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Modeling of Response, Socioeconomic, and Natural Resource Damage Costs for Hypothetical Oil Spill Scenarios in San Francisco Bay

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Abstract

Oil spill response and socioeconomic costs, and natural resource damages were estimated for hypothetical vessel oil spill scenarios in San Francisco Bay for three spill sizes (20th, 50th, and 95th percentile) and four oil types (gasoline, diesel, heavy fuel oil, and crude oil). Oil spread onto the water surface and into the water column, and shoreline oiling were modeled using Applied Science Associates' stochastic modeling software, SIMAP. Response costs, natural resource damages, and socioeconomic impact were modeled and estimated based on spill trajectory and fate.

Response costs were higher for mechanical recovery-based operations than for dispersant-based operations, as well as for the more persistent oils (crude and heavy fuel oil). For diesel and gasoline spills, the response costs comprised approximately 20% of total costs, in contrast to approximately 43% for crude and heavy fuel oil spills. Natural resource damages were generally higher for the more toxic lighter fuels (gasoline and diesel). The lighter, more toxic fuels tend to have a greater water column impact with less shoreline oiling leading to greater natural resource damages, while the heavier oils tend to have a greater shoreline impact with resultant higher response costs and socioeconomic costs. Socioeconomic costs varied by impact locations, but tended to override both response costs and natural resource damage costs, comprising 61% and 76% for gasoline and diesel spills, respectively, and 45% and 53% for crude and heavy fuel oil spills. The proportions of the various costs are discussed with regard to various spill factors.

1 Introduction

The incorporation of damage and response costs into oil spill stochastic modeling provides valuable input for contingency planning and cost-benefit analyses, as well as increases knowledge about the full range of oil spill impacts. This study on hypothetical spills in San Francisco Bay serves both as a demonstration of this comprehensive modeling and as an assessment of the effect of oil type, spill size, and stochastic processes on the broad spectrum of spill impacts and costs.

Response costs have been previously shown to be influenced by oil type, spill size, response strategy, and location factors (Etkin, 1998a, 1998b, 1999, 2000, 2001a). This study serves as further verification of the influence of these factors on response costs, especially with regard to the cost benefits of the use of dispersants.

The assumption that natural resource damages constitute the majority portion of spill costs is disputed in support of the studies conducted by Helton and Penn (Helton, et al., 1997; Helton and Penn, 1999). The influence of oil type and location-specific factors on natural resource damages is demonstrated in this study.

Socioeconomic damages are examined over the full range of impacts, including tourism losses, fishing impacts, port closure impacts, and recreational losses, to be put into perspective with response costs and natural resource damages.

2 Spill Scenario Development

Scenarios were developed for each of four oil types with respect to the 20^{th} percentile, 50^{th} percentile, and 95^{th} percentile oil spills from groundings of crude and product tankers and freight vessels with drafts deeper than 11.2 meters in San Francisco Bay. The spill size for the "20^{th} percentile spill" was defined as the spill size that was larger than 20% of all spills, but smaller than 80% of all spills. Likewise, the "50^{th} percentile spill" was defined as the median spill, and the "95^{th} percentile spill" was defined as the spill size that was larger than 95% of all spills and smaller than only 5% of all spills.

Probabilistic modeling of likely scenarios based on local vessel traffic and spill sizes for groundings was conducted. The modeling involved an analysis of actual hard grounding incidents in the US and internationally to determine the percentage of total cargo or bunkers spilled per incident. The data were adjusted to remove spills irrelevant to circumstances in San Francisco Bay, i.e., spills due to catastrophic drift groundings and other situations with a complete loss of vessel control. This provided a distribution of the percentage of cargo or bunkers likely to be lost in hypothetical grounding incidents – e.g., 8% of tanker spills due to groundings involve the loss of 15% of onboard oil, whereas in 69% of grounding-related tanker spills only 1% of the oil spills. Since different-sized tankers and freighters carry different amounts of oil (as cargo or bunker fuel), a wide range of spill sizes could be expected due to original oil capacity and the percentage of capacity spilled.

A cumulative probability distribution function was developed to show the relative percentage of spill sizes expected to occur based on local vessel traffic and oil transport. This distribution showed the size of oil spill that was larger than 20% of spills expected, i.e., the 20^{th} percentile spill, as well as the 50^{th} percentile, and 95^{th} percentile spills for the three general vessel types – product tankers, crude tankers, and freighters.

The calculated volumes for each scenario were adjusted based on future tanker configurations that will reduce expected oil outflow in the event of grounding. The sizes of median and smaller tanker spills would not be expected to be reduced with double hulls (Rawson, et al., 1998). Oil outflow in the largest spills (95^{th} percentile) would be expected to be 50% that of incidents involving single-hulled vessels. The bunker spill volumes from freighter groundings were not adjusted as oil outflow is not likely to change significantly with changes in bunker tank configurations based on studies by Michel and Thomas (2000).

Oil type selection was based on oils most commonly carried by product tankers (gasoline and No. 2 diesel) and crude tankers (North Slope crude) in San Francisco Bay. Heavy fuel oil (HFO) was selected as the fuel most commonly carried by diesel-powered ships. Nearly all international-flagged freighters in US waters employ diesel propulsion. Although a significant number of US-flagged containerships are powered by steam, which typically burn heavier residuals such as Bunker C, most of these vessels are more than 25 years of age and will soon be replaced by diesel-powered vessels.

The final spill volumes for the bio-economic modeling of spill scenarios for hard groundings in San Francisco Bay are shown in Table 1.

Table 1 Oil Spill Scenarios for Vessel Groundings in San Francisco Bay

Oil Type	20^{th} Percentile	50^{th} Percentile	95^{th} Percentile
Gasoline[1] (Product Tanker)	50,000 gallons (152 tonnes)	270,000 gallons (821 tonnes)	1,250,000 gallons (3,800 tonnes)
No. 2 Diesel[1] (Product Tanker)	50,000 gallons (171 tonnes)	270,000 gallons (922 tonnes)	1,250,000 gallons (4,266 tonnes)
North Slope Crude[1] (Crude Tanker)	100,000 gallons (369 tonnes)	600,000 gallons (2,214 tonnes)	3 million gallons (10,239 tonnes)
Heavy Fuel Oil[1] (Freighter)	25,000 gallons (95 tonnes)	100,000 gallons (379 tonnes)	410,000 gallons (1,553 tonnes)

[1]US gallon to tonne (t) conversion based on: gal = (921.5t)/(3.785 · sp. gr.) Specific gravity (sp. gr.) for gasoline = 0.74; sp. gr. for diesel = 0.83; sp. gr. for crude = 0.90; sp. gr. for HFO = 0.92.

3 Spill Trajectory and Fate Modeling

The trajectory and fate of each of the spill scenarios in Table 1 were modeled with 100 stochastic runs for a site near Alcatraz Island in San Francisco Bay [37.8355N 122.4405W] using Applied Science Associates' SIMAP software, as described in detail in McCay, et al. (2002) [this volume]. Included in the SIMAP modeling were placement of protective booms at 31 locations indicated in the San Francisco Bay Area Contingency Plan (US Coast Guard, 1997). The modeling incorporated boom characteristics such as the ability to withstand different wave heights and current speeds. When the wave heights and/or current speeds exceeded boom specifications, oil could pass the booms and enter sensitive coastal locations or inlets. Oil could also pass under booms when the oil was in the water column.

The scenarios were first run in stochastic mode to determine the frequency distribution of fates and impacts. From these data, the 50^{th} and 95^{th} percentile runs (based on variation in environmental conditions) were identified and examined in detail to determine impacts and NRDA, socioeconomic, and response costs. For the lighter fuels, the 50^{th} and 95^{th} percentile runs were defined based on natural resource impacts. For the persistent oils, these runs were based on shoreline cost impact.

The time-sequenced surface oiling portion of the SIMAP output was used to determine equipment and labor requirements for on-water responses and potential port blockages during response operations and recreational boating and fishing impacts for use in socioeconomic cost modeling. Shoreline type-specific impacts from SIMAP (rocky, gravel, sand, mudflat, wetland, and artificial) were used to determine shoreline response costs and impacts to socioeconomically important sites in the bay.

4 Response Cost Estimation

Response costs for the median and worst (95^{th} percentile) runs for each of the twelve scenarios were estimated for mechanical-recovery based operations and for dispersant-based operations. Both types of estimates included resultant shoreline cleanup.

4.1 Mechanical Containment and Recovery-Based Operations

Inherent in the modeling of on-water containment and recovery operation costs are the following assumptions (based on Etkin 2001*a*; Michel and Cotsapas 1997):

1. The pay scales for workers are as shown in Table 2. These pay scales are based on a comprehensive survey of Basic Ordering Agreements (BOA) made with the US Coast Guard (USCG) Office of Maintenance and Logistics for the 11^{th} USCG District. The hourly pay figures have been updated to 2001 US$.
2. Wages are paid as: 67% straight wages, 20% premium wages, and 13% overtime wages. Cleanup crews work for 12-hour workdays.
3. Crews consist of: 1% project managers, 3% supervisors, 67% skilled laborers, and 29% unskilled laborers. Worker numbers and ratios of worker types were verifed by a review of Area Contingency Plans and oil company contingency plans. Adjustments to work requirements for each oil type and shoreline type were made by professional judgment based on case studies and oil behavior by oil type (evaporation and dispersion rate) as calculated by SIMAP.
4. The rental rates for equipment are as shown in Table 3. These rental rates are based on a comprehensive survey of 11^{th} USCG District BOAs. The daily rental figures have been updated to 2001 US$.
5. Equipment requirements were determined by reviews of Area Contingency Plans, Incident Action Plans from US previous spills, mandated response capability requirements in USCG Response Capability Standards (USCG, 1999), and analyses of spill case studies and SIMAP output for slick spread.
6. Actual oil recovery rate of *floatin*g oil is 15% (for determining disposal costs).
7. Dispersed or evaporated oil cannot be recovered by mechanical recovery.
8. Disposal rates for collected oil-water mixtures and oily waste/debris are US$0.65/gallon (US$0.17/liter) and US$200/cubic yard (US$153/m^3). These rates are based on a survey of BOAs updated to 2001 US$ (Etkin, 1998*b*).
9. There are no chemical applications implemented in the response.
10. The oil slick is assumed to cover surface waters shown by the SIMAP runs.
11. Emulsification increases oily liquid volume by four. Diesel fuel and gasoline do not emulsify.
12. Costs for shore-based support for skimming systems are 12% of on-water costs.
13. Helicopter overflights are charged for 12-hour days for the time oil is present on water surfaces (one helicopter employed for smaller spills, two for larger.)
14. On-water oil removal (assumed to be at most 15%) is not taken into account to discount the oil on the shoreline.
15. Basic salvage/lightering costs (source control) are US$5 million for the freighters (HFO spills), US$9 million for the product tankers (diesel and gasoline spills), and US$12 million for the crude tankers (crude spills), based on an extrapolation of salvage/lightering costs in the T/B Morris J. Berman spill (Etkin, 1995). These costs include costs for the US Navy Supervisor of Salvage (SUPSALV).
16. Base costs for mobilization of response contractors and equipment are $500,000 (based on spill cost information on several spills as well as mobilization costs for oil spill preparedness drills). These costs are incurred regardless of whether an actual spill response operation is initiated or not.

Table 2 Average Hourly Pay for Oil Spill Response Personnel (2001 US$)

Labor Type	Straight Pay	Overtime Pay	Premium Pay
Unskilled labor	$42.02	$57.82	$69.03
Skilled labor	$46.34	$63.69	$100.86
Supervisor	$63.00	$76.52	$79.19
Project Manager	$83.22	$101.34	$113.17
Workboat Operator	$51.56	$66.91	$66.61
Biologist	$71.86	$84.62	$87.89
Vacuum Truck Operator	$42.31	$55.45	$60.17
Skimmer Craft Operator	$60.14	$71.68	$76.93
Based on Basic Ordering Agreement Survey for 11th USCG District (Etkin 1998*b*)			

Table 3 Typical Rental Rates for Response Equipment (2001 US$)

Equipment Type	Rental Rates
Kepner Sea Curtain (Boom) (12” x 100’)	$124/day
Kepner Sea Curtain (Boom) (18” x 100’)	$126/day
Kepner Sea Curtain (Boom) (24” x 100’)	$151.day
Harbor Oil Boom (36”)	$300/day
MFG Weir Skimmer (1,500 gal/hour)	$192/day
Class Skimmer	$420/day
Weir Floating Skimmer	$217/day
Walosep Skimmer	$765/day
Based on Basic Ordering Agreement survey for 11th USCG District (Etkin 1998*b*)	

4.2 Dispersant-Based Operations

Costs for a response in which chemical dispersants are used as a first-order response tool *instead of* on-water mechanical containment and recovery were calculated for the spill scenarios as it is likely that chemical dispersion will become a viable response option in the San Francisco Bay during the coming decade, according to a report from the California Office of Spill Prevention and Response, US Coast Guard, and American Petroleum Institute (Pond, et al. 2000).

The following assumptions are made in developing the cost model (based on Pond, et al. 2000; Etkin 1999*b;* Moller, et al. 1987; Allen and Ferek 1993):

1. All necessary dispersant approvals and/or authorizations are in place.
2. All vessels and airplanes equipped with fire monitors are available for deployment.
3. Weather conditions are suitable for flying airplanes and conducting all other aspects of dispersant application can be conducted safely.
4. The dispersant-to-oil ratio used in all operations is 1:20 (5 gallons/acre).
5. Corexit 9500 is applied to HFO and Corexit 9527 is applied to other oil types.
6. Both Corexit 9500 and Corexit 9527 are available in the San Francisco Bay area. [In 2002, only Corexit 9527 is being stockpiled. State officials are reviewing the results of Pond, et al. 2000 to determine the advisability of additionally stockpiling Corexit 9500 in the near future.]

7. The number of C-130 aircraft sorties required is determined by Figure 1 and Tables 4 - 5.
8. Hourly charges for the C-130 aircraft (including field operational support, administrative support, and depreciation) would follow USCG standard rates for non-government operations ($5,445/hour in 2001 US$). All fractional hour usage is billed to next highest hour charge as per USCG policy.
9. Two additional hours of C-130 aircraft usage costs are factored in to allow for transit to and from spill site.
10. The "lower" dispersant efficiency is assumed to be 35% for HFO and 40% for the other oil types; the "higher" dispersant efficiency is assumed to be 70% for HFO and 80% for the other oil types (based on Pond et al. 2000). HFO is generally less dispersible due to its higher viscosity. These values were used to reduce shoreline oiling and resultant shoreline cleanup costs proportionately.
11. Dispersant is applied to oil remaining on the surface 12 hours after the spill occurs.
12. Dispersant chemicals cost $41/gallon.

Figure 1 ADDSPACK-Equipped C-130 Planes Required By Spill Size (Based on Lewis and Aurand, 1997)

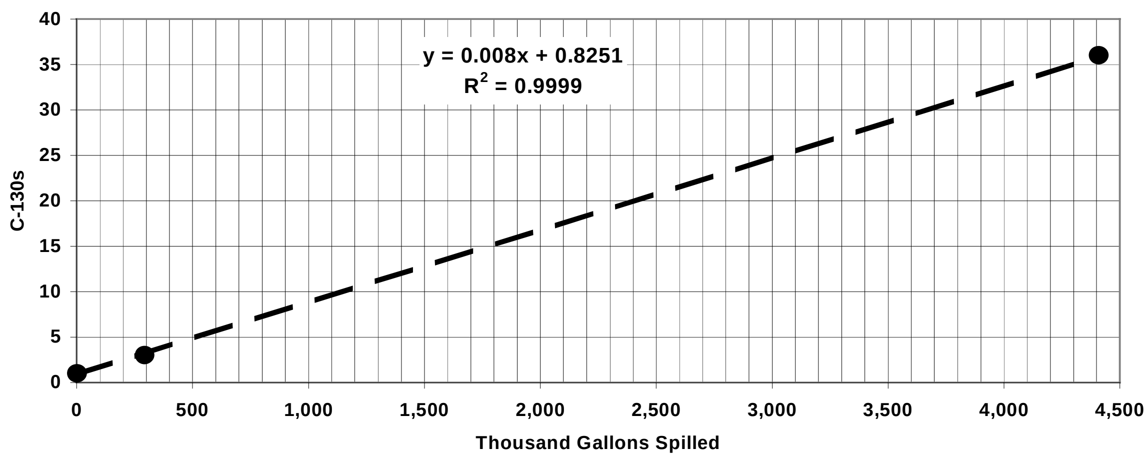

Table 4 Dispersant Platform Sortie Requirements By Spill Size

Spill Size	Dispersant Needed To Treat Entire Spill	Sorties Small Helo	Sorties Large Helo	Sorties ADDSPACK-equipped C-130s
2,100 gal (7 t)	105 gal (397 liters)	1	1	1
294,000 gal (1,000 t)	12,810 gal (48,486 liters)	50	17	3
4,410,000 gal (15,000 t)	192,510 gal (728,650)	750	250	36
Source: Lewis and Aurand 1997				

Table 5 Dispersant Application Platform Parameters (NOAA Spill Tools 1998)

Specifications	Application Platform Type					
	Bell 212 Suspended Bucket	C-130 with Addspack	DC-4	Air Tractor	Large Vessel \(100 ft.)	Small Vessel (20-40 ft.)
Swath Width	16.8 m	45.7 m	36.6 m	25.9 m	24.4 m	29.0 m
Application Speed	30 m/s	73 m/s	78 m/s	75 m/s	3.5 m/s	7 m/s
Pump Rate	197 l/min	410 l/min	1,287 l/min	1,446 l/min	537 l/min	2,214 l/min
Reposition Speed	40 m/s	70 m/s	83 m/s	75 m/s	continuous spray	--
Transit Speed	40 m/s	130 m/s	87 m/s	100 m/s	8 m/s	13 m/s
Dispersant Load Time	2 min	20 min	20 min	10 min	60 min	10 min
Fuel Load Time	10 min	10 min	10 min	5 min	0 min	10 min
U-Turn Time	0 min	1.2 min	1.5 min	1 min	--	--
Max. Operating Time	1.7 h	4 h	4 h	2.5 h	100+ h	20 h
Dispersant Payload	908 l	11,355 l	8,213 l	3,028 l	11,355 l	1,893 l
Range of Doses	7.5 – 200 l/hectare	13-153 l/hectare	7.5-96 l/hectare	--	21-335 l/hectare	10-166 l/hectare

4.3 Cost Estimations For Shoreline Response Operations

Shoreline response costs were estimated based on the amount of shoreline oiled as modeled by McCay et al. (2002) using SIMAP. Each of six shoreline types was analyzed separately – rocky, gravel, sand beach, mudflat, wetland, and artificial shoreline (concrete, piers, jetties). The four oil types – gasoline, diesel, heavy fuel oil, and crude – were also factored in separately as they present very different challenges in cleanup responses, as shown in Table 6.

Gasoline and diesel fuel will dissolve into water and evaporate over the course of hours into the first days after a spill. They may also penetrate deeply into shoreline sand and gravel where they can persist for longer periods of time. While gasoline and diesel cannot readily be *seen* when onshore, their irritating fumes can cause problems and necessitate that cleanup measures (such as sand removal) be taken. Crude and HFO persist on water surfaces and on impacted shoreline surfaces. Their darker color makes them readily visible, causing the need for removal from shoreline surfaces and structures. Their sticky consistency makes them more difficult to remove.

Table 6 Influence of Oil Properties on Oil Impact (based on Fingas 2001). Lower numbers indicate more favorable conditions to the environment and faster recovery after a spill

Oil Type	Viscosity	Adhesion	Penetration	Degradation
Gasoline	1	1	5	4
Diesel	2	2	4	1
Crude	4	4	2	3
HFO	5	5	1	5

The unit area shoreline cleanup costs used in modeling for each shoreline type by oil thickness are shown in Table 7. A "rule of thumb" of 0.06 worker-days per m^2 was used to estimate worker numbers, based on information provided by response organizations on a rate of $1,000 per worker-day (Michel and Cotsapas 1997). These values were verified based on a comprehensive survey of historical cost data, incident action plans, contingency plans, and case studies (Etkin 2001*b*). Professional judgment was also used to discount or increase unit costs based on the relative difficulty of removing each oil type based on the criteria in Table 6.

Table 7 Shoreline Cleanup Cost Factors (2001 US$/$m^2$) for Personnel and Equipment (excluding government costs, monitoring, spill management, decontamination, and disposal)

Shoreline Type	Thickness on Shoreline							
	Gasoline		Diesel		Crude		Heavy Fuel	
	0.1-1 mm	>1mm	0.1-1 mm	>1mm	0.1-1 mm	>1mm	0.1-1 mm	>1mm
Rocky	$3	$5	$8	$10	$24	$32	$25	$63
Gravel	$3	$5	$8	$10	$24	$32	$25	$63
Sand	$6	$8	$10	$13	$31	$40	$45	$113
Mud flat	$6	$8	$11	$14	$34	$44	$28	$70
Wetland	$6	$8	$11	$14	$34	$44	$30	$75
Artificial	$3	$5	$8	$10	$24	$32	$25	$63

The unit costs were multiplied by shoreline area for each shoreline type by thickness oiled for each model run. The total shoreline cleanup costs for each run is the sum of costs per shoreline type based on the unit cost:

$SC_i = C_i A_i$,

Where, SC_i = shoreline cleanup (oil removal) cost for shoreline type, *i* (in $);$C_i$ = unit shoreline cleanup cost for shoreline type, *i* (in $/$m^2$); A_i = area of shoreline type, *i*, oiled

$$SC_{total} = SC_{rocky} + SC_{gravel} + SC_{sand} + SC_{mudflat} + SC_{wetland} + SC_{artificial}$$

4.4 Shoreline Cleanup Cost Summary

The median and maximum shoreline cleanup costs are shown in Table 8. Shoreline cleanup costs were estimated for model runs representing the median (50th percentile) and worst (95th percentile) impacts for the water column and shoreline. In general, the more oil that impacts the water column, the less oil stranding on the shoreline. In some cases both shoreline oiling *and* water column impact were reduced due to the oil trajectory as impacted by winds and currents for that particular run.

Table 8 Estimated Total Shoreline Cleanup Costs (2001 US$)

Scenario		Estimated Shoreline Cleanup Costs[1]			
Fuel	Spill Size	Median Shoreline Impact	Worst.[2] Shoreline Impact	Median Water Column Impact	Worst.[2] Water Column Impact
Diesel	50,000 gal	$2,310,000	$4,280,000	$2,080,000	$4,260,000
	270,000 gal	$6,336,000	$10,280,000	$7,303,000	$1,593,000
	1,250,000 gal	$15,200,000	$26,000,000	$11,570,000	$16,340,000
Gasoline	50,000 gal	$14,000	$39,000	$16,000	$2,000
	270,000 gal	$108,000	$416,000	$150,000	$116,000
	1,250,000 gal	$1,116,000	$1,963,000	$295,000	$1,918,000
Heavy fuel oil	25,000 gal	$3,370,000	$5,670,000	$3,370,000	$4,450,000
	100,000 gal	$20,770,000	$36,200,000	$35,940,000	$28,730,000
	410,000 gal	$47,140,000	$91,260,000	$56,410,000	$55,580,000
Crude	100,000 gal	$8,510,000	$14,990,000	$11,470,000	$14,650,000
	600,000 gal	$21,670,000	$39,870,000	$30,950,000	$16,580,000
	3,000,000 gal	$48,120,000	$96,160,000	$43,390,000	$51,680,000

[1]Costs include equipment and personnel costs, but not waste disposal costs.
[2]95th percentile.

4.5 Total Response Cost Results

Estimated total response costs for mechanical recovery-based operations and consequent shoreline operations are shown in Table 9. Costs for dispersant-based operations and consequent shoreline cleanup for high-effectiveness dispersant operations and low-effectiveness dispersant operations are shown in Tables 10 - 11.

4.6 Cost Comparison Between Response Strategies

A comparison between the total response costs (including on-water and shoreline response costs) for operations with primary on-water mechanical recovery strategies and operations with primary on-water dispersant application strategies is shown in Tables 12 - 13. Dispersant responses were broken into two categories depending on effectiveness. “Low dispersant effectiveness” refers to situations in which the dispersant application dispersed 35% of the heavy fuel and 40% of the diesel, gasoline, or crude oil. “High dispersant effectiveness” refers to situations in which the dispersant chemical application effectively dispersed 70% of the heavy fuel and 80% of the diesel, gasoline, or crude oil.

Total costs for on-water and shoreline response operations in which dispersant application is the primary on-water response operation is considerably lower than the costs for operations in which mechanical recovery is the primary on-water response strategy. This is particularly true for larger spills and for persistent oils and to a lesser extent, diesel. Smaller spills are less impacted by the cost reduction since costs for initialization of the response (mobilization) are realized even at very low spill levels.

(In fact, these costs may be incurred if there were a significant *threat* of a spill without any ultimate spillage.) The costs for gasoline spills are impacted slightly if at

Table 9 Estimated Total Response Costs (With Mechanical Recovery)

Spill Scenario		Estimated Costs				
Oil Type	Scenario Percentile	On-Water Mechanical Recovery[1]	Shoreline Cleanup[1,2] median/worst	Salvage/ Source Control	Spill Mgt	Total Cost[2] median worst
Diesel	20th	$893,000	$2,113,000	$9,000,000	$200,000	$12,205,500
			$4,293,000			$14,385,500
	50th	$2,010,000	$7,479,000	$9,000,000	$300,000	$18,788,500
			$1,769,000			$13,078,500
	95th	$4,512,000	$12,383,000	$9,000,000	$1,000,000	$26,894,500
			$17,153,000			$31,664,500
Gasoline	20th	$825,000	$26,000	$9,000,000	$170,000	$10,021,000
			$12,000			$10,007,000
	50th	$1,620,000	$204,000	$9,000,000	$220,000	$11,044,000
			$170,000			$11,010,000
	95th	$3,207,000	$545,000	$9,000,000	$650,000	$13,402,000
			$2,168,000			$15,025,000
Heavy Fuel Oil	20th	$2,470,000	$3,750,000	$5,000,000	$400,000	$11,619,000
			$6,050,000			$13,919,000
	50th	$6,817,000	$22,290,000	$5,000,000	$1,000,000	$35,107,000
			$37,720,000			$50,537,000
	95th	$17,915,000	$53,372,000	$5,000,000	$1,800,000	$78,087,000
			$97,492,000			$122,207,000
Crude	20th	$6,839,000	$9,710,000	$12,000,000	$1,000,000	$29,549,000
			$16,190,000			$36,029,000
	50th	$22,628,000	$28,870,000	$12,000,000	$2,000,000	$65,498,000
			$47,070,000			$83,698,000
	95th	$78,024,000	$84,120,000	$12,000,000	$8,000,000	$182,144,000
			$132,160,000			$230,184,000

[1]Includes disposal/decontamination costs as appropriate. [2]Shoreline costs for median/ worst water column-impacted runs for diesel and gasoline and median/worst shoreline cost runs for HFO and crude based on SIMAP modeling runs.

Table 10 Estimated Total Response Costs (With Dispersant Use) Lower Dispersant Efficiency

Spill Scenario		Estimated Costs (US 2001$)				
Oil Type	Scenario Percentile	Dispersant Application	Shoreline Cleanup[1,2] median/worst	Salvage/ Lightering	Spill Mgt.	Total Cost[2] median/worst
Diesel	20th	$85,000	$1,268,000	$9,000,000	$100,000	$10,453,000
			$2,576,000			$11,761,000
	50th	$476,000	$4,487,000	$9,000,000	$150,000	$14,113,000
			$1,061,000			$10,687,000
	95th	$2,562,000	$7,430,000	$9,000,000	$500,000	$19,492,000
			$10,292,000			$22,354,000
Gasoline	20th	$93,000	$16,000	$9,000,000	$85,000	$9,194,000
			$7,000			$9,185,000
	50th	$449,000	$122,000	$9,000,000	$110,000	$9,681,000
			$102,000			$9,661,000
	95th	$1,993,000	$327,000	$9,000,000	$325,000	$11,645,000
			$1,301,000			$12,619,000
Heavy Fuel Oil	20th	$70,000	$2,438,000	$5,000,000	$200,000	$7,708,000
			$3,933,000			$9,203,000
	50th	$198,000	$14,489,000	$5,000,000	$500,000	$20,187,000
			$24,518,000			$30,216,000
	95th	$632,000	$34,692,000	$5,000,000	$900,000	$41,224,000
			$63,370,000			$69,902,000
Crude	20th	$164,000	$5,826,000	$12,000,000	$500,000	$18,490,000
			$9,714,000			$22,378,000
	50th	$1,030,000	$17,322,000	$12,000,000	$1,000,000	$31,352,000
			$28,242,000			$42,272,000
	95th	$4,873,000	$50,472,000	$12,000,000	$4,000,000	$71,345,000
			$79,296,000			$100,169,000

[1]Assumes 35% reduction for HFO and 40% for other oils in shoreline oiling with dispersant use.
[2]Shoreline costs for median and worst water column-impacted runs for diesel and gasoline and median and worst shoreline cost runs for HFO and crude based on SIMAP modeling runs.

Table 11 Estimated Total Response Costs (With Dispersant Use) Higher Dispersant Efficiency

Spill Scenario		Estimated Costs				
Oil Type	Scenario Percentile	Dispersant Application	Shoreline Cleanup[1,2] median/worst	Salvage/ Lightering	Spill Mgt.	Total Cost[2] median/worst
Diesel	20th	$85,000	$422,600	$9,000,000	$100,000	$9,608,000
			$858,600			$10,044,000
	50th	$476,000	$1,495,800	$9,000,000	$150,000	$11,122,000
			$353,800			$9,980,000
	95th	$2,562,000	$2,476,600	$9,000,000	$500,000	$14,539,000
			$3,430,600			$15,493,000
Gasoline	20th	$93,000	$5,200	$9,000,000	$85,000	$9,183,000
			$2,400			$9,180,000
	50th	$449,000	$40,800	$9,000,000	$110,000	$9,600,000
			$34,000			$9,593,000
	95th	$1,993,000	$109,000	$9,000,000	$325,000	$11,427,000
			$433,600			$11,752,000
Heavy Fuel Oil	20th	$70,000	$1,125,000	$5,000,000	$200,000	$6,395,000
			$1,815,000			$7,085,000
	50th	$198,000	$6,687,000	$5,000,000	$500,000	$12,385,000
			$11,316,000			$17,014,000
	95th	$632,000	$16,011,600	$5,000,000	$900,000	$22,544,000
			$29,247,600			$35,780,000
Crude	20th	$164,000	$1,942,000	$12,000,000	$500,000	$14,606,000
			$3,238,000			$15,902,000
	50th	$1,030,000	$5,774,000	$12,000,000	$1,000,000	$19,804,000
			$9,414,000			$23,444,000
	95th	$4,873,000	$16,824,000	$12,000,000	$4,000,000	$37,697,000
			$26,432,000			$47,305,000

[1]Assumes 70% reduction for HFO and 80% for other oils in shoreline oiling with dispersant use.
[2]Shoreline costs for median and worst water column-impacted runs for diesel and gasoline and median and worst shoreline cost runs for HFO and crude based on SIMAP modeling runs.

all since the shoreline response operations are relatively minor since little gasoline impacts the shoreline and relatively little can be done to remove gasoline when it does impact the shoreline. The percentage cost reduction with the use of dispersants is shown in Table 14.

Table 12 Total Response Costs (2001 US$)

Scenario		Spill Outcome	Primary On-Water Response Strategy		
Oil Type	Percentile		Mechanical	Dispersant *Low Effectiveness*	Dispersant *High Effectiveness*
Diesel	20^{th}	Median	$12,205,500	$10,453,000	$9,608,000
		Worst	$14,385,500	$11,761,000	$10,044,000
	50^{th}	Median	$18,788,500	$14,113,000	$11,122,000
		Worst	$13,078,500	$10,687,000	$9,980,000
	95^{th}	Median	$26,894,500	$19,492,000	$14,539,000
		Worst	$31,664,500	$22,354,000	$15,493,000
Gasoline	20^{th}	Median	$10,021,000	$9,194,000	$9,183,000
		Worst	$10,007,000	$9,185,000	$9,180,000
	50^{th}	Median	$11,044,000	$9,681,000	$9,600,000
		Worst	$11,010,000	$9,661,000	$9,593,000
	95^{th}	Median	$13,402,000	$11,645,000	$11,427,000
		Worst	$15,025,000	$12,619,000	$11,752,000
Heavy Fuel Oil	20^{th}	Median	$11,619,000	$7,708,000	$6,395,000
		Worst	$13,919,000	$9,203,000	$7,085,000
	50^{th}	Median	$35,107,000	$20,187,000	$12,385,000
		Worst	$50,537,000	$30,216,000	$17,014,000
	95^{th}	Median	$78,087,000	$41,224,000	$22,544,000
		Worst	$122,207,000	$69,902,000	$35,780,000
Crude	20^{th}	Median	$29,549,000	$18,490,000	$14,606,000
		Worst	$36,029,000	$22,378,000	$15,902,000
	50^{th}	Median	$65,498,000	$31,352,000	$19,804,000
		Worst	$83,698,000	$42,272,000	$23,444,000
	95^{th}	Median	$182,144,000	$71,345,000	$37,697,000
		Worst	$230,184,000	$100,169,000	$47,305,000

Table 13 Estimated Total Per-Gallon Response Costs (2001 US$)

Scenario		Spill Outcome	Primary On-Water Response Strategy		
Oil Type	Percentile Gallons		Mechanical	Dispersant *Low Effectiveness*	Dispersant *High Effectiveness*
Diesel	20th	Median	$244	$209	$192
		Worst	$288	$235	$201
	50th	Median	$70	$52	$41
		Worst	$48	$40	$37
	95th	Median	$22	$16	$12
		Worst	$25	$18	$12
Gasoline	20th	Median	$200	$184	$184
		Worst	$200	$184	$184
	50th	Median	$41	$36	$36
		Worst	$41	$36	$36
	95th	Median	$11	$9	$9
		Worst	$12	$10	$9
Heavy Fuel Oil	20th	Median	$465	$308	$256
		Worst	$557	$368	$283
	50th	Median	$351	$202	$124
		Worst	$505	$302	$170
	95th	Median	$190	$101	$55
		Worst	$298	$170	$87
Crude	20th	Median	$295	$185	$146
		Worst	$360	$224	$159
	50th	Median	$109	$52	$33
		Worst	$139	$70	$39
	95th	Median	$61	$24	$13
		Worst	$77	$33	$16

Table 14 Percentage Cost Reduction With Dispersant Use Instead of Mechanical

Oil Type	Scenario	Percentage Reduction Of Total Response Costs	
		Dispersant Operations *Lower Effectiveness*[2]	Dispersant Operations *Higher Effectiveness*[3]
Diesel	Median 20th	14%	21%
	Worst 20th	18%	30%
	Median 50th	25%	41%
	Worst 50th	18%	24%
	Median 95th	28%	46%
	Worst 95th	29%	51%
Gasoline	Median 20th	8%	8%
	Worst 20th	8%	8%
	Median 50th	12%	13%
	Worst 50th	12%	13%
	Median 95th	13%	15%
	Worst 95th	16%	22%
HFO	Median 20th	34%	45%
	Worst 20th	34%	49%
	Median 50th	42%	65%
	Worst 50th	40%	66%
	Median 95th	47%	71%
	Worst 95th	43%	71%
Crude	Median 20th	37%	51%
	Worst 20th	38%	56%
	Median 50th	52%	70%
	Worst 50th	49%	72%
	Median 95th	61%	79%
	Worst 95th	56%	79%

In actual practice, it is unlikely that dispersants (and subsequent shoreline cleanup) would be used in *complete* isolation from any on-water mechanical containment and recovery operations. There may be some locations, such as protected inlets, where on-water recovery might be particularly successful and would likely be attempted. In addition, there would likely be certain locations where dispersant use would be inadvisable due to particular sensitivity of the environment or because of inaccessibility. In these cases the costs would represent a combination of dispersant operations and mechanical recovery operations.

At the same time, there may be situations in which weather (e.g., a large storm) would make dispersant operations impracticable or less effective (particularly calm waters), though the latter is somewhat unlikely in San Francisco Bay. In these cases, there may be greater reliance on mechanical recovery. Any delays in response (for either dispersant application or mechanical containment and recovery operations) due to weather or other logistical complications, would likely cause a greater spread of oil onto the shoreline. The costs of situations with greater shoreline impact are reflected in the mechanical containment and recovery cost estimates presented.

5 Natural Resource Damages

The methodology for estimating natural resource damages is described in McCay, et al. (2002). The results of the damage estimates are shown in Table 15 and are presented here for a comparison to the other cost categories.

Table 15 Natural Resource Damages For Spill Scenarios (McCay, et al., 2002)

Oil Type	Volume Percentile	Volume	Impact Percentile	NRDA for Ecological Damages US$
Diesel	20th	50,000 gal (171 t)	50th	$16,300,000
			95th	$3,079,000
	50th	270,000 gal (922 t)	50th	$7,308,000
			95th	$7,500,000
	95th	1,250,000 gal (4,266 t)	50th	$72,209,000
			95th	$58,396,000
Gasoline	20th	50,000 gal (152 t)	50th	$3,967,000
			95th	$1,000
	50th	270,000 gal (821 t)	50th	$751,000
			95th	$1,970,000
	95th	1,250,000 gal (3,800 t)	50th	$2,062,000
			95th	$10,731,000
HFO	20th	25,000 gal (95 t)	50th	$474,000
			95th	$3,250,000
	50th	100,000 gal (379 t)	50th	$5,157,000
			95th	$4,426,000
	95th	410,000 gal (1,553 t)	50th	$5,759,000
			95th	$20,378,000
Crude	20th	100,000 gal (369 t)	50th	$2,773,000
			95th	$5,354,000
	50th	600,000 gal (2,214 t)	50th	$9,722,000
			95th	$52,153,000
	95th	3,000,000 gal (10,239 t)	50th	$40,166,000
			95th	$56,892,000

6 Socioeconomic Costs

An oil spill can have serious socioeconomic impacts on the affected region, local communities, residents, the state, and the federal government. These impacts include damages to real and personal property, loss of use of natural resources (parks and recreation areas), and loss of income and expenses (fishing, tourism, recreation, shipping and other commerce). As a major shipping port and tourist and recreation area, San Francisco Bay is particularly vulnerable to socioeconomic impacts from oil spills. Reduction in tourism, commercial fishing, and blocking the shipping port could have widespread impacts.

Modeling results show that even the *smallest* spill associated with a deep-draft vessel grounding in San Francisco Bay (25,000 gallons of heavy fuel oil) will result in a 97-100% chance of impact to sites of major socioeconomic import such as Fishermans Wharf, Golden Gate National Recreation Area, Mt. Tamalpais State Park, Sausalito, and Emery Cove and Berkeley marinas. Even locations as far as northeast as Glen Cove in the Carquinez Strait have an 83% chance of impact and as far south in the bay as San Leandro have a 73% chance of impact.

The impacts may be felt *within* the bay and on the *outer Pacific coast*. The largest potential spill (3 million gallons of crude oil) has a 98% chance of impacting as far south as Half Moon Bay and a 46% of impacting as far north as Stinson Beach.

The estimated socioeconomic costs associated with potential oil spills from vessel groundings range from $20 million to $195 million depending on the size of the spill and type of oil. On a per-gallon basis this amounts to $63 to $839 of socioeconomic damage *per gallon of oil spilled*. Estimated damages are summarized in Table 16 - 17 for each of the modeled oil spill scenarios.

The largest socioeconomic costs are those associated with tourism, both in terms of lost tourism spending and in the impact on jobs associated with the area's $27-million per day tourism industry. Port blockage can result in costs of nearly $3 million per day. Commercial fishing damages from lost income and damages to boats and equipment range from $800,000 to as much as $21 million.

Additional costs include the value of the lost oil ranging from $30,000 to as high as $1.3 million, as shown in Table 18.

Socioeconomic costs for this study were derived from detailed examinations of reports, documents, and data on:

1. Direct and indirect income derived from the local tourist industry as reported by San Francisco and state tourist bureaus, and other sources (including Moller and Fitz 1997);
2. Direct and indirect income derived from the local recreation facilities as reported by state tourist bureaus, and other sources (including Moller and Fitz 1997);
3. Recreation lost-use estimates were estimated based on methodology described in US Army Corps of Engineers economic guidance documents (2000a, b, e);
4. Port blockage costs were estimated based on the amount of time of the blockage (based on case study analysis and placement of booms and equipment in vessel traffic lanes as required based on oil spread and trajectory) and vessel operating costs as determined by methodologies and costs in US Army Corps of Engineering economic guidance documents (2000a, c, d) and port use direct and indirect income as derived from Moller and Fitz (1997); and
5. Commercial fishing impacts were based on figures in Moller and Fitz (1997).

Table 16 Total Estimated Socioeconomic Damages From Oil Spills in San Francisco Bay (in thousand US$)

Oil Type	Scen.	Port Blockage Costs	Tourism Income Loss	Recrea-tion Income Loss	Total Lost-Use Damages	Total Fishing Damages	Marina Property Damage	Total
Diesel	20thM	$9,544	$17,301	$270	$817	$6	$28,391	$56,329
	20thW	$4,081	$17,301	$270	$2,449	$24	$25,516	$49,641
	50thM	$5,305	$41,521	$647	$4,701	$130	$53,052	$105,356
	50thW	$4,372	$41,521	$647	$5,327	$65	$56,007	$107,939
	95thM	$11,790	$103,801	$1,617	$15,534	$300	$134,654	$267,696
	95thW	$10,106	$103,801	$1,617	$15,534	$375	$133,266	$264,699
Gaso-line	20thM	$3,498	$17,301	$270	$811	$2	$22,022	$43,904
	20thW	$1,633	$17,301	$270	$811	$2	$20,098	$40,115
	50thM	$4,897	$41,521	$647	$1,562	$5	$48,983	$97,615
	50thW	$875	$41,521	$647	$3,123	$5	$47,921	$94,092
	95thM	$875	$103,801	$1,617	$3,813	$38	$110,980	$221,124
	95thW	$1,225	$103,801	$1,617	$3,251	$75	$110,494	$220,463
HFO	20thM	$1,225	$17,301	$270	$1,981	$12	$20,979	$41,768
	20thW	$2,245	$17,301	$270	$583	$72	$20,539	$41,010
	50thM	$7,860	$41,521	$647	$4,332	$144	$55,938	$110,442
	50thW	$5,742	$41,521	$647	$3,682	$336	$52,353	$104,281
	95thM	$4,430	$72,661	$1,132	$8,401	$1,640	$97,482	$185,746
	95thW	$5,130	$72,661	$1,132	$7,935	$1,640	$90,780	$179,278
Crude	20thM	$2,245	$24,221	$378	$1,720	$96	$32,545	$61,205
	20thW	$1,458	$24,221	$378	$2,579	$144	$28,995	$57,775
	50thM	$2,653	$62,281	$970	$13,010	$576	$81,131	$160,621
	50thW	$9,544	$62,281	$970	$15,306	$864	$91,491	$180,456
	95thM	$8,758	$145,321	$2,263	$21,310	$5,040	$189,298	$371,990
	95thW	$10,218	$145,321	$2,263	$21,310	$6,000	$195,304	$380,416

Table 17 Total Socioeconomic Costs For San Francisco Bay Oil Spills (2001 US$)

Oil Type	Scenario	Amount Spilled	TOTAL Costs	Total Cost Per-Gallon
Diesel	20^{th}MED	50,000 gal (152 t)	$56,329,000	$1,126.58
	20^{th}WST		$49,641,000	$992.82
	50^{th}MED	270,000 gal (821 t)	$105,356,000	$390.21
	50^{th}WST		$107,939,000	$399.77
	95^{th}MED	1,250,000 gal (3,800 t)	$267,696,000	$214.16
	95^{th}WST		$264,699,000	$211.76
Gasoline	20^{th}MED	50,000 gal (171 t)	$43,904,000	$878.08
	20^{th}WST		$40,115,000	$802.30
	50^{th}MED	270,000 gal (922 t)	$97,615,000	$361.54
	50^{th}WST		$94,092,000	$348.49
	95^{th}MED	1,250,000 gal (4,266 t)	$221,124,000	$176.90
	95^{th}WST		$220,463,000	$176.37
HFO	20^{th}MED	25,000 gal (95 t)	$41,768,000	$417.68
	20^{th}WST		$41,010,000	$410.10
	50^{th}MED	100,000 gal (379 t)	$110,442,000	$184.07
	50^{th}WST		$104,281,000	$173.80
	95^{th}MED	410,000 gal (1,553 t)	$185,746,000	$61.92
	95^{th}WST		$179,278,000	$59.76
Crude	20^{th}MED	100,000 gal (369 t)	$61,205,000	$2,448.20
	20^{th}WST		$57,775,000	$2,311.00
	50^{th}MED	600,000 gal (2,214 t)	$160,621,000	$1,606.21
	50^{th}WST		$180,456,000	$1,804.56
	95^{th}MED	3,000,000 gal (10,239 t)	$371,990,000	$907.29
	95^{th}WST		$380,416,000	$927.84

Table 18 Cost of Lost Oil For San Francisco Bay Spill Scenarios (2001 US$)

Oil Type	Scenario	Gallons Spilled	Oil Cost
Diesel	20^{th} Percentile	50,000 gal	$30,750
	50^{th} Percentile	270,000 gal	$166,050
	95^{th} Percentile	1,250,000 gal	$768,750
Gasoline	20^{th} Percentile	50,000 gal	$30,750
	50^{th} Percentile	270,000 gal	$166,050
	95^{th} Percentile	1,250,000 gal	$768,750
Heavy Fuel Oil	20^{th} Percentile	25,000 gal	$10,835
	50^{th} Percentile	100,000 gal	$43,340
	95^{th} Percentile	410,000 gal	$177,694
Crude	20^{th} Percentile	100,000 gal	$43,310
	50^{th} Percentile	600,000 gal	$259,857
	95^{th} Percentile	3,000,000 gal	$1,299,286

Based on *Depart. of Energy Weekly Petroleum Status Report* (21 January 2002)
Crude: $18.19/bbl ($0.43/gal); Gasoline: $0.4334/gal; Diesel: $0.615/gal; HFO: $0.62/gal

7 Analysis of Total Costs

Total costs for all spill scenarios are shown in Table 19. The percentage of the total costs by cost category (natural resource damages, response costs, and socio-economic damages are shown in Tables 20 – 21.

Per-gallon costs by cost category are shown in Table 22. Figures 2 – 5 show the rate of decrease in per-gallon costs with increasing spill size.

Socioeconomic damage costs exceed costs in other categories in all cases. These costs are often settled in or out of court at a reduced rate depending on circumstances of the spill and local court standards reducing these costs in the final outcome. The potential for significant socio-economic damages from oil spills should be borne in mind when considering overall impacts.

Table 19 Total Oil Spill Scenario Costs (2001 US$)

Oil Type	Scenario	NRDA for Ecological Damages	Socio-economic Costs	Response Costs (mechanical)	Total Costs
Diesel	20thM	$16,300,000	$56,329,000	$12,206,000	$84,835,000
	20thW	$3,079,000	$49,641,000	$14,386,000	$67,106,000
	50thM	$7,308,000	$105,356,000	$18,789,000	$131,453,000
	50thW	$7,500,000	$107,939,000	$13,079,000	$128,518,000
	95thM	$72,209,000	$267,696,000	$26,895,000	$366,800,000
	95thW	$58,396,000	$264,699,000	$31,665,000	$354,760,000
Gasoline	20thM	$3,967,000	$43,904,000	$10,021,000	$57,892,000
	20thW	$1,000	$40,115,000	$10,007,000	$50,123,000
	50thM	$751,000	$97,615,000	$11,044,000	$109,410,000
	50thW	$1,970,000	$94,092,000	$11,010,000	$107,072,000
	95thM	$2,062,000	$221,124,000	$13,402,000	$236,588,000
	95thW	$10,731,000	$220,463,000	$15,025,000	$246,219,000
HFO	20thM	$474,000	$41,768,000	$11,619,000	$53,861,000
	20thW	$3,250,000	$41,010,000	$13,919,000	$58,179,000
	50thM	$5,157,000	$110,442,000	$35,107,000	$150,706,000
	50thW	$4,426,000	$104,281,000	$50,537,000	$159,244,000
	95thM	$5,759,000	$185,746,000	$78,087,000	$269,592,000
	95thW	$20,378,000	$179,278,000	$122,207,000	$321,863,000
Crude	20thM	$2,773,000	$61,205,000	$29,549,000	$93,527,000
	20thW	$5,354,000	$57,775,000	$36,029,000	$99,158,000
	50thM	$9,722,000	$160,621,000	$65,498,000	$235,841,000
	50thW	$52,153,000	$180,456,000	$83,698,000	$316,307,000
	95thM	$40,166,000	$371,990,000	$182,144,000	$594,300,000
	95thW	$56,892,000	$380,416,000	$230,184,000	$667,492,000

Table 20 Total Oil Spill Scenario Costs: Percent By Category (2001 US$)

Oil Type	Scenario	NRDA for Ecological Damages	Socio-economic Costs	Response Costs
Diesel	20thM	19.2%	66.4%	14.4%
	20thW	4.6%	74.0%	21.4%
	50thM	5.6%	80.1%	14.3%
	50thW	5.8%	84.0%	10.2%
	95thM	19.7%	73.0%	7.3%
	95thW	16.5%	74.6%	8.9%
	Average	11.9%	75.4%	12.8%
Gasoline	20thM	6.9%	75.8%	17.3%
	20thW	0.0%	80.0%	20.0%
	50thM	0.7%	89.2%	10.1%
	50thW	1.8%	87.9%	10.3%
	95thM	0.9%	93.5%	5.7%
	95thW	4.4%	89.5%	6.1%
	Average	2.5%	86.0%	11.6%
HFO	20thM	0.9%	77.5%	21.6%
	20thW	5.6%	70.5%	23.9%
	50thM	3.4%	73.3%	23.3%
	50thW	2.8%	65.5%	31.7%
	95thM	2.1%	68.9%	29.0%
	95thW	6.3%	55.7%	38.0%
	Average	3.5%	68.6%	27.9%
Crude	20thM	3.0%	65.4%	31.6%
	20thW	5.4%	58.3%	36.3%
	50thM	4.1%	68.1%	27.8%
	50thW	16.5%	57.1%	26.5%
	95thM	6.8%	62.6%	30.6%
	95thW	8.5%	57.0%	34.5%
	Average	7.4%	61.4%	31.2%

Natural resource damage assessments have often been maligned as being the most significant portion of oil spill costs for the responsible party in a US spill case. Previous studies by Helton and Penn (1999) and Helton, et al. (1997) showed that in actual spill cases, natural resource damages rarely exceeded 25% of total costs. The results of this modeling study lend further support to this finding.

The relatively larger natural resource damage costs associated with the diesel spills (due to higher water column impacts) are shown in Table 20 which compares all three cost categories and Table 21 which compares only mechanical recovery response and natural resource damage costs (eliminating socio-economic costs).

Table 21 Relative Percentage By Cost Category (% of NRDA plus mechanical response cost totals, eliminating socio-economic costs) (2001 US$)

Oil Type	Scenario	NRDA for Ecological Damages	Response Costs (Mechanical)
Diesel	20thM	57.2%	42.8%
	20thW	17.6%	82.4%
	50thM	28.0%	72.0%
	50thW	36.4%	63.6%
	95thM	72.9%	27.1%
	95thW	64.8%	35.2%
	Average	*46.2%*	*53.8%*
Gasoline	20thM	28.4%	71.6%
	20thW	0.0%	100.0%
	50thM	6.4%	93.6%
	50thW	15.2%	84.8%
	95thM	13.3%	86.7%
	95thW	41.7%	58.3%
	Average	*17.5%*	*82.5%*
HFO	20thM	3.9%	96.1%
	20thW	18.9%	81.1%
	50thM	12.8%	87.2%
	50thW	8.1%	91.9%
	95thM	6.9%	93.1%
	95thW	14.3%	85.7%
	Average	*10.8%*	*89.2%*
Crude	20thM	8.6%	91.4%
	20thW	12.9%	87.1%
	50thM	12.9%	87.1%
	50thW	38.4%	61.6%
	95thM	18.1%	81.9%
	95thW	19.8%	80.2%
	Average	*18.5%*	*81.5%*

The relative proportion of costs will likely be shifted to some extent in the future with the increasing reliance on dispersants as a first-order response in US waters as is indicated in Pond, et al. (2000). This will decrease response costs and perhaps reduce natural resource and socio-economic damages with lesser shoreline and habitat impacts. The potential for impacts by dispersants themselves or dispersed oil was not taken into account in the current study, but is discussed with regard to San Francisco Bay in Pond, et al. (2000).

Likely response strategies for San Francisco Bay over the course of this decade are shown in Table 23. There is an assumption that with time there will be increased effectiveness of dispersant application based on more timely and efficient application procedures and the introduction of more effective dispersant formulations.

Table 22 Total Per-Gallon Oil Spill Scenario Costs (2001 US$)

Oil Type	Scenario	NRDA Costs	Socio-economic Costs	Response Costs	Total Costs
Diesel	20thM	$326.00	$1,126.58	$244.12	$1,696.70
	20thW	$61.58	$992.82	$287.72	$1,342.12
	50thM	$27.07	$390.21	$69.59	$486.86
	50thW	$27.78	$399.77	$48.44	$475.99
	95thM	$57.77	$214.16	$21.52	$293.44
	95thW	$46.72	$211.76	$25.33	$283.81
Gasoline	20thM	$79.34	$878.08	$200.42	$1,157.84
	20thW	$0.02	$802.30	$200.14	$1,002.46
	50thM	$2.78	$361.54	$40.90	$405.22
	50thW	$7.30	$348.49	$40.78	$396.56
	95thM	$1.65	$176.90	$10.72	$189.27
	95thW	$8.58	$176.37	$12.02	$196.98
HFO	20thM	$18.96	$1,670.72	$464.76	$2,154.44
	20thW	$130.00	$1,640.40	$556.76	$2,327.16
	50thM	$51.57	$1,104.42	$351.07	$1,507.06
	50thW	$44.26	$1,042.81	$505.37	$1,592.44
	95thM	$14.05	$453.04	$190.46	$657.54
	95thW	$49.70	$437.26	$298.07	$785.03
Crude	20thM	$27.73	$612.05	$295.49	$935.27
	20thW	$53.54	$577.75	$360.29	$991.58
	50thM	$16.20	$267.70	$109.16	$393.07
	50thW	$86.92	$300.76	$139.50	$527.18
	95thM	$13.39	$124.00	$60.71	$198.10
	95thW	$18.96	$126.81	$76.73	$222.50

Figure 2 Total Costs For Diesel Spills (Median and Worst Runs) (2001 US$)

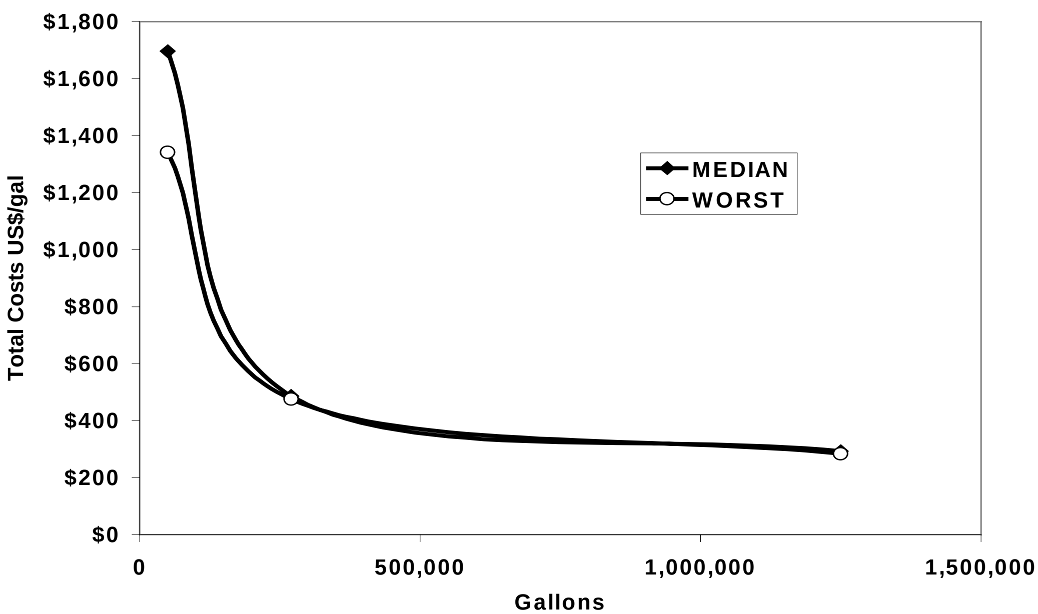

Figure 3 Total Costs For Gasoline Spills (Median and Worst Runs) (2001 US$)

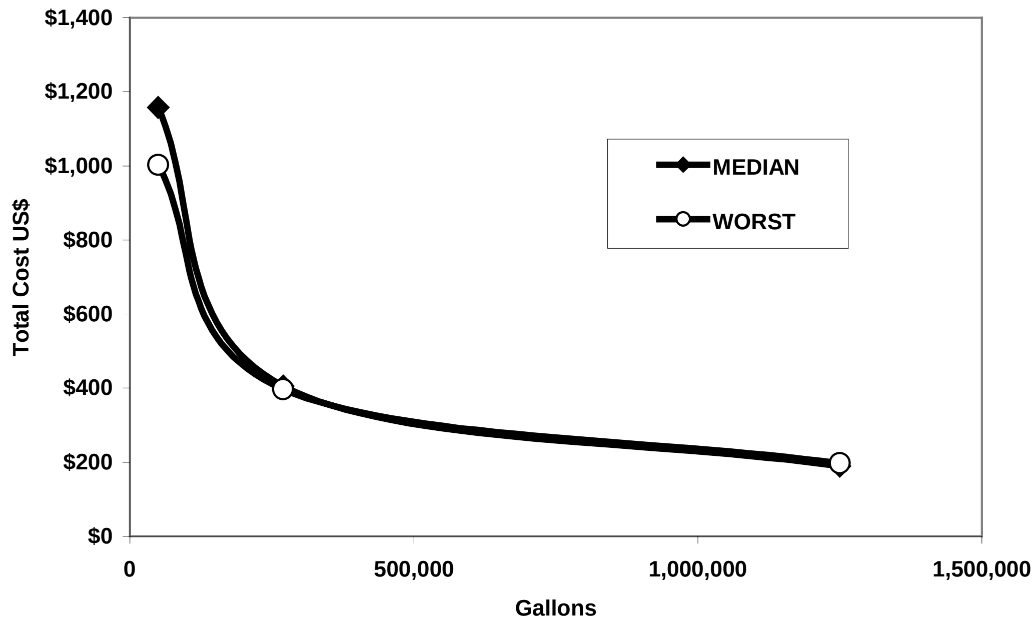

Figure 4 Total Costs For HFO Spills (Median and Worst Runs) (2001 US$)

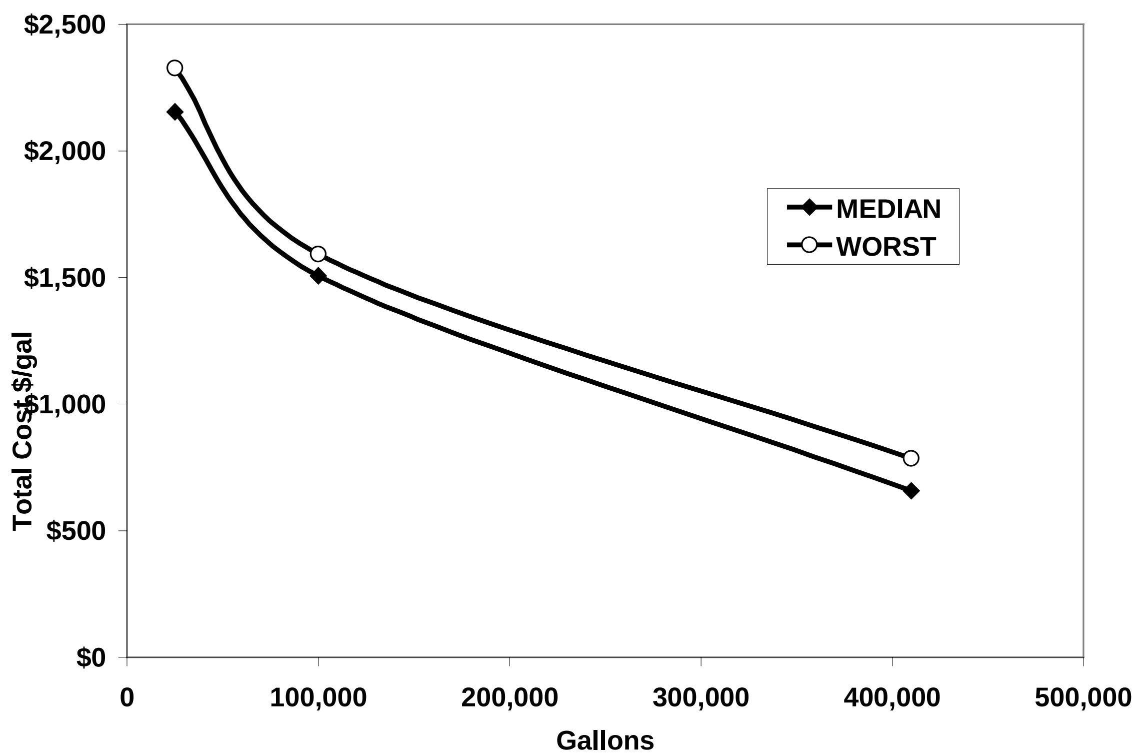

Figure 5 Total Costs For Crude Spills (Median and Worst Runs) (2001 US$)

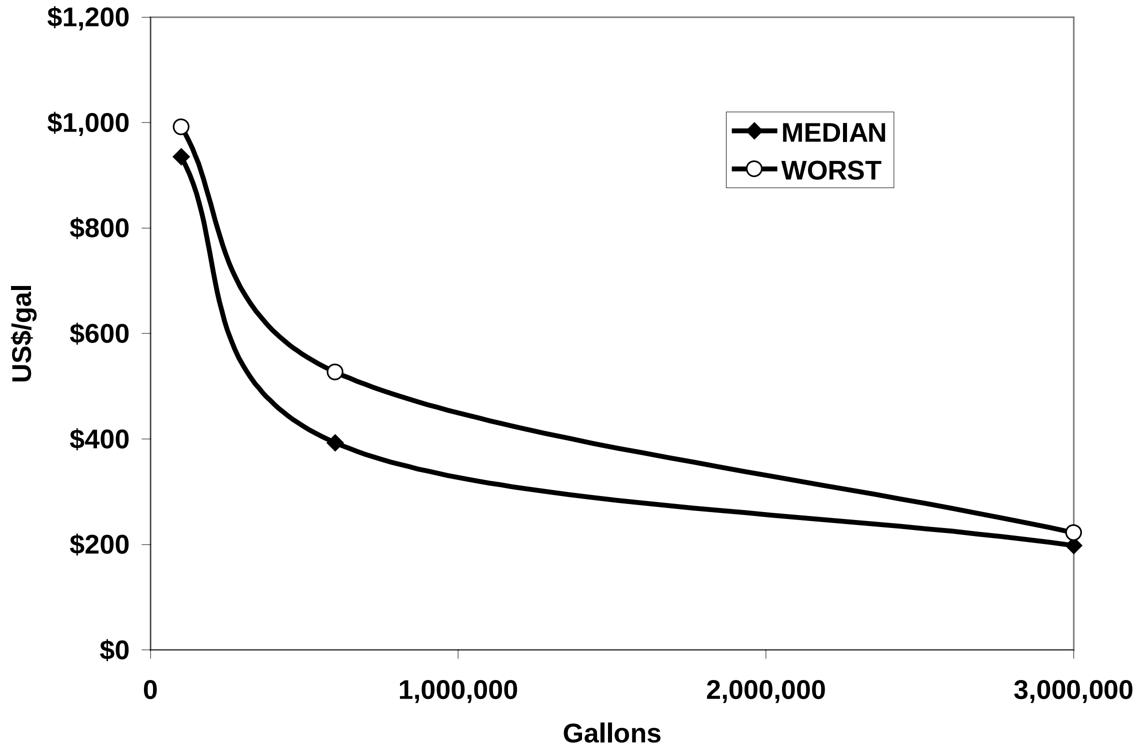

Table 23 Projected Response Cost Basis [Based on On-Water Response Strategy Options]

Scenario Percentile	Approximate Spill Volume (gallons)	Time Period		
		Present (2002 –2004)	2005 - 2007	2008 - 2010
20th	<100,000	*Mechanical only*	*Dispersant (low-effect.)*	*Dispersant (high-effect.)*
50th	100,000 – 500,000	*Mechanical only*	*Mechanical + Dispersant (low effect.)*	*Mechanical + Dispersant (high effect.)*
95th	>500,000	*Mechanical only*	*Mechanical + Dispersant (low effect.)*	*Mechanical + Dispersant (high effect.)*

[1]Cost basis refers to cost estimations made for on-water response strategies (including all associated shoreline operations costs) employing mechanical containment and recovery and dispersant application (with low- and high-effectiveness).

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