Financial Implications of Hypothetical San Francisco Bay Oil Spill Scenarios: Response, Socioeconomic, and Natural Resource Damage Costs

Dagmar Schmidt Etkin
Environmental Research Consulting
750 Main Street
Winchester, MA 01890 USA

Deborah French-McCay, Jill Jennings,
Nicole Whittier, Sankar Subbayya,
William Saunders, Colleen Dalton
Applied Science Associates, Inc.
70 Dean Knauss Drive
Narragansett, RI 02882-1143 USA

ABSTRACT

This study provides a comprehensive examination of the use of trajectory modeling to estimate financial impacts of oil spills, including natural resource damages, response costs, and socioeconomic costs, as well as an opportunity to examine how spill size, oil type, response strategy, and probabilistic trajectory factors impact costs. The inclusion of NRDA, response, and socioeconomic costs in the modeling allows for an assessment of the relative proportion of NRDA costs to response and socioeconomic costs to further support the findings of past studies that refute the myth that NRDA costs are the overriding factors in most spill cases. The study demonstrates the overall financial and NRDA benefits of dispersant use. Estimated total bio-economic costs for oil spill scenarios involving four oil types and three spill sizes for two locations in San Francisco Bay, were modeled. Assuming present-day mechanical-only response, total costs range from $30 to $520 million. Estimated total bio-economic costs would be reduced to $11 to $113 million if dispersants were used with high effectiveness. Dispersant use would reduce response costs, and if used effectively, could reduce NRDA and socioeconomic damages substantially, as both of these costs are driven by the amount of surface and shoreline oiling.

INTRODUCTION

The US Army Corps of Engineers San Francisco District is evaluating oil spill risks associated with four submerged rock pinnacles (Harding, Shag, Arch and Blossom Rocks) located adjacent to Alcatraz Island in San Francisco Bay. As these rocks are located near navigation channels, the concern is the potential for a loaded oil tanker or freighter striking these pinnacles and causing an oil spill. The purpose of this study was to evaluate the ecological and financial consequences of such spills using bio-economic oil spill modeling.

METHODOLOGY

Modeling of fates and impacts of oil spills from deep-draft vessel groundings on two submerged rock pinnacles (Shag Rock and Blossom Rock) in different locations in San Francisco Bay was performed using Applied Science Associates modeling software, Spill Impact Model Application Package (SIMAP), for twelve scenarios as shown in Table 1 (French-McCay *et al.* 2002a,b). Shag Rock was selected as representative of Harding, Shag, and Arch Rocks, which are in close proximity to each other (Figure 1). Stochastic results from 100 randomly-selected spill dates for each scenario were used to determine 50^{th} (median) and 95^{th} ("worst") percentile runs *for each scenario in each of the two locations* on which to perform detailed analyses to determine ecological impacts, natural resource damages, and socioeconomic and response costs, *i.e.,* a total of 48 runs – *two locations x four oil types x three spill sizes x two runs*. Median and worst runs were determined based on shoreline impact (taking into account both *total amount* of shoreline oiling and amount of each shoreline type oiled with higher impacts factored in for the shoreline types more difficult and expensive to clean – wetlands and mudflats) for the heavier oils, crude and HFO, and based on *water column impact* for the light fuels, gasoline and diesel, as the shoreline oiling was hypothesized to be the driving factor in costs for the heavy fuel oil (HFO) and crude scenarios and natural resource damages from water column impacts were hypothesized to be the driving factor in costs for the light fuels.

The SIMAP fates model uses wind data, current data, and transport and weathering algorithms to calculate mass balance of fuel components in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, *etc.*), oil pathway over time (trajectory), surface distribution, shoreline oiling, and concentrations of the fuel components in water and sediments. Hourly wind speed and direction data over a long historical period were obtained from four meteorological stations in and just outside the bay. Tidal and other currents were modeled based on known water heights, using a hydrodynamic model based on physical laws, and that conserves mass and momentum. SIMAP was used to evaluate exposure of aquatic habitats and organisms to whole oil and potentially toxic components from the fuels, resulting mortality and ecological losses. NRDA damages were estimated based on costs of restoration.

Trajectory modeling results for each detailed run were used to determine appropriate spill response operations – and associated costs -- based on procedures outlined in local contingency plans and historical case studies for mechanical-recovery operations and two types of dispersant-based responses (low- and high-effectiveness based on Pond *et al.* 2000 as in Table 2) (Etkin *et al.* 2002). SIMAP coastal impact results were used to determine shoreline response costs based on oil- and shoreline type-specific factors. On-water response costs were added to shoreline response costs, as well as to costs for source control, spill management, and state and federal monitoring. Socioeconomic costs, including tourism and recreation income loss, port blockage impacts, park lost-use, and commercial fishing impacts, were determined for each scenario based on on-water response strategy (Etkin *et al.* 2002). Reductions in socioeconomic impacts with dispersant use were calculated based on dispersant effectiveness assumptions (Table 2). A methodology for estimating future cost based on likely dispersant use was also developed.

RESULTS

The costs for the median and worst runs of each scenario for Shag Rock with mechanical recovery as the primary on-water response strategy are shown in Table 3. [Note: All costs in tables have been rounded to the nearest $million.] The corresponding percentages of total costs for each cost category are shown in Table 4. Note that the response costs reflect not only the on-water response costs, but also shoreline cleanup costs, protective booming of sensitive sites as stipulated in the area contingency plan, source control, spill management, and official monitoring. Details of costs for mechanical response operations and socioeconomic costs are presented in Etkin *et al.* 2002. Details on NRDA costs are presented in French-McCay *et al.* 2002a. Costs for median and worst runs for each Shag Rock scenario with low-effectiveness and high-effectiveness dispersant operations as the primary on-water response strategy are shown in Tables 5 – 6, with the corresponding percentages in Tables 7 – 8. Dispersant operations for gasoline scenarios are assumed to be *limited* application of dispersant chemicals to the small amount of fuel that has not evaporated naturally to reduce flammability and explosion hazards. The majority of response costs for the gasoline operations represent protective booming of sensitive locations as per local contingency plans, mobilization of equipment and personnel, monitoring, spill management, and source control. Details of costs for dispersant response operations and socioeconomic costs are shown in Etkin *et al.* 2002. The corresponding results for spills occurring at Blossom Rock are shown in Tables 9 – 14.

The impacts and costs related to the spills naturally depended on the actual trajectory of the oil slicks and shoreline oiling, making for differences in results for the two spill locations, differences in stochastic runs (median and worst) from the same location, differences between oil types (with different behavior), and differences in spill amounts. Bird species affected by oil spills differ for inside versus outside of San Francisco Bay. For the diesel and gasoline spills, which evaporate and disperse rapidly, the majority of estimated bird kills are for waterfowl (diving ducks and grebes inside the bay) and seabirds (murres outside the bay), as these groups are in open waters first affected by the spill. For the crude and heavy fuel oil spills, waders and shorebirds on shorelines and flats are most affected because of the much higher shoreline impact. From the SIMAP model estimates, diesel and crude spills would impact the highest number of birds (as a total of all species). The diesel and crude spills have a larger impact on water column biota than HFO spills, because heavier fuels emulsify rapidly, minimizing entrainment and dissolution into the water. Only the crude and diesel spills were estimated to have significant impacts on fish and water column invertebrates. Gasoline is less toxic and volatilizes quickly, minimizing water column exposure. The majority of the fish and invertebrate injuries were squid and small pelagic fish, such as herring.

NRDA costs were based on estimated costs to restore equivalent resources and/or ecological services. According to Habitat Equivalency Analysis (HEA) and Resource Equivalency Analysis (REA)-scaled calculations, crude and diesel spills would be the most expensive spills when deriving projects to restore habitat and wildlife lost. Of the four oils modeled, the least expensive spill in terms of restoration costs would be a gasoline spill of small volume. Seabird restoration costs are relatively higher for Shag Rock than Blossom Rock spills, because oil is more likely to exit the bay originating from Shag Rock and there are much higher abundances of seabirds outside the bay. Other wildlife restoration costs are relatively lower for Shag Rock than Blossom Rock spills, because of much higher abundances of waterfowl and waders inside the bay. The fish and invertebrate restoration costs are in all cases much lower than the wildlife costs. For gasoline and heavy fuel oil spills, fish and invertebrate restoration costs are typically very low and an insignificant percentage of the damages, except in rare events for larger spills.

Response costs were higher for mechanical recovery-based operations than for dispersant-based operations, as well as for the more persistent oils (crude and HFO). While responses to most US spills have entailed mechanical containment and recovery methodology, risk assessment studies on San Francisco Bay (Pond *et al.* 2000) and changes in state and national dispersant use policy indicate that dispersants will likely become a first-order response option for this region within the next few years. Any comprehensive analysis of response costs and cost projections for the next decade should properly involve an examination of dispersant costs in addition to mechanical recovery costs. In the future, spill responses will likely employ a combination of response strategies. The cost projections for a combined response strategy can be proportionately extrapolated from the costs for the different strategies as shown in Table 15.

An oil spill can have serious socioeconomic impacts on the San Francisco Bay area, as it is a major shipping port and tourist and recreation area. Impacts estimated in the socioeconomic cost modeling analysis 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). Modeling results show that even the *smallest* spill evaluated that would be 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.

In comparing cost categories, socioeconomic and response costs are generally much higher than NRDA costs for crude and HFO spills, because of the relatively large response effort and persistence of the oil. For light fuels, where response costs are relatively lower, socioeconomic costs predominate. NRDA costs may be of similar order of magnitude under worst conditions (95^{th} impact percentile). However, NRDA costs are typically 20% or less under 50^{th} percentile impact conditions. NRDA costs vary considerably by spill condition, whereas socioeconomic and response costs are more similar under median versus worst conditions. Some cases involve high biological impacts and NRDA damages, while most are modest in NRDA cost.

An interesting result is that NRDA costs are, on average, modest in comparison to response and socioeconomic costs. NRDA costs are often described as being very high for oil spills, much higher than response costs, and the largest monetary liability for the responsible party. These results show that, often, socioeconomic costs can dwarf the NRDA and response costs, and that response costs are usually much higher than NRDA costs, a result that further supports the work of Helton *et al.* (1997, 1999). Exceptions occur when birds are highly abundant, in certain months of the year (*e.g.*, murres in summer and waterfowl in winter) or when aggregated in specific habitats (*e.g*., shorebirds in mudflats). In the central bay area that would be affected by spills resulting from groundings on the pinnacles, the water is very deep, currents are strong, and natural dispersion rates are high. Thus, the water column impacts of the spills examined were relatively low in consideration of the large volumes spilled. Thus, the NRDA costs are driven by the impacts to birds, of which there are several highly vulnerable species in the area.

Estimated total bio-economic costs for these spills, assuming present-day mechanical-only response, range from $30 to $520 million. Estimated total bio-economic costs would be reduced to $11 to $113 million if dispersants were used with high effectiveness. Dispersant use would reduce response costs, and if used effectively, could reduce NRDA and socioeconomic damages substantially, as both of these costs are driven by the amount of surface and shoreline oiling.

CONCLUSIONS

This study provides a comprehensive examination of both the use of modeling to estimate the financial impacts of oil spills, as well as an opportunity to examine how spill size, oil type, response strategy, and probabilistic trajectory factors impact costs. The inclusion of NRDA, response, and socioeconomic costs in the modeling allows for an assessment of the relative proportion of NRDA costs to response and socioeconomic costs to further support the findings of past studies that refute the myth that NRDA costs are the overriding factors in most spill cases. The study also demonstrates the overall financial and NRDA benefits of dispersant use.

ACKNOWLEDGEMENTS

This study was funded by US Army Corps of Engineers, San Francisco District (Contract DACW07-01-R-0001). Applied Science Associates, Inc., was the prime contractor with Environmental Research Consulting as a subcontractor.

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.

REFERENCES

Etkin, D.S., D.French-McCay, N. Whittier, S. Sankaranarayanan, and J. Jennings. 2002. Modeling of response, socioeconomic, and natural resource damage costs for hypothetical oil spill scenarios in San Francisco Bay. *Proc. 25th Arctic & Marine Oilspill Prog. Tech. Sem.*: 1,075 – 1,102.

French McCay, D, J. Jennings, N. Whittier, S. Subbayya, W. Saunders and C. Dalton, 2002a. Draft Final Report, San Francisco Rocks Removal Study Bio-Economic Oil Spill Modeling: Shag and Blossom Rock Spills, Contract DACW07-01-C-0018, US Army Corps of Engineers, Sacramento District, Sacramento, CA, July 2002.

French-McCay, D., N.Whittier, S. Sankaranarayanan, J. Jennings, and D.S. Etkin. 2002b. Modeling fates and impacts for bio-economic analysis of hypothetical oil spill scenarios in San Francisco Bay. *Proc. 25th Arctic & Marine Oilspill Program Tech. Sem.*: 1,051 – 1,074.

Helton, D., and T. Penn. 1999. Putting response and natural resource damage costs into perspective. *Proc.1999 International Oil Spill Conference:* 577-583.

Helton, D., T. Penn, and R. Hicks. 1997. The costs of oil spills: Putting response and natural resource damage costs into perspective. *Proc. 20th Arctic & Marine Oilspill Prog. Tech. Sem*: 981-994.

Pond, R.G., D.V. Aurand, and J.A. Kraly. 2000. *Ecological Risk Assessment Principles Applied to Oil Spill Response Planning in the San Francisco Bay Area.* California Office of Spill Prevention & Response, Calif. Dept. Fish & Game, Sacramento, California, USA, 200 pp.

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

Oil Type	20th Percentile	50th Percentile	95th 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 x spg.). Specific gravity (spg.) for gasoline = 0.74; spg. for diesel = 0.83; spg. for crude = 0.90; spg. for HFO = 0.92.

Table 2: Assumed Dispersant Effectiveness for Dispersant-Response Operations

Dispersant Operation	Oil Type			
	Diesel	**Gasoline[1]**	**HFO**	**Crude**
Low-Effectiveness	40%	40%	35%	40%
High-Effectiveness	80%	80%	70%	80%

Based on Pond *et al.* 2000. [1]Dispersants used only on gasoline remaining on water surface after most has evaporated naturally to reduce flammability explosion hazard.

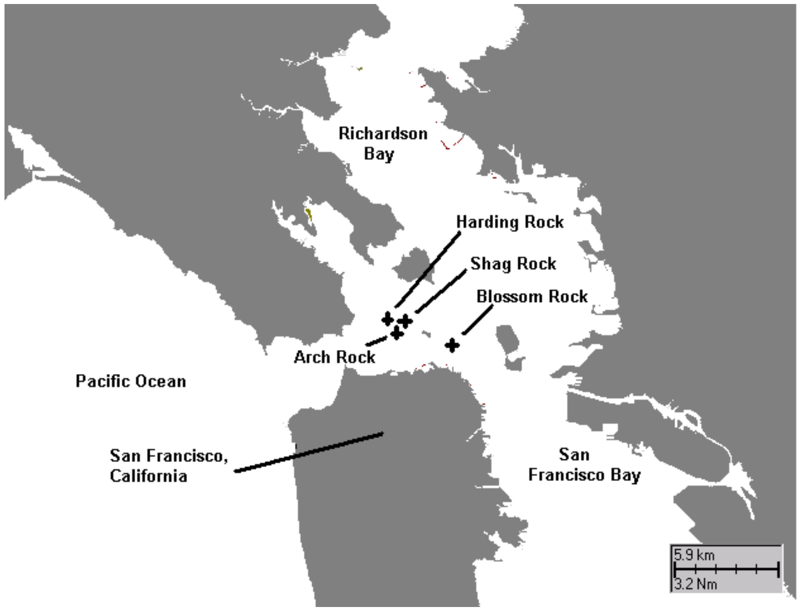

Table 3: Costs for Shag Rock Spills: Mechanical Response (2001 $)						
Oil Type	**Gallons**	**Impact**	**NRDA Costs**	**Socioeconomic**	**Response[1]**	**Total**
Diesel	**50,000**	**median**	$3,000,000	$28,000,000	$12,000,000	$44,000,000
		worst	$9,000,000	$26,000,000	$14,000,000	$49,000,000
	270,000	**median**	$15,000,000	$53,000,000	$19,000,000	$87,000,000
		worst	$56,000,000	$56,000,000	$13,000,000	$125,000,000
	1,250,000	**median**	$33,000,000	$135,000,000	$27,000,000	$194,000,000
		worst	$83,000,000	$133,000,000	$32,000,000	$248,000,000
Gasoline	**50,000**	**median**	$2,000,000	$22,000,000	$10,000,000	$34,000,000
		worst	$7,000,000	$20,000,000	$10,000,000	$37,000,000
	270,000	**median**	$6,000,000	$49,000,000	$11,000,000	$66,000,000
		worst	$36,000,000	$48,000,000	$11,000,000	$95,000,000
	1,250,000	**median**	$9,000,000	$111,000,000	$13,000,000	$133,000,000
		worst	$38,000,000	$110,000,000	$15,000,000	$163,000,000
HFO	**25,000**	**median**	$1,000,000	$21,000,000	$12,000,000	$33,000,000
		worst	$1,000,000	$21,000,000	$14,000,000	$36,000,000
	100,000	**median**	$2,000,000	$56,000,000	$35,000,000	$93,000,000
		worst	$4,000,000	$52,000,000	$51,000,000	$107,000,000
	410,000	**median**	$3,000,000	$97,000,000	$78,000,000	$179,000,000
		worst	$7,000,000	$91,000,000	$122,000,000	$220,000,000
Crude	**100,000**	**median**	$18,000,000	$33,000,000	$30,000,000	$80,000,000
		worst	$51,000,000	$29,000,000	$36,000,000	$116,000,000
	600,000	**median**	$14,000,000	$81,000,000	$65,000,000	$160,000,000
		worst	$23,000,000	$91,000,000	$84,000,000	$198,000,000
	3,000,000	**median**	$26,000,000	$189,000,000	$182,000,000	$397,000,000
		worst	$94,000,000	$195,000,000	$230,000,000	$519,000,000

[1]Including on-water/shoreline response, source control, monitoring/management, booming

Table 4: % Costs for Shag Rock Spills (Median/Worst Scenarios) Mechanical Response (2001 $)												
Cost Type	**Spill Scenario**											
	Diesel			**Gasoline**			**HFO**			**Crude**		
	20th	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**
NRDA	8% **18%**	18% **45%**	17% **33%**	6% **18%**	10% **38%**	6% **23%**	2% **4%**	3% **4%**	2% **3%**	23% **44%**	9% **12%**	6% **18%**
Socio-economic	64% **53%**	61% **45%**	69% **54%**	65% **55%**	74% **50%**	83% **68%**	63% **57%**	60% **49%**	55% **41%**	41% **25%**	51% **46%**	48% **38%**
Response	28% **30%**	22% **10%**	14% **13%**	29% **27%**	17% **12%**	10% **9%**	35% **39%**	38% **47%**	44% **56%**	37% **31%**	41% **42%**	46% **44%**
Bold-faced number is for worst percentile; regular-faced number is for median percentile												

Table 5: Costs for Shag Rock Spills: Low-Effective Dispersant Response[1] (2001 $)						
Oil Type	**Gallons**	**Impact**	**NRDA Costs**	**Socioeconomic**	**Response[2]**	**Total**
Diesel	**50,000**	**median**	$2,000,000	$21,000,000	$10,000,000	$33,000,000
		worst	$5,000,000	$17,000,000	$12,000,000	$34,000,000
	270,000	**median**	$9,000,000	$34,000,000	$14,000,000	$57,000,000
		worst	$33,000,000	$35,000,000	$11,000,000	$79,000,000
	1,250,000	**median**	$20,000,000	$86,000,000	$19,000,000	$125,000,000
		worst	$50,000,000	$84,000,000	$22,000,000	$156,000,000
Gasoline	**50,000**	**median**	$1,000,000	$15,000,000	$9,000,000	$25,000,000
		worst	$4,000,000	$13,000,000	$9,000,000	$26,000,000
	270,000	**median**	$4,000,000	$31,000,000	$10,000,000	$45,000,000
		worst	$22,000,000	$29,000,000	$10,000,000	$61,000,000
	1,250,000	**median**	$5,000,000	$67,000,000	$12,000,000	$84,000,000
		worst	$23,000,000	$67,000,000	$13,000,000	$102,000,000
HFO	**25,000**	**median**	$440,000	$14,000,000	$8,000,000	$22,000,000
		worst	$1,000,000	$14,000,000	$9,000,000	$24,000,000
	100,000	**median**	$2,000,000	$39,000,000	$20,000,000	$61,000,000
		worst	$3,000,000	$36,000,000	$30,000,000	$69,000,000
	410,000	**median**	$2,000,000	$65,000,000	$41,000,000	$108,000,000
		worst	$5,000,000	$61,000,000	$70,000,000	$135,000,000
Crude	**100,000**	**median**	$11,000,000	$20,000,000	$18,000,000	$50,000,000
		worst	$31,000,000	$18,000,000	$22,000,000	$71,000,000
	600,000	**median**	$8,000,000	$50,000,000	$31,000,000	$89,000,000
		worst	$14,000,000	$59,000,000	$42,000,000	$115,000,000
	3,000,000	**median**	$15,000,000	$117,000,000	$71,000,000	$204,000,000
		worst	$56,000,000	$121,000,000	$100,000,000	$278,000,000
[1]Dispersant effectiveness defined in Table 2. [2]Costs include on-water mechanical response, all shoreline cleanup, source control, monitoring, protective booming, spill management						

Table 6: % Costs for Shag Rock Spills (Median/Worst Scenarios) Low-Effective Dispersant Response (2001 $)												
Cost Type	**Spill Scenario**											
	Diesel			**Gasoline**			**HFO**			**Crude**		
	20th	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**
NRDA	6%	16%	16%	5%	9%	6%	2%	3%	2%	22%	9%	8%
	15%	**42%**	**32%**	**16%**	**36%**	**22%**	**4%**	**4%**	**3%**	**43%**	**12%**	**20%**
Socio-economic	62%	59%	69%	59%	70%	80%	63%	64%	60%	41%	56%	57%
	50%	**44%**	**54%**	**49%**	**48%**	**65%**	**58%**	**52%**	**45%**	**25%**	**51%**	**44%**
Response	31%	25%	16%	37%	22%	14%	35%	33%	38%	37%	35%	35%
	35%	**13%**	**14%**	**35%**	**16%**	**12%**	**38%**	**44%**	**52%**	**31%**	**37%**	**46%**
Bold-faced number is for worst percentile; regular-faced number is for median percentile												

Table 7: Costs for Shag Rock Spills: High-Effective Dispersant Response[1] (2001 $)						
Oil Type	**Gallons**	**Impact**	**NRDA Costs**	**Socioeconomic**	**Response[2]**	**Total**
Diesel	**50,000**	**median**	$1,000,000	$13,000,000	$10,000,000	$24,000,000
		worst	$2,000,000	$8,000,000	$10,000,000	$20,000,000
	270,000	**median**	$3,000,000	$15,000,000	$11,000,000	$29,000,000
		worst	$11,000,000	$15,000,000	$10,000,000	$36,000,000
	1,250,000	**median**	$7,000,000	$36,000,000	$15,000,000	$57,000,000
		worst	$17,000,000	$35,000,000	$15,000,000	$67,000,000
Gasoline	**50,000**	**median**	$400,000	$7,000,000	$9,000,000	$17,000,000
		worst	$1,000,000	$5,000,000	$9,000,000	$16,000,000
	270,000	**median**	$1,000,000	$14,000,000	$10,000,000	$25,000,000
		worst	$7,000,000	$10,000,000	$10,000,000	$27,000,000
	1,250,000	**median**	$2,000,000	$23,000,000	$11,000,000	$36,000,000
		worst	$8,000,000	$23,000,000	$12,000,000	$42,000,000
HFO	**25,000**	**median**	$440,000	$5,000,000	$6,000,000	$12,000,000
		worst	$400,000	$8,000,000	$7,000,000	$15,000,000
	100,000	**median**	$1,000,000	$22,000,000	$12,000,000	$35,000,000
		worst	$1,000,000	$20,000,000	$17,000,000	$38,000,000
	410,000	**median**	$1,000,000	$32,000,000	$23,000,000	$56,000,000
		worst	$2,000,000	$31,000,000	$36,000,000	$69,000,000
Crude	**100,000**	**median**	$4,000,000	$8,000,000	$15,000,000	$27,000,000
		worst	$10,000,000	$7,000,000	$16,000,000	$33,000,000
	600,000	**median**	$3,000,000	$18,000,000	$20,000,000	$41,000,000
		worst	$5,000,000	$26,000,000	$23,000,000	$54,000,000
	3,000,000	**median**	$5,000,000	$45,000,000	$38,000,000	$88,000,000
		worst	$19,000,000	$47,000,000	$47,000,000	$113,000,000
[1]Dispersant effectiveness defined in Table 2. [2]Costs include on-water mechanical response, all shoreline cleanup, source control, monitoring, protective booming, spill management						

Table 8: % Costs for Shag Rock Spills (Median/Worst Scenarios) High-Effective Dispersant Response (2001 $)												
Cost Type	Spill Scenario											
	Diesel			Gasoline			HFO			Crude		
	20th	50th	95th	20th	50th	95th	20th	50th	95th	20th	50th	95th
NRDA	3% **9%**	11% **31%**	11% **25%**	2% **8%**	5% **27%**	5% **18%**	2% **3%**	2% **3%**	2% **3%**	14% **31%**	7% **9%**	6% **17%**
Socio-economic	56% **42%**	51% **41%**	63% **52%**	43% **34%**	56% **38%**	64% **54%**	44% **51%**	63% **52%**	58% **45%**	31% **21%**	45% **48%**	51% **42%**
Response	41% **50%**	38% **28%**	25% **23%**	55% **58%**	39% **35%**	32% **28%**	54% **47%**	35% **45%**	40% **52%**	55% **48%**	48% **43%**	43% **42%**
Bold-faced number is for worst percentile; regular-faced number is for median percentile												

Table 9: Costs for Blossom Rock Spills: Mechanical Response (2001 $)						
Oil Type	Gallons	Impact	NRDA Costs	Socioeconomic	Response[1]	Total
Diesel	50,000	median	$13,000,000	$23,000,000	$11,000,000	$47,000,000
		worst	$28,000,000	$20,000,000	$11,000,000	$59,000,000
	270,000	median	$13,000,000	$54,000,000	$14,000,000	$81,000,000
		worst	$69,000,000	$44,000,000	$18,000,000	$132,000,000
	1,250,000	median	$29,000,000	$130,000,000	$30,000,000	$189,000,000
		worst	$57,000,000	$111,000,000	$23,000,000	$191,000,000
Gasoline	50,000	median	$1,000,000	$20,000,000	$10,000,000	$31,000,000
		worst	$2,000,000	$20,000,000	$10,000,000	$33,000,000
	270,000	median	$1,000,000	$46,000,000	$11,000,000	$59,000,000
		worst	$6,000,000	$50,000,000	$11,000,000	$67,000,000
	1,250,000	median	$11,000,000	$116,000,000	$14,000,000	$141,000,000
		worst	$62,000,000	$114,000,000	$14,000,000	$189,000,000
HFO	25,000	median	$2,000,000	$23,000,000	$12,000,000	$36,000,000
		worst	$4,000,000	$26,000,000	$14,000,000	$43,000,000
	100,000	median	$14,000,000	$50,000,000	$26,000,000	$90,000,000
		worst	$43,000,000	$47,000,000	$33,000,000	$123,000,000
	410,000	median	$20,000,000	$91,000,000	$64,000,000	$175,000,000
		worst	$24,000,000	$82,000,000	$80,000,000	$186,000,000
Crude	100,000	median	$55,000,000	$32,000,000	$28,000,000	$115,000,000
		worst	$120,000,000	$28,000,000	$34,000,000	$182,000,000
	600,000	median	$9,000,000	$85,000,000	$61,000,000	$155,000,000
		worst	$15,000,000	$82,000,000	$74,000,000	$171,000,000
	3,000,000	median	$21,000,000	$192,000,000	$169,000,000	$383,000,000
		worst	$70,000,000	$200,000,000	$193,000,000	$463,000,000
[1]Costs include on-water response, shoreline cleanup, source control, monitoring, protective booming, spill management						

Table 10: % Costs for Blossom Rock Spills (Median/Worst Scenarios) Mechanical Response (2001 $)

Cost Type	Spill Scenario											
	Diesel			Gasoline			HFO			Crude		
	20th	50th	95th	20th	50th	95th	20th	50th	95th	20th	50th	95th
NRDA	28% **48%**	16% **53%**	15% **30%**	4% **7%**	2% **10%**	7% **33%**	5% **8%**	16% **35%**	12% **13%**	48% **66%**	6% **9%**	6% **15%**
Socio-economic	49% **34%**	66% **34%**	69% **58%**	63% **62%**	79% **74%**	83% **60%**	62% **59%**	55% **38%**	53% **44%**	28% **15%**	55% **48%**	50% **43%**
Response	23% **18%**	18% **14%**	16% **12%**	32% **31%**	19% **16%**	10% **7%**	33% **33%**	29% **27%**	36% **43%**	24% **19%**	39% **43%**	44% **42%**

Bold-faced number is for worst percentile; regular-faced number is for median percentile

Table 11: Costs for Blossom Rock Spills: Low-Effective Dispersant Response[1] (2001 $)

Oil Type	Gallons	Impact	NRDA Costs	Socioeconomic	Response[2]	Total
Diesel	50,000	median	$8,000,000	$15,000,000	$9,000,000	$33,000,000
		worst	$17,000,000	$12,000,000	$10,000,000	$38,000,000
	270,000	median	$8,000,000	$35,000,000	$11,000,000	$54,000,000
		worst	$42,000,000	$27,000,000	$14,000,000	$82,000,000
	1,250,000	median	$17,000,000	$79,000,000	$21,000,000	$118,000,000
		worst	$34,000,000	$67,000,000	$17,000,000	$118,000,000
Gasoline	50,000	median	$1,000,000	$13,000,000	$9,000,000	$23,000,000
		worst	$1,000,000	$13,000,000	$9,000,000	$23,000,000
	270,000	median	$1,000,000	$29,000,000	$10,000,000	$39,000,000
		worst	$4,000,000	$32,000,000	$10,000,000	$45,000,000
	1,250,000	median	$6,000,000	$72,000,000	$12,000,000	$90,000,000
		worst	$37,000,000	$69,000,000	$12,000,000	$118,000,000
HFO	25,000	median	$1,000,000	$16,000,000	$8,000,000	$25,000,000
		worst	$2,000,000	$19,000,000	$9,000,000	$31,000,000
	100,000	median	$9,000,000	$34,000,000	$14,000,000	$58,000,000
		worst	$28,000,000	$31,000,000	$19,000,000	$78,000,000
	410,000	median	$13,000,000	$62,000,000	$32,000,000	$107,000,000
		worst	$16,000,000	$54,000,000	$42,000,000	$112,000,000
Crude	100,000	median	$33,000,000	$20,000,000	$17,000,000	$71,000,000
		worst	$72,000,000	$18,000,000	$21,000,000	$111,000,000
	600,000	median	$6,000,000	$55,000,000	$29,000,000	$89,000,000
		worst	$9,000,000	$52,000,000	$36,000,000	$97,000,000
	3,000,000	median	$13,000,000	$121,000,000	$64,000,000	$197,000,000
		worst	$42,000,000	$127,000,000	$78,000,000	$247,000,000

[1]Dispersant effectiveness defined in Table 2. [2]Costs include on-water mechanical response, all shoreline cleanup, source control, monitoring, protective booming, spill management

Table 12: % Costs for Blossom Rock Spills (Median/Worst Scenarios) Low-Effective Response (2001 $)												
Cost Type	**Spill Scenario**											
	Diesel			**Gasoline**			**HFO**			**Crude**		
	20th	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**
NRDA	24% **44%**	15% **51%**	15% **29%**	4% **6%**	2% **9%**	7% **31%**	5% **7%**	16% **36%**	12% **14%**	47% **65%**	6% **10%**	7% **17%**
Socio-economic	47% **31%**	64% **33%**	67% **57%**	56% **55%**	73% **70%**	80% **59%**	64% **62%**	59% **40%**	58% **48%**	29% **16%**	62% **53%**	61% **51%**
Response	29% **25%**	21% **16%**	28% **14%**	41% **39%**	25% **21%**	13% **10%**	31% **30%**	24% **24%**	30% **38%**	25% **19%**	32% **37%**	32% **32%**
Bold-faced number is for worst percentile; regular-faced number is for median percentile												

Table 13: Costs for Blossom Rock Spills: High-Effective Dispersant Response[1] (2001 $)						
Oil Type	**Gallons**	**Impact**	**NRDA Costs**	**Socioeconomic**	**Response[2]**	**Total**
Diesel	**50,000**	**median**	$3,000,000	$8,000,000	$9,000,000	$20,000,000
		worst	$6,000,000	$4,000,000	$9,000,000	$19,000,000
	270,000	**median**	$3,000,000	$16,000,000	$10,000,000	$29,000,000
		worst	$14,000,000	$9,000,000	$11,000,000	$34,000,000
	1,250,000	**median**	$6,000,000	$29,000,000	$15,000,000	$49,000,000
		worst	$11,000,000	$23,000,000	$14,000,000	$48,000,000
Gasoline	**50,000**	**median**	$300,000	$5,000,000	$9,000,000	$15,000,000
		worst	$400,000	$6,000,000	$9,000,000	$15,000,000
	270,000	**median**	$300,000	$12,000,000	$10,000,000	$21,000,000
		worst	$1,000,000	$14,000,000	$10,000,000	$25,000,000
	1,250,000	**median**	$2,000,000	$28,000,000	$12,000,000	$42,000,000
		worst	$12,000,000	$25,000,000	$12,000,000	$49,000,000
HFO	**25,000**	**median**	$1,000,000	$10,000,000	$6,000,000	$17,000,000
		worst	$1,000,000	$13,000,000	$7,000,000	$21,000,000
	100,000	**median**	$4,000,000	$19,000,000	$10,000,000	$33,000,000
		worst	$13,000,000	$15,000,000	$12,000,000	$40,000,000
	410,000	**median**	$6,000,000	$33,000,000	$18,000,000	$58,000,000
		worst	$7,000,000	$26,000,000	$23,000,000	$57,000,000
Crude	**100,000**	**median**	$11,000,000	$8,000,000	$14,000,000	$34,000,000
		worst	$24,000,000	$7,000,000	$15,000,000	$47,000,000
	600,000	**median**	$2,000,000	$25,000,000	$19,000,000	$46,000,000
		worst	$3,000,000	$21,000,000	$21,000,000	$46,000,000
	3,000,000	**median**	$4,000,000	$49,000,000	$35,000,000	$89,000,000
		worst	$14,000,000	$54,000,000	$40,000,000	$108,000,000
[1]Dispersant effectiveness defined in Table 2. [2]Costs include on-water mechanical response, all shoreline cleanup, source control, monitoring, protective booming, spill management						

Table 14: % Costs for Blossom Rock Spills (Median/Worst Scenarios) High-Effective Response (2001 $)												
Cost Type	**Spill Scenario**											
	Diesel			**Gasoline**			**HFO**			**Crude**		
	20th	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**	**20th**	**50th**	**95th**
NRDA	13% **29%**	9% **41%**	12% **24%**	2% **3%**	1% **5%**	5% **25%**	3% **5%**	13% **32%**	11% **13%**	33% **51%**	4% **7%**	5% **13%**
Socio-economic	39% **22%**	55% **27%**	58% **48%**	36% **37%**	54% **56%**	67% **51%**	59% **61%**	58% **39%**	58% **46%**	25% **15%**	55% **47%**	55% **50%**
Response	47% **48%**	35% **32%**	31% **28%**	62% **60%**	45% **38%**	28% **48%**	38% **34%**	29% **29%**	32% **41%**	42% **33%**	41% **47%**	40% **37%**
Bold-faced number is for worst percentile; regular-faced number is for median percentile												

Table 15: Weighting of Mechanical and Dispersant Efforts For Future Spill Responses[1,2]						
Volume (gallons)	**Year**					
	2005	**2006**	**2007**	**2008**	**2009**	**2010**
<100,000	$0.8D_l + 0.2M$	$0.85D_l + 0.15M$	$0.9D_l + 0.1M$	$0.9D_h + 0.1M$	$0.95D_h + 0.05M$	$0.99D_h + 0.01M$
100,000 to 500,000	$0.7D_l + 0.3M$	$0.75D_l + 0.25M$	$0.8D_l + 0.2M$	$0.8D_h + 0.2M$	$0.85D_h + 0.15M$	$0.9D_h + 0.1M$
>500,000	$0.6D_l + 0.4M$	$0.7D_l + 0.3M$	$0.75D_l + 0.25M$	$0.75D_h + 0.25M$	$0.8D_h + 0.2M$	$0.85D_h + 0.15M$

[1] D_l = low-effectiveness dispersant application effort; D_h = high-effectiveness dispersant application effort; M = mechanical containment and recovery effort
[2] The equations presented refer to the weighting of the relative *effort* from each of the response strategies. The estimated *costs* associated these response efforts are shown in Tables 3 – 14. Costs in these tables when applied to future spills would have to be adjusted by approximately 2.5% annually from the year 2002 or the Consumer Price Index increase as appropriate.

CAPTIONS
(Note titles for tables appear as the first line of each table).

Fig. 1: San Francisco Bay, California, USA, showing submerged rock pinnacles