The user has a choice of specifying square meters of different types of shoreline impacted in a table such as shown in Table 1. Multiple selections are allowable for both shoreline type and oil thickness.

- Specify Shoreline Area Impact: by shoreline type and oil thickness/ coverage

- **Shoreline Oil Coverage**

The user has the choice of having shoreline area impacted estimated by OSRCEAT based on previous user input on oil type, spill amount, and response efficiency.

- Select Shoreline Oil Cover: Continuous/Broken/Patchy/Sporadic [Default = Patchy]
- Select Shoreline Oil Thickness: Pooled (> 1 cm)/Cover (>0.1-1 cm)/Coat (<0.1 cm)/Stain/Film [Default = Coat]

- **Shoreline (ESI) Type**

- Select Shoreline (ESI) Type (as in Table 1).

- **Surface Oiling**

- Select Shoreline Surface Oiling: Fresh Oil/Mousse/Tarballs/Patties/Tar Strands/Surface Residue/Asphalt Pavement [Default = Fresh Oil]

Shoreline Type (ESI)	Cover*	Pooled m ²	Cover m ²	Coat m ²	Stain m ²	Film m ²
1A: Exposed Rocky						
2: Rocky Platform						
3: Fine Sand						
4: Coarse Sand						
5: Mixed Sand/Gravel						
6A: Gravel Beach						
6B: Riprap Structures						
7: Exposed Tidal Flat						
8A: Sheltered Rocky						
8B: Sheltered Solid						
9: Sheltered Tidal Flat						
10A: Salt/Brackish Marsh						
10B: Freshwater Marsh						
10C: Swamp						
10D: Mangrove						

*User fills in C = Continuous; B = Broken; P = Patchy; or S = Sporadic

- ***Shoreline Response Method***

The user makes a selection on response method based on each shoreline type as in Table 2. Those responses that are not appropriate for a particular shoreline are indicated with “NA” for “not applicable” or “not advisable”.

- Select Shoreline Response: Natural Recovery/Manual/Mechanical/Sorbents/Sediment Rework/Vegetation Removal/Burn/Flooding/Low-Pressure Cold Wash/High-Pressure Cold Wash/Low-Pressure Hot Wash/High-Pressure Hot Wash/Steam Clean/Sand Blast/Cleaning Agents/Bioremediation [Default = Natural Recovery]

- ***“How Clean is Clean” Criteria***

- Select “How Clean Is Clean”: Maximum/High/Medium/Low/Minimum [Default = Medium]

- ***Shoreline-Based Socioeconomic Resources***

The user selects the shoreline socioeconomic resources at risk from oiling. More than one can be selected. But it is important for the user to keep in mind that the algorithms calculating the cost of these resources are based on the total amount of oil that hits the shoreline. The modifying factors are additive, so that if two or more resources are selected, the damages are added to each other. If the same oil, in essence, causes different damage in different locations, selecting more than one resource may be appropriate. If the oil overall impacts more than one kind of resource, the user should pick the most sensitive, expensive one.

- Select Shoreline-Based Socioeconomic Resources: Tourist Beach/Wildlife Viewing/Industrial/Port/Residential/High Value/Medium Value/Low Value [Default = Medium Value]

- ***Shoreline-Based Natural Resources***

- Select Shoreline-Based Natural Resources: Birds/Mammals/Endangered Species/High Sensitive/Moderate Sensitive/Low Sensitive [Default = Moderate Sensitive]

- ***Water-Based Socioeconomic Resources***

- Select Water-Based Socioeconomic Resources: Fisheries/Ports/Boating/Water Intake/Drink Water/Recreation Fishing/Other High/Low Use [Default = Other High]

- ***Water-Based Natural Resources***

- Select Water-Based Natural Resources: Fish/Mammals/Birds/Coral Reef/Other High/Low [Default = Other High]

4 OSRCEAT Base Cost Calculations

The steps to calculate the various base costs to determine response benefits and cost:benefit ratios are as follows. The costs shown in brackets (e.g., [Cost D]) refer to Table 5.

- ***Step 1: Calculate Percent Oil Remaining***

The percent oil remaining is based on response time and oil type. User-entered response time needs to be adjusted based on distance to shore input. (If distance to shore = nearshore, add 0 hrs; if <3 miles, add 2 hrs; if 3-10 miles, add 6 hrs, if 10-50 miles, add 12 hrs; if 50 miles, add 24 hrs.) The adjusted response time is used in the calculations. The

percent remaining is further adjusted by wind and/or temperature adjusters if the default settings of 20deg/15 kts are not used.

- Percent oil remaining X spill amount = gallons oil remaining (before response) [This value will later be used in estimating oil damage *without* response.]

Step 2: Calculate On-Water Socioeconomic Resource Damages [Cost D], [Cost B]

The user must use a formula based on oil type.

- Enter spill amount (G). This gives per-gallon costs. Multiply the whole result by spill amount and modifiers (depending on socioeconomic resources selected).

Step 3: Calculate On-Water Response Impact [Cost F]

This step is only needed if on-water response is “dispersant” *and* on-water socioeconomic resources include fisheries, drinking water, recreational fishing, and/or water intake.

- If this is all true, then on-water response impact = 0.12 x on-water socioeconomic damages.

Step 4: Calculate On-Water Natural Resource Damages [Cost E], [Cost C]

The user must use a formula based on oil type.

- Enter spill amount (G). This gives per-gallon costs.
- Multiply the result by spill amount and modifiers (depending on natural resources selected). Remember the modifiers are additive if more than one resource selected. Selecting more than two resources will skew results.

Step 5: Calculate On-Water Response Efficiency (Percent On-Water Removal)

The on-water response efficiency is based on formulae with adjusted response time for mechanical response, and on oil type for dispersant response. It is based on a set response efficiency of 50% for burn if adjusted response time is less than 36 hours. (Also burning is only applicable as a response if oil type is *not* jet fuel or gasoline, and not if the distance to shore is “nearshore” or less than 3 miles, or if the wind is strong or gale). For no response, response efficiency equals 0. The user can override this calculation and *specify* response efficiency, if desired.

Step 6: Calculate On-Water Response Cost [Cost A]

- On-Water Response Cost = Monitoring Base Cost + Mobilization Base Cost + (Additional Per-Gallon Cost X Spill Amount) + Disposal Cost
- Monitoring Base Cost is derived from formula based on spill amount
- Mobilization Base Cost is derived from formula based on spill amount (except = 0 for no response)
- Per-Gallon Cost from table based on oil type and response type.
- Multiply Per-Gallon Cost by spill amount.
- Disposal Cost only for response = Mechanical
- Disposal = 5 x [Percent Oil Remaining X Response Efficiency X Spill Amount]

Step 7: Calculate Actual Oil Remaining

- Actual Oil Remaining = [Percent Oil Remaining X Spill Amount] X [100% - Percent Response Efficiency]

This result needs to be adjusted if wind direction is offshore and the distance to shore is 3-10 miles, 10-50 miles or 50 miles, and the surface water type is “open marine” or “open fresh”. If this is true, multiply actual oil remaining (calculated above) by 0.1

Step 8: Calculate Shoreline Response Oiling

Shoreline oiling is calculated based on the actual oil remaining (previously calculated) multiplied by the total area that oil would cover assuming a “coat” thickness with continuous coverage. The user has to select shoreline type(s) present. OSRCEAT assumes that Total Shoreline Area Oiled is spread evenly across shoreline types selected (if more than one). The Total Area needs to be divided by the number of shoreline types selected. (e.g., if 10,000 gallons hits shoreline and 4 shoreline types are oiled, each shoreline type gets hit with 2,500 gallons x 3.785 m² in area.)

- Actual Oil Remaining x 3.785 m² = Total Area (m²) Shoreline Oiled (This assumes thickness = coat, and coverage = continuous).

The user can override this feature by specifying specific shoreline oiling in web-based user interface. There the user can select shoreline type(s), coverage, and oil thickness.

Step 9: Calculate Shoreline Response Cost [Cost G]

Shoreline response cost depends on area covered, shoreline type, oil type, thickness, coverage, and “how clean is clean” (HCIC).

- Multiply Per-Area Shoreline Response Cost X Area X Coverage Adjuster X HCIC Adjuster

If multiple shoreline types selected, the cost needs to be calculated by adding each shoreline type/oil thickness-appropriate value for:

- Per-Area Cost X Area Covered X Coverage Adjuster and multiplying the result X HCIC Adjuster

Step 10: Calculate Shoreline Response Effectiveness

Shoreline response effectiveness is related to shoreline type, shoreline response method, and HCIC. Table 3 shows the assumed response method effectiveness for each shoreline type and response method combination as H (high) (80%), M (medium) (20%), or L (low) (10%). This factor is then used to reduce shoreline socioeconomic and natural resource impact

If more than one shoreline type/response type is selected, the response efficiency will need to be averaged through the use of a weighted average based on the relative areas of the different shoreline types.

Step 11: Calculate Shoreline Response Impact [Cost J]

- Multiply Shoreline Response Cost X Response Impact Modifier

Response Impact Modifier values are shown in Table 4 based on shoreline type and response method employed. For H = 0.3; M = 0.1; L = 0

- Multiply whole result by HCIC factor. If HCIC = maximum, multiply by 3.0; if HCIC = high, multiply by 1.5; if HCIC = medium, multiply by 1.0; if HCIC = maximum, multiply by 3.0; if HCIC = low, multiply by 0.5; if HCIC = minimum, multiply by 0.1

$$\text{Shoreline Response Cost X Response Impact Modifier X HCIC Factor} \\ = \text{Shoreline Response Impact}$$

Table 3: Assumed Shoreline Response Effectiveness															
Response	Response Effectiveness by Shoreline Type (ESI)														
	1A	2	3	4	5	6A	6B	7	8A	8B	9	10A	10B	10C	10D
Natural	H	H	L	L	L	M	H	M	M	M	L	L	L	L	L
Manual	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Mechanical	NA	NA	M	M	M	M	L	L	M	L	M	M	M	M	M
Sorbent	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Sediment Rework	NA	NA	M	M	M	M	L	M	NA	NA	L	L	L	L	L
Remove Vegetation	NA	NA	NA	NA	NA	NA	L	L	NA	NA	M	M	M	M	M
Burn	L	L	L	L	L	L	L	M	L	L	M	M	M	M	M
Flood	M	M	M	M	M	M	M	L	M	M	L	L	L	L	L
Low Cold Wash	M	M	M	M	M	M	M	M	M	M	L	L	L	L	L
High Cold Wash	M	M	M	M	M	M	M	M	M	M	L	L	L	L	L
Low Hot Wash	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L
High Hot Wash	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L
Steam	H	H	L	L	L	L	L	L	L	H	L	L	L	L	L
Sanding	M	M	M	L	L	L	NA	NA	NA	NA	NA	NA	NA	NA	NA
Agents	M	M	L	L	L	L	L	L	M	M	L	L	L	L	L
Bio-Remediation	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

NA = "not applicable" or "not advisable". H = 80%; M = 50%; L = 10%

Step 12: Calculate Shoreline Socioeconomic Damages [Cost H]

Per-gallon shoreline socioeconomic cost is derived from a formula based on oil type and amount of oil hitting shoreline (same as actual oil remaining) multiplied by shoreline socioeconomic resource modifier. Multiply per-gallon cost by actual amount oil remaining. Shoreline socioeconomic damages are then multiplied by 100% – % shoreline response effectiveness to get Actual Shoreline Socioeconomic Resource Damages

Step 13: Calculate Shoreline Natural Resource Damages [Cost I]

Per-gallon shoreline Natural Resource Damage cost derived from formula based on oil type and amount of oil hitting shoreline (same as actual oil remaining) multiplied by shoreline Natural Resource Damage modifier. Multiply per-gallon cost by actual amount oil remaining. Shoreline Natural Resource Damages are then multiplied by 100% minus % shoreline response effectiveness to get Actual Shoreline Natural Resource Damages.

Step 14: Calculate On-Water and Shoreline Socioeconomic and Natural Resource Damages With No Response [Cost D], [Cost E], [Cost K], [Cost L]

For On-Water Socioeconomic and Natural Resource Damages, the results are the same as for Steps 2 and 4. For Shoreline Socioeconomic and Natural Resource Damages, Repeat Steps 12 and 13, but use default Minimum % Oil Remaining multiplied by Spill Amount.

Table 4: Assumed Shoreline Response Impact															
Response	Shoreline Response Impact by Shoreline Type (ESI)														
	1A	2	3	4	5	6A	6B	7	8A	8B	9	10A	10B	10C	10D
Natural	H	H	L	L	L	M	H	M	M	M	L	L	L	L	L
Manual	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Mechanical	NA	NA	M	M	M	M	L	L	M	L	M	M	M	M	M
Sorbent	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Sediment Rework	NA	NA	M	M	M	M	L	M	NA	NA	L	L	L	L	L
Remove Vegetation	NA	NA	NA	NA	NA	NA	L	L	NA	NA	M	M	M	M	M
Burn	L	L	L	L	L	L	L	M	L	L	M	M	M	M	M
Flood	M	M	M	M	M	M	M	L	M	M	L	L	L	L	L
Low Cold Wash	M	M	M	M	M	M	M	M	M	M	L	L	L	L	L
High Cold Wash	M	M	M	M	M	M	M	M	M	M	L	L	L	L	L
Low Hot Wash	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L
High Hot Wash	H	H	H	H	H	H	H	H	H	H	L	L	L	L	L
Steam	H	H	L	L	L	L	L	L	L	H	L	L	L	L	L
Sanding	M	M	M	L	L	L	NA	NA	NA	NA	NA	NA	NA	NA	NA
Agents	M	M	L	L	L	L	L	L	M	M	L	L	L	L	L
Bioremediation	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

NA = "not applicable" or "not advisable"

Step 15: Calculate Total Costs

- o Total On-Water Response Cost = Cost A
- o Total Shoreline Response Cost = Cost G
- o Total Response Cost = Cost A + Cost G = Cost M
- o On-Water Response Impact = Cost F
- o Shoreline Response Impact = Cost J
- o Total Response Impact = Cost F + Cost J = Cost Q
- o Total On-Water Socioeconomic Damages Without Response = Cost D
- o Total On-Water Natural Resource Damages Without Response = Cost E
- o Total Shoreline Socioeconomic Damages Without Response = Cost K
- o Total Shoreline Natural Resource Damages Without Response = Cost L
- o Total Damages Without Response = Cost D + Cost E + Cost K + Cost L = Cost R
- o Total On-Water Socioeconomic Damages With Response = Cost B
- o Total On-Water Natural Resource Damages With Response = Cost C
- o Total Shoreline Socioeconomic Damages With Response = Cost H
- o Total Shoreline Natural Resource Damages With Response = Cost I
- o Total Damages With Response = Cost B + Cost C + Cost H + Cost I = Cost P
- o Response Benefit = Cost R – [Cost P + Cost Q]
- o Cost Benefit Ratio = Cost M : [Response Benefit]

The relationship between oil damages without response, oil damages with response, damage from the response itself, and response benefit are illustrated in Figure 1.

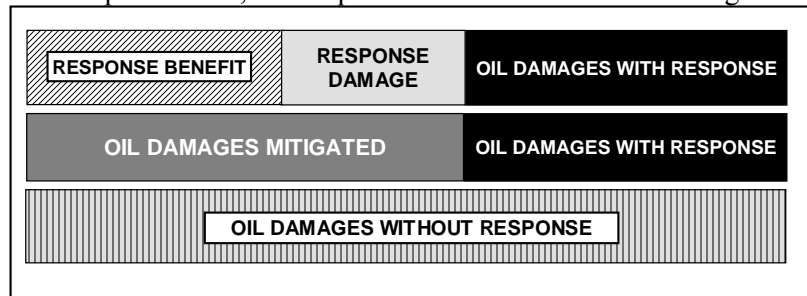


Figure 1: Schematic drawing of derivation of response benefit

Total Response Cost ÷ Benefit of Response = Cost/Benefit Ratio

Cost/Benefit Ratio can be calculated based on the damages to both socioeconomic *and* natural resources or calculated based *only* on damages to natural resources, as needed.

5 OSRCEAT Final Output

OSRCEAT's final output provides these results (refer to Table 5 for cost types):

- Total On-Water Response Cost = Cost A
- Total Shoreline Response Cost = Cost G
- Total Response Cost = Cost M = Cost A + Cost G
- On-Water Response Impact = Cost F
- Shoreline Response Impact = Cost J
- Total Response Impact = Cost Q = Cost F + Cost J
- Total On-Water Socioeconomic Damages *Without* Response = Cost D
- Total On-Water Natural Resource Damages *Without* Response = Cost E
- Total Shoreline Socioeconomic Damages *Without* Response = Cost K
- Total Shoreline Natural Resource Damages *Without* Response = Cost L
- Total Damages *Without* Response, Cost R = Cost D + Cost E + Cost K + Cost L
- Total On-Water Socioeconomic Damages *With* Response = Cost B
- Total On-Water Natural Resource Damages *With* Response = Cost C
- Total Shoreline Socioeconomic Damages *With* Response = Cost H
- Total Shoreline Natural Resource Damages *With* Response = Cost I
- Total Damages *With* Response = Cost P = Cost B + Cost C + Cost H + Cost I
- Response Benefit = Cost R – Cost P + Cost Q
- Cost Benefit Ratio = Cost M ÷ (Cost R – Cost P + Cost Q)

6 OSRCEAT Base Algorithms

The calculations within the steps involves a series of algorithms based on empirical data, as described below.

6.1 Percent Oil Remaining

The “percent oil remaining” calculations estimate the percentage of the original oil spilled that remains on the water based on oil type, spill amount, prevailing conditions (wind, water temperature), and time of the response. The percent oil remaining formulae are based on application of NOAA's ADIOS (Version 2) software at various spill sizes, water temperatures, and wind speeds for the oil types that can be selected in the OSRCEAT model. Best-fit equations were developed from graphic output of ADIOS results. Simplified modifiers for water temperature and winds were estimated based on comparison of graphs with different settings. Other information was derived from Davis, *et al.* (2004), NRC (1999, 2003), and Fingas (2001).

The percent oil remaining is then applied to the original spill amount to estimate the amount of oil on the water that can be dealt with in the response. t = hours since spill (response time); y = percent oil remaining. (There is a minimum percentage of oil remaining regardless of time to response, depending on oil type.) Response timing is adjusted based on distance of spill from shore. The arrival time at the shoreline is the base time, with 2 hours added for <3 miles, 6 hours for 3-10 miles, 12 hours for 10-50 miles, and 24 hours for 50 miles. No adjustment is made for nearshore spills.

Table 5: Cost Variables in OSRCEAT Calculations		
Variable	Variable Name	Description
COST A	on-water response cost	on-water response cost based on spill size, oil type, and response type
COST B	on-water socioeconomic resource damages	on-water socioeconomic resource damages based on oil type and spill amount and on-water socioeconomic resources selected
COST C	on-water natural resource damages	on-water natural resource damages based on oil type and actual amount of oil on water after response and on-water natural resources selected
COST D	on-water socioeconomic damages if no response on water	on-water socioeconomic resource damages based on oil type and actual amount of oil on water with no response
COST E	on-water socioeconomic damages if no response on water	on-water natural resource damages based on oil type and actual amount of oil on water with no response
COST F	natural resource damage due to response	socioeconomic damages to fisheries/aquaculture based on disperant use
COST G	shoreline response cost	cost of shoreline response based on oiling, area, coverage, type, response method, and “how clean is clean” criteria
COST H	shoreline socioeconomic damages	shoreline socioeconomic damages based on amount of oiling and socioeconomic resources selected
COST I	shoreline natural resource damages	shoreline natural resource damages based on amount of oiling and natural resources selected
COST J	damages to natural resources from shoreline response	damages to natural resources from shoreline response based on response type and HCIC criteria
COST K	cost of socioeconomic shoreline damage if no response on water	cost of socioeconomic shoreline damage if no response on water
COST L	cost of natural resource shoreline damage if no response on water	cost of natural resource shoreline damage if no response on water
COST M	total response cost	total of on-water plus shoreline response costs
COST N	total socioeconomic damages from oil with response	total of on-water and shoreline socioeconomic damages taking into account on-water response
COST O	total natural resource damages from oil with response	total of on-water and shoreline natural resource damages taking into account on-water response
COST P	total damages from oil with response	total of on-water and shoreline natural and socioeconomic resource damages taking into account on-water response
COST Q	total natural resource damages from response	total natural resource damages due to on-water and shoreline response
COST R	total oil damages without response	total natural resource and socioeconomic damages if no response on water

Medium Crude (Default Oil Type)

- If Water Temperature = Default 20°C and Wind = Default (Moderate 15 Kts)
- Minimum = 32%
- 500 – 999 gal: $y = 0.6208 t^{-0.1114}$
- 1,000 – 4,999 gal: $y = 0.6478 t^{-0.1098}$
- 5,000 – 9,999 gal: $y = 0.7367 t^{-0.1281}$
- 10,000 – 49,999 gal: $y = 0.7855 t^{-0.1333}$
- 50,000 – 99,999 gal: $y = 0.8831 t^{-0.1392}$
- 100,000 – 499,999 gal: $y = 0.9178 t^{-0.1413}$
- 500,000 – 999,999 gal: $y = 0.9807 t^{-0.1322}$
- 1,000,000 – 4,999,999 gal: $y = 1.0090 t^{-0.1342}$
- 5,000,000 – 9,999,999 gal: $y = 1.0464 t^{-0.1234}$
- 10,000,000 + gal: $y = 1.0562 t^{-0.1158}$
- If Temperature = 5°C, multiply results by 1.2; if 10°C, by 0.9; if 30°C, by 0.8.
- If Wind = calm-light, multiply results by 1; if strong, by 0.85; if gale, by 0.75

Gasoline

- For all selections of water, then wind, and oil amount the formula is: $y = -1.7714t + 11.533$
- Minimum = 0% [No adjustments necessary for temperature or wind]

Jet Fuel

- If Water Temperature = Default 20°C and Wind = Default (Moderate 15 Kts)
- Minimum = 13%
- 500 – 999 gal: 13% remaining at all hours
- 1,000 – 4,999 gal: $y = 1.0245t^{1.0792}$
- 5,000 – 9,999 gal: $y = 0.3418t^{-0.2222}$
- 10,000 – 49,999 gal: $y = 0.4286t^{-0.2903}$
- 50,000 – 99,999 gal: $y = 0.8177t^{-0.4986}$
- 100,000 – 499,999 gal: $y = 1.0934t^{-0.5639}$
- 500,000 – 999,999 gal: $y = 1.2939t^{-0.5073}$
- 1,000,000 – 4,999,999 gal: $y = 1.8974t^{-0.6204}$
- 5,000,000 – 9,999,999 gal: $y = 1.5667t^{-0.4827}$
- 10,000,000 + gal: $y = 1.7885t^{-0.5353}$
- If Temperature = 5°C, multiply results by 2; if 10°C, by 1.5; if 30°C, by 0.5.
- If Wind = calm-light, multiply results by 7.8; if strong, by 0.8; if gale, by 0.5

Diesel

- If Water Temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 12%
- 500 – 999 gal: $y = 0.3921t^{-0.872}$
- 1,000 – 4,999 gal: $y = 0.4316t^{-0.9739}$
- 5,000 – 9,999 gal: $y = 0.6588t^{1.011}$
- 10,000 – 49,999 gal: $y = 0.9879t^{-1.2696}$
- 50,000 – 99,999 gal: $y = 2.9769t^{-1.4679}$
- 100,000 – 499,999 gal: $y = 3.8658t^{-1.5375}$
- 500,000 – 999,999 gal: $y = 1.3289t^{-0.548}$
- 1,000,000 – 4,999,999 gal: $y = 1.5943t^{-0.658}$
- 5,000,000 – 9,999,999 gal: $y = 1.6798t^{-0.5579}$
- 10,000,000 + gal: $y = 1.6854t^{-0.512}$

- If Temperature = 5°C, multiply results by 1.3; if 10°C, by 1.1; if 30°C, by 0.85.
- If Wind = calm-light, multiply results by 2.5; if strong, by 0.77; if gale, by 0.45

Light Crude

- If Water Temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 39%
- 500 – 999 gal: $y = 0.3792x^{-0.0679}$
- 1,000 – 4,999 gal: $y = 0.4253x^{-0.0687}$
- 5,000 – 9,999 gal: $y = 0.567x^{-0.078}$
- 10,000 – 49,999 gal: $y = 0.6365x^{-0.0841}$
- 50,000 – 99,999 gal: $y = 0.7609x^{-0.0911}$
- 100,000 – 499,999 gal: $y = 0.7992x^{-0.0938}$
- 500,000 – 999,999 gal: $y = 0.8769x^{-0.0975}$
- 1,000,000 – 4,999,999 gal: $y = 0.8973x^{-0.0985}$
- 5,000,000 – 9,999,999 gal: $y = 0.9486x^{-0.1011}$
- 10,000,000 + gal: $y = 0.9684x^{-0.1017}$
- If Temperature = 5°C, multiply results by 1.12; if 10°C, by 1.05; if 30°C, by 0.91.
- If Wind = calm-light, multiply results by 1.05 if strong, by 0.91; if gale, by 0.74

Heavy Crude

- If Water Temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 63%
- 500 – 999 gal: $y = 0.5989x^{-0.0315}$
- 1,000 – 4,999 gal: $y = 0.6283x^{-0.0317}$
- 5,000 – 9,999 gal: $y = 0.7198x^{-0.0386}$
- 10,000 – 49,999 gal: $y = 0.755x^{-0.0417}$
- 50,000 – 99,999 gal: $y = 0.82x^{-0.0501}$
- 100,000 – 499,999 gal: $y = 0.8458x^{-0.0547}$
- 500,000 – 999,999 gal: $y = 0.9089x^{-0.0661}$
- 1,000,000 – 4,999,999 gal: $y = 0.9238x^{-0.0675}$
- 5,000,000 – 9,999,999 gal: $y = 0.9668x^{-0.0696}$
- 10,000,000 + gal: $y = 0.9851x^{-0.0719}$
- If Temperature = 5°C, multiply results by 1.03; if 10°C, by 1; if 30°C, by 0.96.
- If Wind = calm-light, multiply results by 1 if strong, by 1; if gale, by 0.96.

No. 6 Fuel

- If water temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 10%
- 500 – 999 gal: $y = 0.00000001x^4 - 0.000004x^3 + 0.0004x^2 - 0.024x + 0.9361$
- 1,000 – 4,999 gal: $y = 0.00000001x^4 - 0.000004x^3 + 0.0004x^2 - 0.0245x + 0.9472$
- 5,000 – 9,999 gal: $y = 0.00000001x^4 - 0.000004x^3 + 0.0004x^2 - 0.0258x + 0.9778$
- 10,000 – 49,999 gal: $y = 0.00000001x^4 - 0.000004x^3 + 0.0004x^2 - 0.0253x + 0.9912$
- 50,000 – 99,999 gal: $y = 0.00000006x^4 - 0.000002x^3 + 0.0003x^2 - 0.0196x + 1.015$
- 100,000 – 499,999 gal: $y = 0.00000005x^4 - 0.000002x^3 + 0.0002x^2 - 0.0178x + 1.0222$
- 500,000 – 999,999 gal: $y = -0.000000001x^4 - 0.000000008x^3 + 0.00008x^2 - 0.0121x + 1.0267$
- 1,000,000 – 4,999,999 gal: $y = -0.000000005x^4 + 0.0000009x^3 - 0.000007x^2 - 0.0089x + 1.0229$
- 5,000,000 – 9,999,999 gal: $y = -0.000000008x^4 + 0.000002x^3 - 0.0001x^2 - 0.0035x + 1.0108$
- 10,000,000 + gal: $y = -0.000000008x^4 + 0.000002x^3 - 0.0002x^2 - 0.0014x + 1.0027$
- If Temperature = 5°C – 10°C, then % remaining = 100%; if 30°C, multiply results by

0.91.

- If Wind = calm-light, multiply results by 1.3 if strong, by 0.38; if gale, by 0.15

IFO (Intermediate Fuel Oil)

- If water temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 79%
- 500 – 999 gal: $y = 0.9158x^{-0.0524}$
- 1,000 – 4,999 gal: $y = 0.9265x^{-0.0552}$
- 5,000 – 9,999 gal: $y = 0.9591x^{-0.0624}$
- 10,000 – 49,999 gal: $y = 0.9725x^{-0.0643}$
- 50,000 – 99,999 gal: $y = 1.0158x^{-0.0699}$
- 100,000 – 499,999 gal: $y = 1.0334x^{-0.0714}$
- 500,000 – 999,999 gal: $y = 1.0607x^{-0.0708}$
- 1,000,000 – 4,999,999 gal: $y = 1.0729x^{-0.0694}$
- 5,000,000 – 9,999,999 gal: $y = 1.0793x^{-0.0635}$
- 10,000,000 + gal: $y = 1.0803x^{-0.0601}$
- If Temperature = 5°C, multiply results by 1.06; if 10°C, by 1.02; if 30°C, by 0.96.
- If Wind = calm-light, multiply results by 1.06; if strong, by 0.98; if gale, by 0.96.

Lube Oil

- If water temperature = Default 20°C and Wind = Default (Moderate 15 kts)
- Minimum = 12%
- 500 – 999 gal: $y = -0.098x + 0.7493$
- 1,000 – 4,999 gal: $y = -0.1051x + 0.8065$
- 5,000 – 9,999 gal: $y = -0.1136x + 0.9621$
- 10,000 – 49,999 gal: $y = -0.1117x + 1.0367$
- 50,000 – 99,999 gal: $y = -0.081x + 1.1176$
- 100,000 – 499,999 gal: $y = -0.0577x + 1.0834$
- 500,000 – 999,999 gal: $y = -0.0283x + 1.0172$
- 1,000,000 – 4,999,999 gal: $y = -0.0191x + 1.0037$
- 5,000,000 – 9,999,999 gal: $y = 1.9893x^{-0.4933}$
- 10,000,000 + gal: $y = 1.6995x^{-0.3852}$
- If Temperature = 5°C, multiply results by 3; if 10°C, by 2; if 30°C, by 0.75.
- If Wind = calm-light, % remaining = 100%, if strong, multiply results by 0.7; if gale, by 0.8.

6.2 On-Water Response Damage

- On-Water Response Damage (Cost D)
- If On-Water Response = None, Cost D = 0
- If On-Water Response = Mechanical, Cost D = 0
- If On-Water Response = Burn, Cost D = 0
- If On-Water Response = Dispersant *and* On-Water Socioeconomic = Fisheries, Drink Water, Rec Fishing, and/or Water Intake, then Cost = 0.12 X On-Water Socioeconomic Damages for Fisheries, Drink Water, Rec Fishing, and/or Water Intake)

On-water response damage by dispersant use is estimated based on modeling and case studies, including: French-McCay and Payne (2001); Etkin (1998a); Etkin (1999b); French-McCay, *et al.* (2004b,c); NRC (1989); various presentations during 2004 to the NRC Ocean Studies Board Committee on Dispersants; and Walker, *et al.* (2000).

6.3 On-Water Socioeconomic Resource Damages

The steps to calculate on-water socioeconomic resource damages (based on oil type and spill size) are as follows:

- If Oil Type = Gasoline or Jet Fuel, then Per-Gallon Socioeconomic Damages = $1,625.6G^{-0.2166}$ and Total Socioeconomic Damages = $S \times G \times (1,626 G^{-0.2166})$
- If Oil Type = Diesel or Lt Crude, then Per-Gallon Socioeconomic Damages = $2,076G^{0.2226}$ and Total Socioeconomic Damages = $S \times G \times (2,076g^{-0.2226})$
- If Oil Type = Medium Crude, Lube Oil, or IFO, then Per-Gallon Socioeconomic Damages = $4,407G^{-0.2283}$ and Total Socioeconomic Damages = $S \times G \times (4,407g^{-0.2283})$
- If Oil Type = Hvy Crude or No. 6 Fuel, then Per-Gallon Socioeconomic Damages = $1370.8G^{-0.2236}$ and Total Socioeconomic Damages = $S \times G \times (1370.8G^{-0.2236})$,
- Where G = Spill Amount (in gallons)
- S = Socioeconomic Modifier (From Table 6)

The resource-type specific factors are additive (*i.e.*, total of modifiers for all resources = total socioeconomic modifier).

On-Water Socioeconomic Resource	Modifier
Fisheries	2.9
Ports	2.4
Boating	1.0
Water Intake	1.4
Drink Water	2.9
Rec Fishing	1.4
Other High Use	1.4
Low Use	0.4

Socioeconomic costs are based on case studies in ERC Oil Spill Databases and modeling in Etkin 2003a, Etkin 2003d, Etkin 2003e, Etkin 2004a, Etkin 2004d, Etkin 2004e, Etkin and Tebeau 2003, Etkin *et al.* 2003, Etkin *et al.* 2005, Etkin *et al.* 2003, Gray *et al.* 2004.

6.4 On-Water Natural Resource Damages

The steps to calculate on-water natural resource damages (based on oil type and spill size) are as follows:

- If Oil Type = Gasoline or Jet Fuel, then Per-Gallon Natural Resource Damages = $186.69G^{-0.1961}$
- Total Shoreline Natural Resource Damages = $S \times G \times (186.69G^{-0.1961})$,
- If Oil Type = Diesel or Lt Crude, then Per-Gallon Natural Resource Damages = $274.15G^{-0.1634}$
- Total Shoreline Natural Resource Damages = $S \times G \times (274.15G^{-0.1634})$,
- If Oil Type = Medium Crude, Lube Oil, or IFO, then Per-Gallon Natural Resource Damages = $279.3G^{-0.1525}$
- Total Shoreline Natural Resource Damages = $S \times G \times (279.3G^{-0.1525})$,
- If Oil Type = Hvy Crude or No. 6 Fuel, then Per-Gallon Natural Resource Damages = $256.28G^{-0.1366}$
- Total Shoreline Natural Resource Damages = $S \times G \times (256.28G^{-0.1366})$,
- Where G = Spill Amount (in gallons)
- S = Natural Resource Modifier (from Table 7)

In the web-based user interface, the user checks off on-water natural resources present. The factors are additive (total of modifiers for all natural resources checked off = total natural resource modifier). Natural resource damages are based on case studies in ERC Oil Spill Databases and modeling in Research Planning, Inc., *et al.* (2002a,b), Etkin (2003a), Etkin (2004d), Etkin and Tebeau (2003), French-McCay, *et al.* (2003), French-McCay, *et al.* (2004a), French-McCay, *et al.* (2004b), French-McCay *et al.* (2004c), and French-McCay, *et al.* (2005).

On-Water Natural Resource	Modifier
Fish	2.5
Mammals	3.0
Other High	4.0
Birds	4.5
Coral Reef	3.5
Low	1.0

6.5 On-Water Response Cost Calculation

The steps to calculate on-water response costs are as follows:

- Monitoring Cost + Mobilization Cost + [Per-Gallon Cost X Spill Amount] + Disposal Cost
- = On-Water Response Cost
- Disposal Cost = 5 X [% Oil Remaining X % On-Water Removal X Spill Amount]
- [Disposal Cost for Mechanical Recovery Only]
- On-Water Response Cost = Monitoring Base Cost (by spill size) + Mobilization Base Cost (by spill size) + [Additional Per-Gallon Cost (by oil type and response type) X Spill Amount] + [5 X (Percent Oil Remaining X Percent On-Water Removal X Spill Amount)] (Additional Per-Gallon Cost shown in Table 8.)
- For All Spill Responses, Monitoring Base Cost = $3236.7 G^{0.4387}$, where G = spill amount
- If Spill Response = No Response, Mobilization Base Cost = 0
- For all spill responses except No Response, Mobilization Base Cost = $35,388 G^{0.2762}$, where G = spill amount
- Multiply Additional Per-Gallon Cost By Spill Amount = Total Additional Cost
- Disposal Cost = 5 X [Percent Oil Remaining X Percent On-Water Removal X Spill Amount]
- Total On-Water Response Cost = Total Additional Cost + Monitoring Base Cost + Mobilization Base Cost + Disposal Cost

Oil spill costs are based on analyses of case studies in ERC Oil Spill Databases, Etkin 1996, Etkin 1998b, Etkin 1998c, Etkin 2000a, Etkin 2001a, 2004a, Etkin 2003a, and modeling of hypothetical spills in Etkin 2000a, Etkin 2003c, Etkin 2003d, Etkin 2004b, Etkin 2004c, Etkin *et al.* 2003, Etkin *et al.* 2005, Etkin *et al.* 2002, Research Planning, Inc., *et al.* 2002, Research Planning, Inc., *et al.* 2003, and Etkin and Tebeau 2003.

Oil Type	Response Type (Costs in US dollars)			
	No Response	Mechanical	Burn	Dispersant
Medium Crude	0	\$28	\$23	\$24
Gasoline	0	\$12	NA ¹	NA ²
Jet Fuel	0	\$12	NA ³	NA ⁴
Diesel	0	\$15	\$13	\$14
Lt Crude	0	\$23	\$18	\$19
Hvy Crude	0	\$36	\$29	\$30
No. 6 Fuel	0	\$37	\$30	\$31
IFO	0	\$28	\$28	\$24
Lube Oil	0	\$26	\$21	\$22

¹In situ burning (ISB) is generally not recommended for gasoline spills. ²Dispersant is generally not recommended for gasoline spills. ³ISB is generally not recommended for jet fuel spills. ⁴Dispersant is generally not recommended for jet fuel spills.

6.6 Response Efficiency Calculation

Response efficiency is applied to *oil still remaining on the surface* based on response timing (allowing for natural evaporation and dispersion into water) to estimate the amount of oil still left to end up on the shoreline. Alternatively, response efficiency can be specified by user. The response efficiency is somewhat over-estimated by OSRCEAT, even though it takes mechanical response inefficiencies into account to some extent. These efficiencies are more accurate for fresh oil and thicker slicks. The user may opt to specify a lower efficiency (say, 10 – 20%) to get more typical response efficiencies.

- If On-Water Response Method = None
- % Response Efficiency = 0%
- If On-Water Response Method = Mechanical, then % Response Efficiency = $[-0.017 \times (\text{Hour of Response})] + 0.941$, *i.e.*, % Response Efficiency = $-0.017T + 0.941$
- Where T = hour of response after spill (based on adjusted response timing)

Response timing is adjusted based on distance of spill from shore. The arrival time at the shoreline is the base time, with 2 hours added for <3 miles, 6 hours for 3-10 miles, 12 hours for 10-50 miles, and 24 hours for 50 miles. No adjustment is made for nearshore spill locations.

Mechanical response costs are based on review of case studies and data in ERC Oil Spill Databases. Reductions in response efficiency with time are based on an adaptation of Gregory, Allen, and Dale (1999); Etkin, *et al.* (2005), Etkin (2004c).

- For All Oil Types: If Slick Coverage = Patchy or Sporadic or If Slick Thickness = Rainbow Sheen, Silver Sheen, Mousse, or Film, or If Prevailing Wind = Strong or Gale, then % Response Efficiency = 0%
- If On-Water Response Method = Burn, then % Response Efficiency = 50%, if Response Timing <36 Hours, unless If Oil Type = Jet Fuel Or Gasoline, or if Prevailing Wind = Strong Or Gale, or if Distance To Shore = Nearshore Or <3 Miles, then = Message: “Not Recommended Due To Safety Concerns”

Burning would not be employed nearshore, in strong winds, or with volatile fuels (*e.g.*, jet fuel or gasoline) except in extraordinary circumstances. Burn response efficiency is based on a review of case studies and data in ERC Oil Spill Databases, modeling in Etkin (2004b,c), and consultations with experts, including Alan A. Allen, Spiltec, Inc.

- If On-Water Response Method = Dispersant *and* if Oil Type = Medium Crude, Heavy Crude, Or Light Crude, then % Response Efficiency = 70%
- If On-Water Response Method = Dispersant *and* if Oil Type = Gasoline, Jet Fuel, # 6 Fuel, IFO, Lube Oil, then % Response Efficiency = 0%
- If On-Water Response Method = Dispersant *and* If Oil Type = Diesel, then % Response Efficiency = 33%

Efficiency of dispersant use is estimated based on modeling and case studies, including: French-McCay and Payne 2001; Etkin 1998*a*; Etkin 1999*b* (review of hundreds of dispersant studies); French-McCay et al. 2004*b,c*; National Research Council 1989; various presentations during 2004 to the National Research Council Ocean Studies Board Committee on Dispersants.

- If Surface Water Type = Open Fresh, Open Estuary, Large River, Small Stream, or Small Lake, then % Response Efficiency = 0%
- If Prevailing Wind = Calm, then % Response Efficiency multiplied by 0.1
- If Response Timing = >36 Hours, then % Response Efficiency = 0%
- If Water Temperature = 5°C, then Response Efficiency = 0%
- If Distance to Shore = Nearshore Or <3 Miles, Then % Response Efficiency = Message “Not Recommended Due To Shoreline Proximity”

6.7 Actual Oil Remaining

The calculation for actual oil remaining is made as follows:

- Actual Oil Remaining = [Spill Amount X % Oil Remaining] X [100% – % Response Efficiency]
- Actual Oil Remaining = Actual Oil to Hit Shoreline
- If Prevailing Wind Direction = Offshore and Distance to Shore = 3-10 Miles, 10-50 Miles, or 50+ Miles and Surface Water = Open Marine or Open Fresh, multiply Actual Oil to Hit Shoreline by 0.1
- Note: Default Wind Direction = To Shore

6.8 Predicted Shoreline Oiling

If the user chooses to have OSRCEAT estimate shoreline area impacted, the following algorithm is used. The actual oil remaining, as previously calculated, will be spread evenly across shoreline types selected at a default thickness (coat <0.1 cm):

$$\text{Gallons Actual Oil Hitting Shoreline} \times 3.785 \text{ m}^2 = \text{Shoreline Area Oiled}$$

6.9 Shoreline Response Cost

Total shoreline response cost is calculated by taking the shoreline response cost for each shoreline type, based on the amount of shoreline impacted and adjustments made for coverage, thickness, and the “how clean is clean” (HCIC) factor:

$$\text{Shoreline Response Cost} = \sum [(\text{Shoreline Oiled Area} \times \text{Shoreline Response Cost Per Area} \text{ By Oil Thickness} \times \text{Coverage Adjustment Factor})] \times \text{HCIC Adjustment Factor}$$

For each oil type, there is a table that gives the response cost per square meter of shoreline oiled based on shoreline type and oil thickness. This table corresponds with the shoreline oiling table in which the user specifies square meters of impact. (Multiply that by the factors in this table.) All of that then gets multiplied by the coverage adjustment factor to get the total shoreline cost.

- Total Cost from Oiling Table (Tables 9 – 17) = Sum of All Boxes (*i.e.*, sum of the square meters of oiling times the \$/m² in the tables).
- [With Default Or Blank Box = 0] Multiplied By Coverage Adjustment Factor
- Coverage Adjustment: Multiply Sum Cost for each row from Oiling Table by factor below.
- [Note for Shoreline Oil Coverage, Default = Patchy]
- Coverage Adjustment Multipliers: Continuous: 3.0; Broken: 2.3; Patchy: 1.0; or Sporadic: 0.2
- Total Cost From Oiling Table X HCIC Factor = Total Shoreline Response Cost
- If HCIC = Maximum, multiply by 2.7; if HCIC = High, multiply by 1.2; if HCIC = Medium, multiply by 1.0; if HCIC = Low, multiply by 0.8; if HCIC = Minimum, multiply by 0.4.

Shoreline response costs are based on case studies in ERC Oil Spill Databases, Etkin (2000b), Etkin (2001b), and Etkin (2003f), and Research Planning, Inc., *et al.* (2002, 2003).

Table 9: Medium Crude Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m ²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$159	\$59	\$15	\$6	\$3
2: Rocky Platform		\$159	\$59	\$15	\$6	\$3
3: Fine Sand		\$159	\$59	\$15	\$6	\$3
4: Coarse Sand		\$159	\$59	\$15	\$6	\$3
5: Mixed Sand/Gravel		\$193	\$71	\$18	\$8	\$4
6a: Gravel Beach		\$193	\$71	\$18	\$8	\$4
6b: Riprap Structures		\$193	\$71	\$18	\$8	\$4
7: Exposed Tidal Flat		\$259	\$96	\$24	\$10	\$5
8a: Sheltered Rocky Shore		\$159	\$59	\$15	\$6	\$3
8b: Sheltered Solid		\$125	\$46	\$12	\$5	\$3
9: Sheltered Tidal Flat		\$259	\$96	\$24	\$10	\$5
10a: Salt/Brackish Marsh		\$259	\$96	\$24	\$10	\$5
10b: Freshwater Marsh		\$259	\$96	\$24	\$10	\$5
10c: Swamp		\$259	\$96	\$24	\$10	\$5
10d: Mangrove		\$259	\$96	\$24	\$10	\$5

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 10: Gasoline Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m ²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$80	\$29	\$7	\$3	\$2
2: Rocky Platform		\$80	\$29	\$7	\$3	\$2
3: Fine Sand		\$80	\$29	\$7	\$3	\$2
4: Coarse Sand		\$80	\$29	\$7	\$3	\$2
5: Mixed Sand/Gravel		\$97	\$36	\$9	\$4	\$2
6a: Gravel Beach		\$97	\$36	\$9	\$4	\$2
6b: Riprap Structures		\$97	\$36	\$9	\$4	\$2
7: Exposed Tidal Flat		\$130	\$48	\$12	\$5	\$3
8a: Sheltered Rocky Shore		\$80	\$29	\$7	\$3	\$2
8b: Sheltered Solid		\$63	\$23	\$6	\$3	\$1
9: Sheltered Tidal Flat		\$130	\$48	\$12	\$5	\$3
10a: Salt/Brackish Marsh		\$130	\$48	\$12	\$5	\$3
10b: Freshwater Marsh		\$130	\$48	\$12	\$5	\$3
10c: Swamp		\$130	\$48	\$12	\$5	\$3
10d: Mangrove		\$130	\$48	\$12	\$5	\$3

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 11: Jet Fuel Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m ²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$80	\$29	\$7	\$3	\$2
2: Rocky Platform		\$80	\$29	\$7	\$3	\$2
3: Fine Sand		\$80	\$29	\$7	\$3	\$2
4: Coarse Sand		\$80	\$29	\$7	\$3	\$2
5: Mixed Sand/Gravel		\$97	\$36	\$9	\$4	\$2
6a: Gravel Beach		\$97	\$36	\$9	\$4	\$2
6b: Riprap Structures		\$97	\$36	\$9	\$4	\$2
7: Exposed Tidal Flat		\$130	\$48	\$12	\$5	\$3
8a: Sheltered Rocky Shore		\$80	\$29	\$7	\$3	\$2
8b: Sheltered Solid		\$63	\$23	\$6	\$3	\$1
9: Sheltered Tidal Flat		\$130	\$48	\$12	\$5	\$3
10a: Salt/Brackish Marsh		\$130	\$48	\$12	\$5	\$3
10b: Freshwater Marsh		\$130	\$48	\$12	\$5	\$3
10c: Swamp		\$130	\$48	\$12	\$5	\$3
10d: Mangrove		\$130	\$48	\$12	\$5	\$3

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 12: Diesel Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m ²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$95	\$35	\$9	\$4	\$2
2: Rocky Platform		\$95	\$35	\$9	\$4	\$2
3: Fine Sand		\$95	\$35	\$9	\$4	\$2
4: Coarse Sand		\$95	\$35	\$9	\$4	\$2
5: Mixed Sand/Gravel		\$116	\$43	\$11	\$5	\$2
6a: Gravel Beach		\$116	\$43	\$11	\$5	\$2
6b: Riprap Structures		\$116	\$43	\$11	\$5	\$2
7: Exposed Tidal Flat		\$155	\$57	\$14	\$6	\$3
8a: Sheltered Rocky Shore		\$95	\$35	\$9	\$4	\$2
8b: Sheltered Solid		\$75	\$28	\$7	\$3	\$2
9: Sheltered Tidal Flat		\$155	\$57	\$14	\$6	\$3
10a: Salt/Brackish Marsh		\$155	\$57	\$14	\$6	\$3
10b: Freshwater Marsh		\$155	\$57	\$14	\$6	\$3
10c: Swamp		\$155	\$57	\$14	\$6	\$3
10d: Mangrove		\$155	\$57	\$14	\$6	\$3

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 13: Light Crude Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$127	\$47	\$12	\$5	\$3
2: Rocky Platform		\$127	\$47	\$12	\$5	\$3
3: Fine Sand		\$127	\$47	\$12	\$5	\$3
4: Coarse Sand		\$127	\$47	\$12	\$5	\$3
5: Mixed Sand/Gravel		\$154	\$57	\$14	\$6	\$3
6a: Gravel Beach		\$154	\$57	\$14	\$6	\$3
6b: Riprap Structures		\$154	\$57	\$14	\$6	\$3
7: Exposed Tidal Flat		\$207	\$77	\$19	\$8	\$4
8a: Sheltered Rocky Shore		\$127	\$47	\$12	\$5	\$3
8b: Sheltered Solid		\$100	\$37	\$9	\$4	\$2
9: Sheltered Tidal Flat		\$207	\$77	\$19	\$8	\$4
10a: Salt/Brackish Marsh		\$207	\$77	\$19	\$8	\$4
10b: Freshwater Marsh		\$207	\$77	\$19	\$8	\$4
10c: Swamp		\$207	\$77	\$19	\$8	\$4
10d: Mangrove		\$207	\$77	\$19	\$8	\$4

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 14: Heavy Crude Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$318	\$118	\$30	\$13	\$6
2: Rocky Platform		\$318	\$118	\$30	\$13	\$6
3: Fine Sand		\$318	\$118	\$30	\$13	\$6
4: Coarse Sand		\$318	\$118	\$30	\$13	\$6
5: Mixed Sand/Gravel		\$386	\$143	\$36	\$15	\$8
6a: Gravel Beach		\$386	\$143	\$36	\$15	\$8
6b: Riprap Structures		\$386	\$143	\$36	\$15	\$8
7: Exposed Tidal Flat		\$518	\$192	\$48	\$21	\$10
8a: Sheltered Rocky Shore		\$318	\$118	\$30	\$13	\$6
8b: Sheltered Solid		\$250	\$93	\$23	\$10	\$5
9: Sheltered Tidal Flat		\$518	\$192	\$48	\$21	\$10
10a: Salt/Brackish Marsh		\$518	\$192	\$48	\$21	\$10
10b: Freshwater Marsh		\$518	\$192	\$48	\$21	\$10
10c: Swamp		\$518	\$192	\$48	\$21	\$10
10d: Mangrove		\$518	\$192	\$48	\$21	\$10

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 15: No. 6 Fuel Oil Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$509	\$188	\$47	\$20	\$10
2: Rocky Platform		\$509	\$188	\$47	\$20	\$10
3: Fine Sand		\$509	\$188	\$47	\$20	\$10
4: Coarse Sand		\$509	\$188	\$47	\$20	\$10
5: Mixed Sand/Gravel		\$618	\$229	\$57	\$25	\$12
6a: Gravel Beach		\$618	\$229	\$57	\$25	\$12
6b: Riprap Structures		\$618	\$229	\$57	\$25	\$12
7: Exposed Tidal Flat		\$829	\$307	\$77	\$33	\$17
8a: Sheltered Rocky Shore		\$509	\$188	\$47	\$20	\$10
8b: Sheltered Solid		\$400	\$148	\$37	\$16	\$8
9: Sheltered Tidal Flat		\$829	\$307	\$77	\$33	\$17
10a: Salt/Brackish Marsh		\$829	\$307	\$77	\$33	\$17
10b: Freshwater Marsh		\$829	\$307	\$77	\$33	\$17
10c: Swamp		\$829	\$307	\$77	\$33	\$17
10d: Mangrove		\$829	\$307	\$77	\$33	\$17

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Table 16: Intermediate Fuel Oil (IFO) Shoreline Oiling Cost Factors						
Shoreline Type (ESI)	Coverage*	\$/m²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$350	\$129	\$33	\$14	\$7
2: Rocky Platform		\$350	\$129	\$33	\$14	\$7
3: Fine Sand		\$350	\$129	\$33	\$14	\$7
4: Coarse Sand		\$350	\$129	\$33	\$14	\$7
5: Mixed Sand/Gravel		\$425	\$157	\$39	\$17	\$8
6a: Gravel Beach		\$425	\$157	\$39	\$17	\$8
6b: Riprap Structures		\$425	\$157	\$39	\$17	\$8
7: Exposed Tidal Flat		\$570	\$211	\$53	\$23	\$11
8a: Sheltered Rocky Shore		\$350	\$129	\$33	\$14	\$7
8b: Sheltered Solid		\$275	\$102	\$26	\$11	\$6
9: Sheltered Tidal Flat		\$570	\$211	\$53	\$23	\$11
10a: Salt/Brackish Marsh		\$570	\$211	\$53	\$23	\$11
10b: Freshwater Marsh		\$570	\$211	\$53	\$23	\$11
10c: Swamp		\$570	\$211	\$53	\$23	\$11
10d: Mangrove		\$570	\$211	\$53	\$23	\$11

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

Shoreline Type (ESI)	Coverage*	\$/m ²				
		Pooled	Cover	Coat	Stain	Film
1a: Exposed Rocky		\$143	\$53	\$13	\$6	\$3
2: Rocky Platform		\$143	\$53	\$13	\$6	\$3
3: Fine Sand		\$143	\$53	\$13	\$6	\$3
4: Coarse Sand		\$143	\$53	\$13	\$6	\$3
5: Mixed Sand/Gravel		\$174	\$64	\$16	\$7	\$3
6a: Gravel Beach		\$174	\$64	\$16	\$7	\$3
6b: Riprap Structures		\$174	\$64	\$16	\$7	\$3
7: Exposed Tidal Flat		\$233	\$86	\$22	\$9	\$5
8a: Sheltered Rocky Shore		\$143	\$53	\$13	\$6	\$3
8b: Sheltered Solid		\$113	\$42	\$10	\$5	\$2
9: Sheltered Tidal Flat		\$233	\$86	\$22	\$9	\$5
10a: Salt/Brackish Marsh		\$233	\$86	\$22	\$9	\$5
10b: Freshwater Marsh		\$233	\$86	\$22	\$9	\$5
10c: Swamp		\$233	\$86	\$22	\$9	\$5
10d: Mangrove		\$233	\$86	\$22	\$9	\$5

*Oil coverage for each shoreline: C = continuous, B = broken, P = patchy, and S = sporadic

6.10 Shoreline Response Effectiveness

Shoreline response effectiveness is related to shoreline type, shoreline response method, and “How Clean Is Clean” (HCIC) criteria. Shoreline response effectiveness is based on case studies in ERC Oil Spill Databases, Etkin (2003f), and recommendations in NOAA (1993, 1994, 1998). The algorithm is as follows:

- Multiply Shoreline Response Effectiveness [from Table 3] by HCIC Factor
- If Shoreline Response = Natural Recovery, HCIC must be set at 1.0
- If HCIC = Maximum, multiply Shoreline Response Effectiveness by 1.23
- If HCIC = High, multiply Shoreline Response Effectiveness by 1.1
- If HCIC = Medium, multiply Shoreline Response Effectiveness by 1.0
- If HCIC = Low, multiply Shoreline Response Effectiveness by 0.5
- If HCIC = Minimum, multiply Shoreline Response Effectiveness by 0.1
- Shoreline Response Effectiveness X HCIC Factor = Actual Shoreline Response Effectiveness
- Shoreline Socioeconomic- and Natural Resource Damages are multiplied by 100% – [Response Effectiveness %] to get actual Shoreline Socioeconomic and Natural Resource Damages.

6.11 Shoreline Response Impact

The Shoreline Response Impact (impact of response itself on shoreline) calculation is based on the factors in Table 4 for each shoreline type, where H equals “high impact”, M equals “moderate impact”, and L equals “low impact”, as modified by the HCIC factor. The impacts are based on shoreline response costs as per the appropriate table by oil type and shoreline conditions (Tables 9 – 17).

- For impact H, impact = 0.3 X Shoreline Response Cost. If impact is M, then impact cost = 0.1 X Shoreline Response Cost. If impact = L, there is no shoreline response impact cost. The shoreline response damage cost is multiplied by a factor to take into account the HCIC criteria, since a more vigorous response can cause damage in some circumstances.
- Multiply Shoreline Response Damage by HCIC factor. If HCIC = maximum, multiply by 3.0; if HCIC = high, multiply by 1.5; if HCIC = medium, multiply by 1.0; if HCIC

- = low, multiply by 0.5; if HCIC = minimum, multiply by 0.1.
- Shoreline Response Damage X HCIC Factor = Shoreline Response Impact

6.12 Shoreline Socioeconomic Resource Damages

Shoreline socioeconomic resource damages depend on oil type and the actual amount of oil that hits the shoreline, as well as the socioeconomic resources present (as selected by the user). The algorithm follows:

- If Oil Type = Gasoline or Jet Fuel, Then Per-Gallon Shoreline Socioeconomic Damages = $1,625.6C^{-0.2166}$ and Total Shoreline Socioeconomic Damages = $S \times C \times (1,626 C^{-0.2166})$
- If Oil Type = Diesel or Lt Crude, then Per-Gallon Shoreline Socioeconomic Damages = $2,076C^{-0.2226}$ and Total Shoreline Socioeconomic Damages = $S \times C \times (2,076C^{-0.2226})$
- If Oil Type = Medium Crude, Lube Oil, or IFO, then Per-Gallon Shoreline Socioeconomic Damages = $4,407C^{-0.2283}$ and Total Shoreline Socioeconomic Damages = $S \times C \times (4,407C^{-0.2283})$
- If Oil Type = Hvy Crude or No. 6 Fuel, then Per-Gallon Shoreline Socioeconomic Damages = $1,371C^{-0.2236}$ and Total Shoreline Socioeconomic Damages = $S \times C \times (1370.8C^{-0.2236})$
- Where C = Actual Amount That Hits Shoreline (In Gallons)
- S = Shoreline Socioeconomic Modifier (From Table 18)

The factors are additive. Shoreline Socioeconomic Resource Damages are multiplied by 100% – [Response Effectiveness %] to get actual Shoreline Socioeconomic Resource Damages. Socioeconomic costs are based on case studies in ERC Oil Spill Databases and modeling in Etkin (2003*a,b,d,e*) Etkin (2004*a,d,e*), Etkin and Tebeau (2003), Etkin, *et al.* (2003), Etkin, *et al.* (2005), Etkin, *et al.* (2003), and Gray *et al.*, (2004).

Shoreline Socioeconomic Resource	Modifier
Tourist Beach	1.4
Wildlife Viewing	2.4
Industrial	0.1
Port	0.4
Residential	1.0
High Value	2.9
Medium Value	1.0
Low Value	0.4

6.13 Shoreline Natural Resource Damages

Shoreline natural resource resource damages depend on oil type and the actual amount of oil that hits the shoreline, as well as the natural resource resources present (as selected by the user). The algorithm follows:

- If Oil Type = Gasoline or Jet Fuel, then Per-Gallon Shoreline Natural Resource Damages = $186.69c^{-0.1961}$ and Total Shoreline Natural Resource Damages = $S \times C \times (186.69c^{-0.1961})$
- If Oil Type = Diesel or Lt Crude, then Per-Gallon Shoreline Natural Resource Damages = $274.15c^{-0.1634}$ and Total Shoreline Natural Resource Damages = $S \times C \times (274.15c^{-0.1634})$
- If Oil Type = Medium Crude, Lube Oil, or IFO, then Per-Gallon Shoreline Natural Resource Damages = $279.3c^{-0.1525}$ and Total Shoreline Natural Resource Damages = $S \times C \times (279.3c^{-0.1525})$,
- If Oil Type = Hvy Crude or No. 6 Fuel, then Per-Gallon Shoreline Natural Resource

$$\text{Damages} = 256.28c^{-0.1366} \text{ and Total Shoreline Natural Resource Damages} = S \times C \times (256.28c^{-0.1366}),$$

- Where C = Actual Amount That Hits Shoreline (In Gallons)
- S = Shoreline Natural Resource Modifier (From Table 19)

Factors are additive. Shoreline Natural Resource Damages are multiplied by 100% – [Response Effectiveness %] for actual Shoreline Natural Resource Damages

Shoreline Natural Resource	Modifier
Birds	4.0
Mammals	2.7
Endangered Species	5.0
Highly Sensitive	4.0
Moderate Sensitive	2.0
Low Sensitive	0.3

Natural resource damages are based on case studies in ERC Oil Spill Databases and modeling in Research Planning, Inc., *et al.* (2002b), Etkin (2003a,d), Etkin and Tebeau (2003), French-McCay, *et al.* (2003), French-McCay, *et al.* (2004a,b,c) and French-McCay, *et al.* (2005).

6.14 Oil Damages With No Response

On-Water Oil Damages With No Response are the damages that would occur from the oil itself with no intervention in the form of a spill response. This is calculated in order to have a “baseline” to which to compare the response-affected oil damages. On-Water Oil Damages Costs are related to the original spill amount. The reasoning behind this is that the resources, such as seabirds, are exposed to the oil (or in the case of socioeconomic resources such as fisheries, exposed or even only *perceived* to be exposed to the oil) even while the response is occurring. Apply this amount to the Per-Gallon Socioeconomic Costs and Natural Resource Damage Costs. Shoreline Oil Damage Costs are related to the amount of oil that actually hits the shoreline (*i.e.*, Percent Oil Remaining X Spill Amount = Actual Oil Hitting Shoreline). For shoreline resource impacts, the amount of oil has already been reduced through evaporation and dispersion.

Percent Oil Remaining is set at the minimum Percent Oil Remaining based on oil type. (The oil gets the maximum opportunity to evaporate until it can no longer evaporate.)

- If Oil Type = Medium Crude, minimum % remaining = 32% [Default]
- If Oil Type = Gasoline, minimum % remaining = 13%; if Oil Type = Jet Fuel, minimum % remaining = 32%; if Oil Type = Diesel, minimum % remaining = 12%; if Oil Type = Lt Crude, minimum % remaining = 39%; if Oil Type = Heavy Crude, minimum % remaining = 63%; if Oil Type = No. 6 Fuel, minimum % remaining = 10%; if Oil Type = IFO, minimum % remaining = 79%; if Oil Type = Lube Oil, minimum % remaining = 12%.
- Multiply % Remaining by Spill Amount = Actual Gallons Remaining
- Apply these amounts to the Per-Gallon Socioeconomic Costs and Natural Resource Damage Costs On Shoreline.

Conclusions

OSRCEAT allows the user to compare the cost of response to the benefit of response. The algorithms on which the model is based are drawn from both oil spill empirical data derived from case studies and modeled hypothetical spills (see Figure 2). The continuing 2005 Arctic & Marine Oilspill Program Technical Seminar

trend towards reduced oil spillage in the US over the last two decades, especially with respect to larger spills, has necessitated the use of estimates and modeling of oil spill impacts to a large extent. OSRCEAT is designed to allow for future updates and changes based on new or better data on oil spill costs and impacts.

The values and formulae used to estimate costs, impacts, effectiveness, and benefits in OSRCEAT are based on best currently available data from actual oil spill case histories, field studies, tank and laboratory tests, observations of oil spill responders and researchers, as well as modeling of hypothetical oil spills. As such, there are many approximations, estimations, and “averaging” of costs and impacts inherent in the analytical tool’s algorithms. In reality, each spill is a unique event with a particular set of complex circumstances that may not be accurately represented by OSRCEAT or any other modeling tool.

The cost-benefit results obtained in the use of OSRCEAT depend both on user input and the application of the algorithms in the model. The potential fallibility of both of these factors, and the uniqueness of each particular spill event, mean that there are inevitable inaccuracies inherent in the use of OSRCEAT. As such, the tool is meant to assist in the oil spill response and contingency planning decision-making process and to act as a basis of discussion in the evaluation and analysis of response options. OSRCEAT should always be applied using the best available information for a particular spill and under the guidance of experienced response officials. Many spill situations will have particularly sensitive resource to protect or special considerations of limitations for response options. Neither ERC nor the sponsors of this project take responsibility for any errors or damages that may result in application of OSRCEAT, its results, or algorithms.

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**Assessing Progress and Benefits of Oil Spill Response
Technology Development Since Exxon Valdez**

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ABSTRACT

This paper describes a simple approach to quantifying progress and benefits associated with improvements in oil spill removal technology over the past decade, focusing on the most significant oil removal technologies: mechanical recovery, dispersant application and *in-situ* burning. All three technologies have been the focus of research and development (R&D) efforts since the Exxon Valdez spill. Notable progress has been made in refining the technologies and defining circumstances under which each option will be successful. These accomplishments have been *qualitatively* described in recent strategic technology assessments. The difficulty that arises in *quantitatively* predicting future benefits of these advances, is that expected increases in oil removal and associated cost savings are as much a function of specific circumstances of future spills as of advances in spill removal technologies. The specifics of future spills, particularly the larger more troublesome ones, are difficult to predict. In order to obtain representative quantitative estimates of these benefits, a hind-cast technique is demonstrated whereby the advanced technologies are applied to past spill scenarios to determine oil recovery and cost savings that would be realized if these spills were to occur in the future.

INTRODUCTION

The Exxon Valdez spill, like several major spills before it, underscored the limited capability to remove spilled oil from the marine environment and sparked a concerted US effort to upgrade oil spill countermeasures and cleanup technology. Over the past decade, advances have been made in mechanical recovery (*e.g.*, recovery in fast water, sinking oil), *in-situ* burning, and dispersants, as described qualitatively in the US Coast Guard (USCG) *Oil Spill Response Capability Review (CAPS)* (1999), the USCG *Oil Spill Prevention, Preparedness and Response (OSPPR) Risk Assessment* (2001), and in past International Oil Spill Conferences. What has *not* been accomplished to date is a *quantitative* assessment of impacts of technology advancements.

The objective of the analysis is to provide an order of magnitude *quantitative* estimate of the level of progress and economic benefits associated with oil spill technology advances by examining impacts these technologies would have had in spills that have occurred since Exxon Valdez. The analysis focuses on selected major and more significant medium spills where these response technologies were or *could have* been employed. Quantitative benefits (costs saved) are estimated based on hypothetical decreased damages associated with more effective oil removal. These include cost savings associated with shoreline cleanup, environmental damage, and socioeconomic impacts that would be prevented or reduced by more effective oil removal.

There is general consensus in the spill response community that significant progress has been made since Exxon Valdez in upgrading oil removal technology and improving resource availability to successfully implement these technologies in the event of a spill. In May 1999, the USCG Office of Marine Safety and Environmental Protection completed a study to determine the adequacy of spill cleanup technology and resource availability to support raising expected oil spill response capabilities on the part of vessel and facility owners. The results of the *Response Plan Equipment CAPS Review* (referred to henceforth as the *CAPS Study*) indicated that, based on technology developments and resource availability, a 25% increase in mechanical recovery response capability was warranted. The study further recommended that contingency plan holders carrying or handling Group II, III, and V products within 50

nautical miles of shore and in areas where dispersants have been pre-approved, should be required to have resources to treat 24,000 bbl of spilled oil within 60 hours of authorization. The study also concluded that technology advances and resource availability for *in-situ* burning warranted that plan holders carrying or handling Group II, III, and V products within 50 nautical miles of shore and in areas where *in-situ* burning has been pre-approved or cleared for expedited approval, should be encouraged to maintain resources to treat 10,000 bbl of spilled oil. This reflects a significant improvement in technology and availability since Exxon Valdez.

Advances in spill response technology for mechanical recovery, dispersants and *in-situ* burning were addressed in the June 2001 *USCG OSPPR Risk Assessment*. This study and other concluded that technology advances, as shown in field testing, testing at the OHMSETT facility and other laboratories as well as implementation in actual spill responses, had improved the “functional effectiveness” of these oil removal techniques, *i.e.*, percentage of spilled oil that can be removed when the technique *can be* applied. For mechanical recovery, a functional effectiveness of 10 – 30% can often be realized, with levels of 50% and greater being reached on occasion (*e.g.*, 78% in Julie N spill). Mechanical recovery is widely applicable to various scenarios. Dispersants can be highly effective under the right circumstances and improvements in formulations have improved the application “window of opportunity.” However, in the US, the applicability remains limited due to current restrictive application approval criteria. *In-situ* burning technology has been significantly improved with developments in fire-resistant boom, increased equipment availability, and growing acceptance of the technique. However, like dispersant application, its applicability is limited by approval criteria. Implementation of expanded approval criteria (as in CAPS study) to allow more field testing of alternative response technology in spills of opportunity will likely lead to demonstration of higher effectiveness levels in a broader array of spill situations and locations.

Granting that improvements in all three removal techniques have been made, the question arises as to how much additional oil might be recovered and how many dollars might be saved in coming years because of these improvements. This is not simply an academic issue, as the continuation of R&D efforts for these technologies may well rest on providing *quantitative* estimates of these benefits to fiscal authorities. Since the passage of OPA 90 and the initial resurgence in oil spill technology R&D, funding has declined steadily. Obtaining additional funding in this area will depend on demonstrating *tangible* benefits in terms of cost savings.

An obvious question is “How many dollars will be saved in the coming years from technology advances accomplished during the past decade?” The main difficulty in answering this question is that cost savings depend both on technology effectiveness and the circumstances of future spills encountered that are yet unknown. The specific circumstances of a spill are important in that they determine whether a cleanup technique can be applied and the achievable level of effectiveness (% oil removal). Key parameters governing cleanup technique applicability and effectiveness are oil type, spill location (including distance from shore and water depth), and weather conditions. Statistical extrapolations of spilled oil recovery and cost savings are difficult because of this sensitivity to specific spill circumstances and the fact that dispersants and *in-situ* burning have rarely been used. Predictions based on current contingency planning scenarios are difficult as the probability of scenario occurrence is unknown. However, the adage “history repeats itself” suggests using a hind-cast approach whereby past spill scenarios are used to predict potential cost savings and provide insight into benefits that may be realized in the future.

METHODOLOGY

The first step was to identify a manageable set of spills for analysis. Because estimating the functional effectiveness and applicability of cleanup techniques depends on specific spill factors, the case histories must be reasonably well-documented for the spills analyzed. This analysis builds on previous efforts by focusing on two spill sets described in detail in the USCG CAPS and OSPPR studies. The first spill set is extracted from a larger set examined in the CAPS study, which was in turn taken from an analysis of applicability of mechanical recovery, dispersants, and *in-situ* burning for spills in 1993 - 1998 by Kucklick and Aurand (1997). Kucklick and Aurand established applicability of the three countermeasures for each spill based on oil type, wind conditions, and distance from shore, as well as

applying both *existing* and *expanded* criteria for dispersant and *in-situ* burning authorization. The results are summarized in Appendix A-1 of the CAPS study. For the current analysis, only spills greater than 10,000 gallons were considered, as it is unlikely that dispersants and *in-situ* burning would be attempted for spills smaller than this. Table 1 lists the CAPS spills considered and cleanup technique applicability. The second spill set included the more significant US spills since Exxon Valdez addressed in the OSPPR study (Appendix C-2). Table 2 lists the OSPPR spills and applicability of each technique based on general criteria in Kucklick and Aurand (1997). In determining applicability, the general spill circumstances were taken into account (volume, oil type, location) but not exact details. e.g., in the spills considered, dispersants were never actually used because of factors encountered and response decisions. However, if circumstances dictated that dispersants *could be* used in a similar future spill, the technique was deemed applicable.

The overall strategy was to determine cost savings associated with applying the three oil removal technologies at their *previous* – pre-Oil Pollution Act of 1990 (OPA 90) – and *current* (post-OPA 90) levels of effectiveness to the spill sets. The difference in costs represents a quantitative measure of progress in developing each technology. This required selecting general effectiveness levels and specifying a cost savings calculation model. In doing so there were a number of assumptions and speculation that will certainly impact the magnitude of cost savings. It must be noted that the purpose of this exercise is *not to precisely* determine expected cost savings but to provide some quantitative insight into *levels of progress*.

The next step was to set response effectiveness levels. Mechanical recovery effectiveness levels (% removal) assumed for the CAPS spills were those specified in the CAPS study: 20% for pre-OPA 90 and 50% for post-OPA 90. For *in-situ* burning, a conservative level of 50% was applied. For dispersants, conservative effectiveness levels were specified corresponding to the lower effectiveness CAPS study levels with % removal based on oil type: light oils and crude – 40%, and heavy fuels – 35% (see also Pond *et al.* 2000). The conservative effectiveness values were chosen in an effort to provide realistic estimates of projected oil removal taking into consideration oil encounter and treatment rates (allowing for evaporation and natural dispersion before response could realistically begin) and the often limited “window of opportunity” for employing dispersants and *in-situ* burning. Effectiveness levels applied to the OSPPR spills were 10%, 20%, and 50% for mechanical recovery. To reflect pre-OPA 90 effectiveness, values of 10% or 20% were assigned to spills where mechanical recovery was applicable; for post-OPA 90 effectiveness, values of 20% or 50% were assigned. For dispersant and *in-situ* burning, the same effectiveness levels used in the CAPS spill analysis were used for post-OPA 90 effectiveness; for pre-OPA 90 it was assumed that neither option would be employed and a lower effective mechanical recovery was assumed. To determine post-OPA 90 costs for spills for which *in-situ* burning and/or dispersants were not applicable, low-effective mechanical recovery was assumed. For spills deemed untreatable by any option, it was assumed that mechanical recovery was attempted (*i.e.*, accruing costs) with no actual effectiveness and no impact reduction. Including mechanical recovery costs in the post-OPA 90 dispersant and *in-situ* burning computations was important, as it meant that cost savings calculated reflected total net cost savings for the whole spill set with each particular technology. In some cases, there would have been no cost advantage to having alternative technologies available, as they were not applicable to the spill situations.

The next step was determining net cost savings associated with the technologies at pre- and post-OPA 90 levels. Net cost savings were calculated as the difference between pre-OPA 90 costs (response costs plus environmental and socioeconomic damages) and post-OPA 90 costs for each spill, following an approach similar to that described by Gautier *et al.* (2001). Response benefits include cost savings associated with reduced shoreline cleanup, socio-economic, and environmental damage costs with the increase in on-water oil removal.

Assigning per-gallon response, environmental, and socio-economic costs to a spill to perform this analysis such was a difficult task at best. Using generalized values can be misleading as costs are sensitive to oil type, location, and specific operational and environmental circumstances in each spill (Etkin 1999, 2000). Using bulk values to estimate costs was not very precise from an analytical standpoint, but attempting to estimate response and damage costs for each spill examined would be an enormous

undertaking. At the same time, using *actual* reported spill costs and extrapolating based on oil removal levels was prohibited by incomplete actual cost data, and the often aberrantly high or low costs values due to specific spill circumstances.

A *consistent but simple* method for calculating “representative costs” if the general spill scenario was encountered in the future was desired. The model adopted for this study is an adaptation of the approach developed for estimating response, environmental, and socio-economic costs for hypothetical spills in San Francisco Bay (Etkin *et al.* 2002, 2003; French-McCay *et al.* 2002). The results of this study were used to derive formulae for per-gallon response costs by method for three oil types – heavy fuel oil (HFO), crude, and diesel (No. 2 fuel), with adjustments for response effectiveness and spill size. This takes into account decreased per-gallon costs for larger spills, with initial mobilization costs are averaged over a larger volume, as well as lower costs for more efficient removal that prevents shoreline impact and expensive shoreline cleanup. Table 3 reflects *total response costs*, including on-water operations, spill management/monitoring, and necessary shoreline cleanup.

A similar matrix (Table 4) was developed based on the San Francisco Bay work to assign costs for natural resource damages and socio-economic costs specified by oil type and adjusted for spill size. The current analysis required an assumption that natural resource and socio-economic damages in the study spills would be *analogous to the magnitude of damages* that occurred in San Francisco Bay. While it is recognized that actual spill location has a tremendous impact on environmental and socio-economic damages, applying the study spills to this one well-documented and already modeled location, in essence, “normalizes” the differences in actual locations between the spills in projecting to future potential spills. Here again, the objective of this analysis was to provide representative quantitative measures of progress and not precise cost savings for each spill. Detailed modeling of environmental and socio-economic damages for the actual spills was prohibitively expensive and *reported* cost data on these spills is incomplete.

For each past spill analyzed, the response costs and damage costs were then calculated using Tables 3 and 4, based on the effectiveness level. Environmental and socio-economic damages were reduced based on % on-water oil removal. With increased on-water oil dispersion or removal reducing shoreline oiling and impacts on natural resources (as modeled in Etkin *et al.* 2002, 2003, taking into account natural oil weathering, dispersion, and evaporation), the costs would be reduced. Socioeconomic impacts are multi-faceted including everything from tourism income to port blockage due to response activities, different parts of which would be impacted to different degrees with improvements in on-water oil removal/dispersion. These issues are included in Etkin *et al.* 2002, 2003 and applied as best possible in the cost reductions included in the current study. Total costs for each spill were calculated at pre- and post-OPA 90 levels of effectiveness for mechanical recovery, *in-situ* burning, and dispersants. Net cost savings were calculated by subtracting post-OPA 90 costs from pre-OPA 90 costs. The difference represents cost savings associated with more efficient oil removal and reduced costs associated with decreased socio-economic and environmental impact.

RESULTS

The cost saving analysis of the CAPS spills (Table 5) shows that for the 35 spills investigated, cleanup operations were possible in 19 spills involving a total of 485,529 gallons of oil. Mechanical recovery was applicable in 15 cases, dispersants were applicable in eight, and *in-situ* burning was applicable in six. The total net cost savings associated with development and application of augmented mechanical recovery (effectiveness increase from 20% to 50%) is \$95.7 million. The total net cost savings associated with dispersant development and application is \$38.1 million. *In-situ* burning development and application accounted for a \$46.5 million net cost savings, despite the fact that the technique had a more limited applicability.

The cost savings results for the OSPPR spills are in Tables 6 – 8 for mechanical recovery, dispersants and *in-situ* burning. For the 28 medium and major spills investigated, cleanup operations were possible in 22 spills involving 15,009,500 gallons of oil. Mechanical recovery was applicable in 22 cases, dispersants were applicable in three, and *in-situ* burning was applicable in five. Total net cost savings associated with development and application of augmented mechanical recovery (effectiveness increase

from 10-20% to 20-50%) was \$633.9 million. Dispersant development and application accounted for \$323.1 million and *in-situ* burning development and application accounted for \$755.5 million net cost savings.

CONCLUSIONS

Analysis results are summarized in Table 9. For medium spill scenarios represented by the CAPS spill set, the highest net cost savings is accrued from advanced mechanical recovery technology (\$95.7 million), assuming a 50% effectiveness level. Net cost savings from dispersants and *in-situ* burning are roughly equivalent at \$38.1 million and \$46.5 million, respectively. Even though the oil volume represented by these spills is small (485,000 gallons), it appears that a substantial net cost savings would be realized if a similar future spill set could be responded to at the proposed effectiveness levels. For the OSPPR spills (representing 15 million gallons of spilled oil), the results are similar with the net cost savings accrued from advanced mechanical recovery technology of \$634 million, assuming a 20-50% effectiveness level. Net cost savings from dispersants and *in-situ* burning are \$325 million and \$755 million, respectively. Mechanical recovery net cost savings are proportionally lower than for the CAPS set, as the effectiveness level varies from 20% to 50%, while it was kept constant at 50% for the CAPS spills. A substantial savings is noted for *in-situ* burning, as there were several high volume spills in the OSPPR spill set where the technique was deemed applicable. The low on-water response cost for this oil-removal technology contributes to the high net cost savings.

Viewed together, the results suggest that the potential net cost savings that could be realized by R&D for these removal technologies over the past decade is substantial. From the OSPPR spill set analysis, it appears that net cost savings may be on the order of *hundreds of millions of dollars* assuming that similar spills were to occur in the next decade. This represents a *substantial* return on investment given that the expenditures on US oil spill R&D have probably not exceeded \$100 million over the past decade. It also suggests that further significant gains can be made by modest expenditures in oil spill response technology development.

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BIOGRAPHY

Dagmar Schmidt Etkin received her B.A. in Biology from University of Rochester, and her A.M. and Ph.D. in Biology (specializing in population biology, ecology, and statistical analysis) from Harvard University. She has analyzed and modeled oil spill data and impacts for 15 years.

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FIGURES

Table 1: Spills from the CAPS Study Analyzed for Cost Savings Using Mechanical Recovery, Dispersants and <i>In-Situ</i> Burning							
Vessel Name	Qty. Spilled (Gals.)	Oil Type	Applicability of Oil Removal Methods for Existing and Expanded Criteria ¹				
			Mech. Recov.	Disp. Exist.	Disp. Exp.	ISB Exist.	ISB Exp.
New Janet Ann	11,000	Diesel	N	N	Y	N	N
Sea-Land Hawaii	25,200	Waste/Lube	Y	Y	Y	Y	Y
Frances Lee	16,000	Diesel	Y	N	N	N	N
Barge 155/Capt. Bouchard	330,000	No. 6 Fuel	N	N	N	N	N
Jin Shing Fa	96,000	Lube	Y	N	N	N	N
Morris J. Berman	750,000	No. 6 Fuel	N	N	N	N	N
IB 20131	40,150	Asphalt	N	N	N	N	N
Chevak	12,000	Diesel	N	N	N	N	N
Bow Sun	35,700	No. 6 Fuel	N	N	N	N	N
Umqua Fisher	20,000	Diesel	Y	N	N	N	N
RTC 20	15,000	Waste/Lube	Y	N	Y	N	Y
Island Enterprise	12,705	Diesel	N	Y	Y	N	N
USS Inchon	19,000	Diesel	N	N	N	N	N
Barge 101/Mercury	26,000	Diesel	Y	N	N	N	N
Skaubay/Berge Banker	37,716	No. 6 Fuel	N	N	N	N	N
Mormac Star	15,918	No. 2 Fuel	Y	N	N	N	N
American Express	12,500	Diesel	N	N	Y	N	N
Leslie	13,062	Naptha	N	N	N	N	N
Interstate 138	92,610	No. 6 Fuel	N	N	N	N	N
Northern Wind	20,000	Diesel	Y	N	N	N	N
M.B. McAllister	25,000	Diesel	Y	Y	Y	Y	Y
Defiant	30,000	Diesel	Y	N	N	N	N
North Cape	828,000	No. 2 Fuel	N	N	N	N	N
Buffalo 292	176,400	No. 6 Fuel	N	N	N	N	N
Anitra	40,000	Crude Oil	Y	N	N	N	Y
Buffalo 286	25,998	No. 6 Fuel	N	N	N	N	N
Unknown Vessel	12,000	Crude Oil	Y	N	N	N	N
Rosie G	16,000	Diesel	N	Y	Y	N	N
BFT No. 39	27,636	Gasoline	N	N	N	N	N
Barge No. 125	26,460	Gasoline	N	N	N	N	N
Kure	40,000	Diesel	Y	N	N	N	N
Barge No. 125	39,000	No. 6 Fuel	N	N	N	N	N
Stone Fuller	31,206	Crude Oil	Y	N	Y	N	Y
Red Seagull	21,000	Med. Crude	Y	N	N	Y	Y
Rosellen	14,300	Vegetable	N	N	N	N	N

¹Y and N (yes or no) indicate whether oil removal method potentially applicable under conditions described for spill and application criteria specified. For dispersants and *in-situ* burning, two application criteria considered: *Existing Criteria* (≥ 3 nautical miles from shore) and *Expanded Criteria* ($\geq 1/4$ mile from shore).

Table 2: Spills from the OSPPR Study Analyzed for Cost Savings Using Mechanical Recovery, Dispersants and <i>In-Situ</i> Burning						
<i>Source</i>	Location	Volume (gal)	Oil Type	Mech	Disp	ISB
Tankers						
World Prodigy	coast/harbor	294,000	No. 2 fuel	N	N	N
President Rivera	river/harbor	300,000	No. 6 fuel	Y	N	N
American Trader	coast/harbor	417,000	light crude	Y	Y	Y
Mega Borg	offshore/ocean	5,000,000	light crude	Y	Y	Y
Jupiter	river	840,000	Gasoline	N	N	N
Julie N	river/harbor	180,000	No.2/No.6 fuel	Y	N	N
Cape Mohican	bay/harbor	98,000	No. 6 fuel	Y	N	N
Command	offshore/ocean	51,500	No. 6 fuel	N	N	N
Barges						
Bouchard 155	coast/bay	333,000	No. 6 fuel	Y	N	N
Morris Berman	nearshore/coast	789,000	No. 6 fuel	Y	N	N
North Cape	nearshore/coast	828,000	No. 2 fuel	Y	N	N
Buffalo 292	nearshore/coast	189,000	IFO	Y	N	N
Buffalo 286	nearshore/coast	42,000	No. 6 fuel	Y	N	N
RTC 320	harbor	50,000	No. 6 fuel	Y	N	N
Offshore Platform						
Greenhill Well	offshore/ocean	687,000	crude	Y	N	N
Freighters and Fishing Vessels						
Sammi Superstars/ Maui	harbor	32,000	No. 6 fuel	Y	N	N
Tenyo Maru	offshore/ocean	173,000	IFO, No. 2 fuel	Y	N	N
Citrus	offshore/coast	9,000	No. 5 fuel	N	N	N
Kure	coast/harbor	4,500	IFO	Y	N	N
Kuroshima	offshore/coast	47,000	No. 2/No. 6 fuel	N	N	N
Star Evviva	offshore/ocean	24,000	No. 6 fuel	N	N	N
New Carissa	nearshore/coast	70,000	No.2/No.4 fuel	Y	N	Y
Onshore Facility						
Texaco Anacortes Refinery	harbor	210,000	crude	Y	N	N
Pipelines						
Exxon Bayway	harbor	567,000	No. 2 fuel	Y	N	N
Colonial, Potomac	river	407,000	No. 2 fuel	Y	N	N
4 Pipelines, San Jacinto R.	river	1,616,000	No.2 fuel, crude	Y	N	Y
Chevon, Oahu	coast/harbor	41,000	No. 6 fuel	Y	N	N
Texaco, Lake Barre	nearshore/coast	276,000	crude	Y	Y	Y
Y and N (yes or no) indicate whether oil removal method potentially applicable under conditions described for spill and application criteria specified.						

Oil Type	Volume (gallons)	Mechanical ^{2,4}				Dispersants ^{3,4}		In-Situ Burn ⁵	
		No Effect 0%	Lower Effect 10%	Low Effect 20%	High Effect 50%	Low Effect	High Effect	Low Effect 50%	High Effect 80%
Light Fuels	1,000 – 100,000	\$85	\$70	\$58	\$40	\$25	\$18	\$18	\$9
	100,000 – 1,000,000	\$72	\$60	\$48	\$25	\$17	\$10	\$10	\$5
	>1,000,000	\$30	\$25	\$17	\$12	\$11	\$6	\$7	\$3
Heavy Fuels	1,000 – 100,000	\$400	\$350	\$300	\$260	\$100	\$60	\$100	\$50
	100,000 – 1,000,000	\$175	\$150	\$125	\$100	\$58	\$53	\$70	\$40
	>1,000,000	\$85	\$75	\$65	\$35	\$52	\$48	\$55	\$25
Crude Oil	1,000 – 100,000	\$190	\$180	\$170	\$135	\$72	\$30	\$60	\$30
	100,000 – 1,000,000	\$120	\$115	\$110	\$90	\$48	\$28	\$35	\$16
	>1,000,000	\$90	\$80	\$74	\$62	\$57	\$13	\$21	\$11

¹Per-gallon response cost based on hypothetical modeling in Etkin *et al.* (2002, 2003) with shore-line oil removal costs adjusted by % reduction of shoreline oiling. Modeling included oil fate by oil type and trajectory with Applied Science Associates' SIMAP (French-McCay *et al.* 2002). ²Per-gallon costs include on-water mechanical recovery, shoreline oil removal, mobilization, and protective booming based on Area Contingency Plan. ³Per-gallon costs include on-water dispersant response, shoreline oil removal, mobilization, sensitive site protective booming. ⁴Removal assumed for on-water recovery or dispersants. Shoreline oiling assumed reduced by % on-water oil removal. Low/high removal by dispersants for diesel/crude 40%/80%, for HFO 35%/70% (Pond *et al.* 2000). ⁵ISB costs based on per-gallon ISB operations costs in Allen and Ferek (1993) updated to 2001 \$ plus costs of shoreline cleanup of oil not burned.

Oil Type	Volume (gallons)	Environmental \$/gallon	Socioeconomic \$/gallon
Gasoline	1,000 – 100,000	\$30	\$400
	100,000 – 1,000,000	\$30	\$180
	>1,000,000	\$10	\$90
Diesel	1,000 – 100,000	\$50	\$500
	100,000 – 1,000,000	\$50	\$200
	>1,000,000	\$20	\$100
Heavy Fuels	1,000 – 100,000	\$25	\$900
	100,000 – 1,000,000	\$20	\$500
	>1,000,000	\$10	\$200
Crude	1,000 – 100,000	\$40	\$300
	100,000 – 1,000,000	\$15	\$140
	>1,000,000	\$10	\$70

¹Based on hypothetical spills in Etkin *et al.* (2002, 2003) with oil fate modeling based with Applied Science Associates' SIMAP (French-McCay *et al.* 2002).

Oil Removal Technology Impact Examined	Pre – OPA 90 Spill Costs (million \$)			Post – OPA 90 Spill Costs (million \$)			Cost Savings (million \$)
	Resp	Enviro	Socio	Resp	Enviro	Socio	
Mechanical Recovery	\$74.3	\$24.6	\$226.4	\$60.5	\$17.0	\$145.7	\$102.1
Dispersant Application	\$74.3	\$24.6	\$226.4	\$59.0	\$22.1	\$206.1	\$38.1
<i>In-Situ</i> Burning	\$74.3	\$24.6	\$226.4	\$54.0	\$20.5	\$197.9	\$52.9

Source Type	No. Spills	Pre – OPA 90 Spill Costs (million \$) <i>Mechanical Recovery</i> 0-20% Effectiveness			Post – OPA 90 Spill Costs (million \$) <i>Mechanical Recovery</i> 20- 50% Effectiveness			Cost Savings (million \$)
		Resp	Enviro	Socio	Resp	Enviro	Socio	
		Tanker	8	\$670.4	\$110.5	\$1,106.8	\$608.6	
Barge	6	\$257.2	\$61.7	\$740.4	\$211.7	\$50.0	\$541.7	\$255.9
Offshore Platform	1	\$79.0	\$9.3	\$86.6	\$75.6	\$8.2	\$76.9	\$14.2
Freighter	7	\$95.1	\$7.2	\$232.1	\$85.4	\$6.0	\$213.0	\$30.0
Shore Facility	1	\$24.2	\$2.8	\$26.5	\$21.0	\$2.5	\$23.5	\$6.5
Pipeline	5	\$223.5	\$57.5	\$383.9	\$189.8	\$45.8	\$294.9	\$134.4
TOTAL	28	\$1,349.4	\$249.0	\$2,576.3	\$1,192.1	\$213.6	\$2,135.8	\$633.9

Source Type	No. Spills	Pre – OPA 90 Spill Costs (million \$) <i>Mechanical Recovery</i> 0-20% Effectiveness			Post – OPA 90 Spill Costs (million \$) <i>Dispersants Available</i> 35-40% Effectiveness			Cost Savings (million \$)
		Resp	Enviro	Socio	Resp	Enviro	Socio	
		Tanker	8	\$670.4	\$110.5	\$1,106.8	\$527.4	
Barge	6	\$257.2	\$61.7	\$740.4	\$257.2	\$61.7	\$740.4	\$0
Offshore Platform	1	\$79.0	\$9.3	\$86.6	\$79.0	\$9.3	\$86.6	\$0
Freighter	7	\$95.1	\$7.2	\$232.1	\$95.1	\$7.2	\$232.1	\$0
Shore Facility	1	\$24.2	\$2.8	\$26.5	\$24.2	\$2.8	\$26.5	\$0
Pipeline	5	\$223.5	\$57.5	\$383.9	\$189.0	\$53.1	\$273.5	\$47.2
TOTAL	28	\$1,349.4	\$249.0	\$2,576.3	\$1,139.9	\$226.7	\$2,280.8	\$323.1

Source Type	No. Spills	Pre – OPA 90 Spill Costs (million \$) <i>Mechanical Recovery</i> 0-20% Effectiveness			Post – OPA 90 Spill Costs (million \$) <i>In-Situ Burning Available</i> 50% Effectiveness			Cost Savings (million \$)
		Resp	Enviro	Socio	Resp	Enviro	Socio	
		Tanker	8	\$670.4	\$110.5	\$1,106.8	\$342.0	
Barge	6	\$257.2	\$61.7	\$740.4	\$257.2	\$61.7	\$740.4	0
Offshore Platform	1	\$79.0	\$9.3	\$86.6	\$79.0	\$9.3	\$86.6	0
Freighter	7	\$95.1	\$7.2	\$232.1	\$77.6	\$6.5	\$206.9	\$43.4
Shore Facility	1	\$24.2	\$2.8	\$26.5	\$24.2	\$2.8	\$26.5	0
Pipeline	5	\$223.5	\$57.5	\$383.9	\$99.3	\$51.3	\$310.0	\$204.3
TOTAL	28	\$1,349.4	\$249.0	\$2,576.3	\$879.3	\$220.2	\$2,319.7	\$755.5

Response Type	Spill Set	Cost Savings (million \$) Compared to Pre-OPA 90			
		Response Cost	Environmental Damages	Socioeconomic Damages	Total
Augmented Mechanical	OSPPR	\$157.3	\$35.4	\$440.5	\$633.9
	CAPS	\$13.8	\$7.6	\$80.7	\$102.1
Dispersant Application	OSPPR	\$177.5	\$20.6	\$227.1	\$323.1
	CAPS	\$15.3	\$2.5	\$20.3	\$38.1
<i>In-Situ</i> Burning	OSPPR	\$470.1	\$28.8	\$256.6	\$755.5
	CAPS	\$20.3	\$4.1	\$28.5	\$52.9