Effectiveness of Larger-Area Exclusion Booming to Protect Sensitive Sites in San Francisco Bay

Final Report

Prepared for

California Department of Fish & Game
Oil Spill Prevention and Response (OSPR)
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ENVIRONMENTAL RESEARCH CONSULTING

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[1] NOAA photo

Executive Summary

This study examined the potential benefits of adding alternative booming to certain areas of concern in San Francisco Bay, sites that had particular natural or socioeconomic resources that would merit additional protection during a spill, if only seasonally.

There were mixed results with regard to the effectiveness of the alternative booming strategies over the existing booming strategies specified in the Area Contingency Plan (ACP).

San Francisco Bay has many sensitive sites, as well as a particularly challenging current system that will not allow booms, both as protection and for containment purposes during on-water recovery operations. In some of the hypothetical spill scenarios (e.g., Grizzly Bay) there was clearly no benefit to the alternative booming unless it could be conducted in such a way so as to overcome the currents that reduced boom effectiveness and allowed entrainment and other boom failures.

In some of the individual scenarios, the oil type played a role in determining the results. For example, at Bay Farm Island, for the diesel spill the alternative booming gave virtually no benefit in protection due to the relatively small amount of oil that would be kept out of the area (an estimated 12 gallons). On the other hand, there appeared to be a definite benefit for HFO and crude oil spills that might impact this site.

For the scenarios in Oakland Harbor, the additional alternative booming did not have any enhancing effect on the protection already provided by ACP booms.

The Berkeley alternative booming offered enhanced protection and thus netted benefits over the existing ACP booming strategy, particularly for HFO spills.

The alternative booming at Ryer Island and Freeman Island might provide some benefits if the spill occurred during a time in which there were particularly susceptible natural resources at risk, particularly migratory or nesting birds.

Overall, the decision to add additional alternative booms at these locations should depend on the particular seasonal resources at risk at the time of the spill, as well as whether the trajectory of the spill appears to indicate a direct or nearly direct hit on these sites. There may also be benefits that cannot be quantified, such as political and social concerns.

It is important to keep in mind that this study examined the specific benefits of alternative booming strategies for specific scenarios. It did not examine the benefits of overall effectiveness in on-water removal operations, which are rarely more than 10 – 25% effective, particularly in areas of high current such as San Francisco Bay.

Abstract
The effectiveness of strategic placement of large deflective, exclusionary booms in addition to shoreline protection tactics was examined with regard to a variety of spill scenarios in San Francisco Bay. Theoretically, the placement of such booms should potentially reduce the impacts to natural and socio-economic sensitive sites, but there are considerable logistical and practical issues that need to be considered before implementing such strategies in response plans. This study examines these issues for modeled spills of heavy fuel and crude oil originating at several locations in San Francisco Bay as described in a companion report by Applied Science Associates, Inc. (ASA)[2]. The hypothetical spill scenarios were analyzed with regard to the potential reduction of shoreline impact and response needs for a number of alternative booming strategies in localized areas of concern.

This project examines two hypotheses:

- Increased deployment of exclusionary or deflection booming will result in reductions of impacts to ecological and socioeconomic resources; and

- Increased deployment of exclusionary or deflection booming will result in reductions of the costs of a spill – Shoreline response costs will be the focus of the analysis, taking into account the costs of acquiring and maintaining additional equipment and capabilities to protect the additional shoreline locations of concern.

Introduction
Spill response planners and area committees are often tasked with developing strategic plans for protecting sensitive shoreline resources in the event of an oil spill. As with many other states in the US, the state of California incorporates specifications for booming of particular sites to keep oil out of sites that stakeholders have noted as being particularly sensitive with regard to ecological or socioeconomic value.

Experiences from past spills, notably the 2007 M/V Cosco Busan spill in San Francisco Bay, have prompted California state regulators to question whether existing booming strategies are sufficient for providing the best achievable protection for sensitive sites. Specifically, the Office of Spill Prevention and Response (OSPR) wanted to test the hypothesis that adding large-area exclusionary booming in addition to boom deployments already designated in the Area Contingency Plan (ACP) would significantly reduce oiling of locations that are of particular concern due to their environmental sensitivity.

San Francisco Bay presents a number of significant challenges for spill responders, including high currents in numerous locations (see Figure 2), tidal movement of oil in and out of the bay through the Golden Gate, the propensity for the oil to spread widely after several tidal cycles, and multiple sensitive areas to protect.

[2] Portions of Phase 1 of this research were presented in the papers Etkin et al. 2008 and French-McCay et al. 2008.

Figure 1: Container ship Cosco Busan after allision with Bay Bridge in San Francisco in November 2007 showing large gash in hull that spilled 53,000 gallons of HFO[3,4]

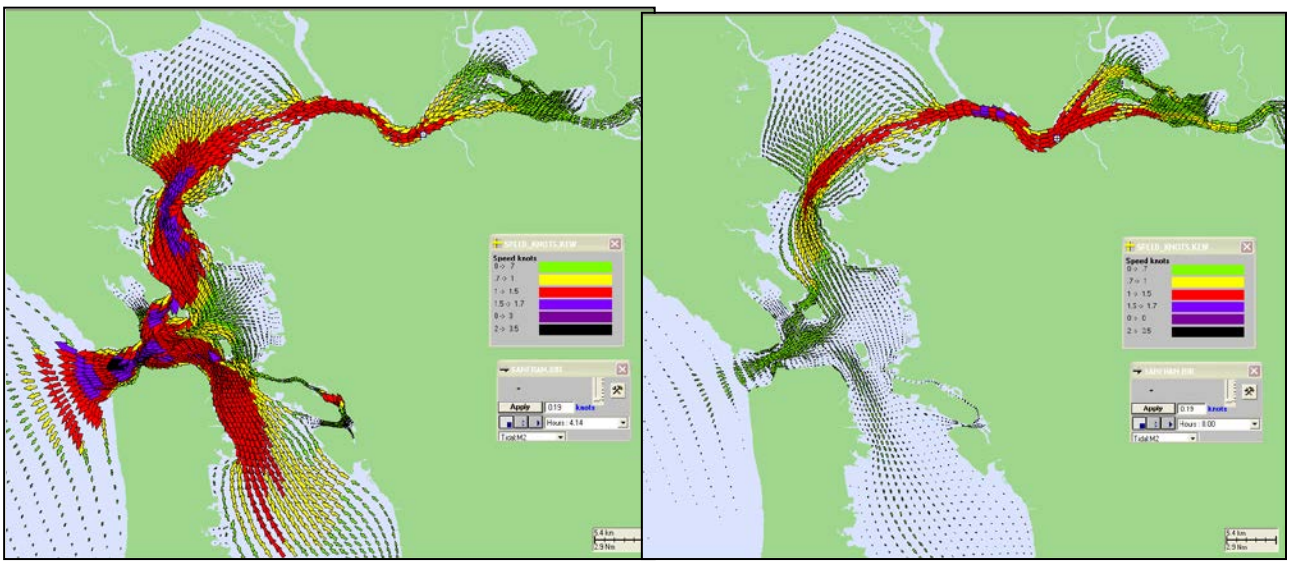


Figure 2: Currents exceed boom capability (>1 kt) in areas in red, purple, and black. Fast-water booming strategies must be used for boom effectiveness.

This project addresses several OSPR program goals:

a) Investigation and evaluation of applied prevention and response programs and technologies;
b) The effects of oil on fish, wildlife, habitat, and water quality;
c) The effects of spill response activities on fish, wildlife, habitat and water quality; and
d) Best achievable protection strategies.

[3] Heavy fuel oil
[4] NOAA photo

While the focus of the study is described by goal (a) or (d), the analysis will provide quantitative estimates of impacts of oil (b), quantify how those impacts would change with alternate response strategies (c), and utilize modeling to estimate injuries from which compensatory restoration scaling may be used to estimate natural resource damages.

Modeling Approach

Modeling of hypothetical spills and alternative response strategies using SIMAP, as described in French-McCay et al. (2008), allowed this hypothesis to be tested. The approach involves three-dimensional modeling of trajectories and fates of hypothetical spills with various spill responses added and comparing the shoreline oiling and impacts of alternative response modes with a no response control scenario.

This modeling approach has been previously applied to evaluate response efficacy in a number of previous studies (Etkin et al., 2002, 2003, 2005, 2006a, 2006b, 2007a, 2007b; French-McCay et al., 2005, 2006).[5]

Phase 1 Scenarios

Hypothetical spills of 100,000 gallons of heavy fuel oil at three locations in the San Francisco Bay, California, area were selected for modeling and analysis in Phase 1 of the study. The three oil release points were: (1) near the San Francisco Docks, (2) at Richmond Long Wharf, and (3) at Martinez in Carquinez Strait, as shown in Figure 3.

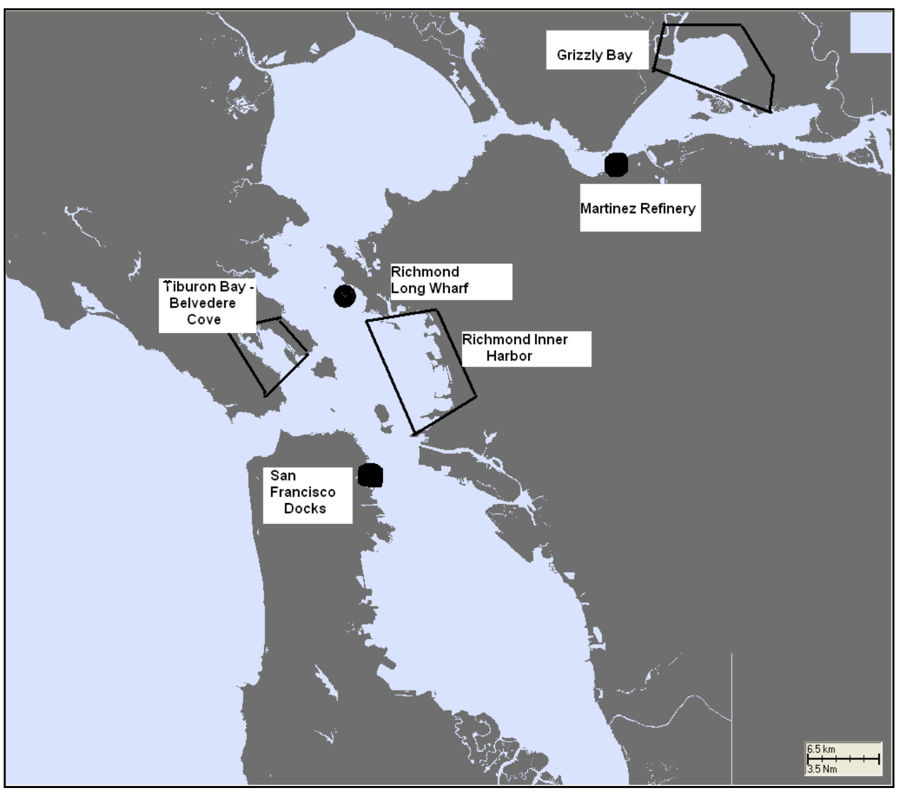


Figure 3: Oil spill release points and study areas for Phase 1 hypothetical modeling in San Francisco Bay

[5] The modeling for this particular study is described in greater detail in French-McCay et al. 2008 and the companion report to this report from Applied Science Associates (French-McCay and Rowe 2009).

For each spill scenario, a particular location for protective booming was evaluated. As described in the companion report[6] (and in French-McCay et al. 2008), specific spill scenario runs were selected based on maximized impacts to these locations. Each of these locations is known to contain marshes and bird-rafting areas.

For the San Francisco Docks spill scenario, the impacts to Richmond Inner Harbor were analyzed. For the spill from the Richmond Long Wharf, impacts to Richardson Bay, Tiburon, and Belvedere Cove were analyzed. For the spill from Martinez in Carquinez Strait, impacts to Grizzly Bay were analyzed.

Phase 1 Booming Strategies

For each of the locations, the following response scenarios were modeled in Phase 1(as summarized in Table 1):

- No response (baseline) with no booms in place and no oil removal;
- ACP[7] booms (booms deployed as designated in the ACP after 6 hours[8] – see Figure 4) and no on-water removal; and
- ACP booms with additional “elective” booms at 54 hours[9] with no on-water oil removal.

In normal oil spill response operations, on-water oil removal, generally through the use of mechanical containment and recovery strategies (containment booms and skimming devices) would be applied. The general effectiveness of this strategy varies considerably depending on environmental conditions (winds, currents, and waves), equipment available, logistics, accessibility, and the manner in which the operations are carried out.

In general, recovery rates of about 10 – 25%, or occasionally higher[10] can be expected under favorable circumstances, though efficiency drops off considerably after the first day or two after the oil has spread.[11] In situations in which the oil is contained around a pre-boomed vessel or in a secluded channel with little current, it is possible to recover more oil.

Because the purpose of this study was to evaluate the potential benefits of alternate booming strategies in excluding oil from specific locations rather than the evaluation of the entire spill response strategy, simulations of mechanical containment and recovery operations were not included in this modeling study.

The comparisons between the various booming strategies thus do not bring in confounding factors of differences in mechanical containment and recovery but focus strictly on the effectiveness of the various alternate booming strategies in specific locations of concern.

[6] See also French-McCay et al. 2008
[7] Area Contingency Plan
[8] The best achievable practice (BAP) timing for placement of the ACP booms is addressed in Jochums et al. 2005.
[9] The 54-hour time frame was suggested by CA OSPR after consultations with Oil Spill Removal Organization (OSRO) representatives with respect to boom deployments that would occur after other required spill response operations had commenced – i.e., 48 hours after the spill occurred and to be completed within six hours.
[10] There are reports of 35% recovery during the cleanup of the Cosco Busan spill, for example.
[11] Gregory et al. 1999; Etkin et al. 2005.

Table 1: Phase 1 Modeled Oil Spill Response Scenarios		
Response	**ACP Booms**	**Elective Alternate Booms**
No Response	no	no
Response A	yes	no
Response B	yes	yes

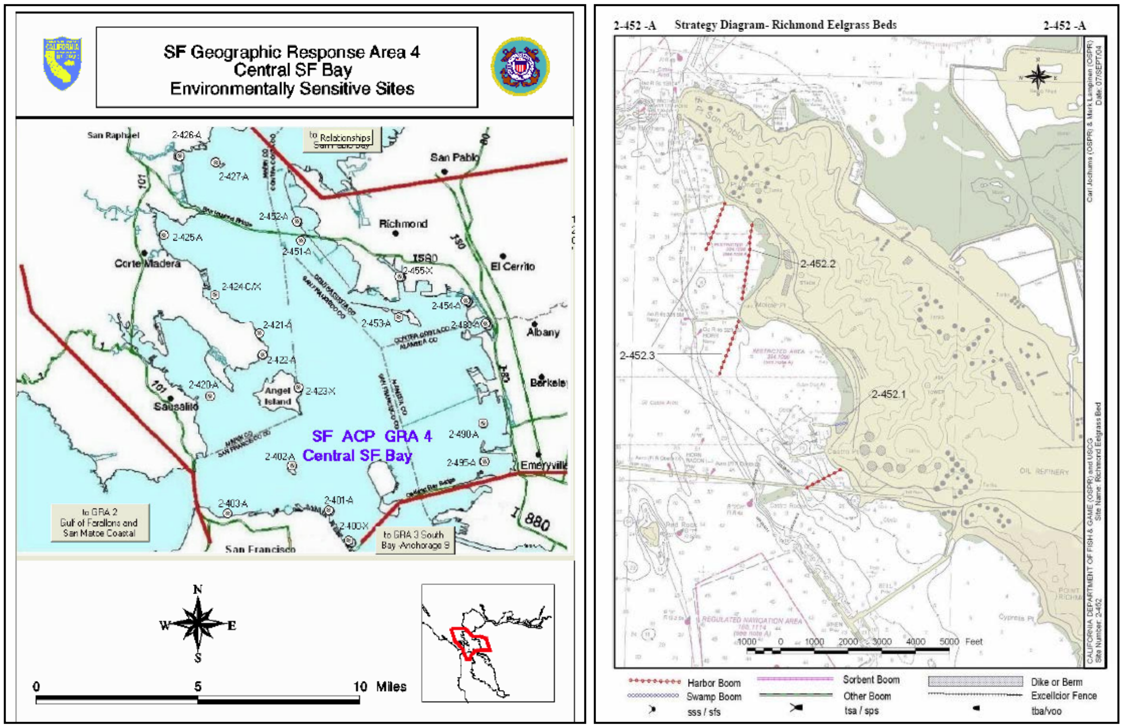


Figure 4: Example of ACP Booms

ACP and alternate (elective) boom placements for Richmond Inner Harbor are shown in Figure 5.

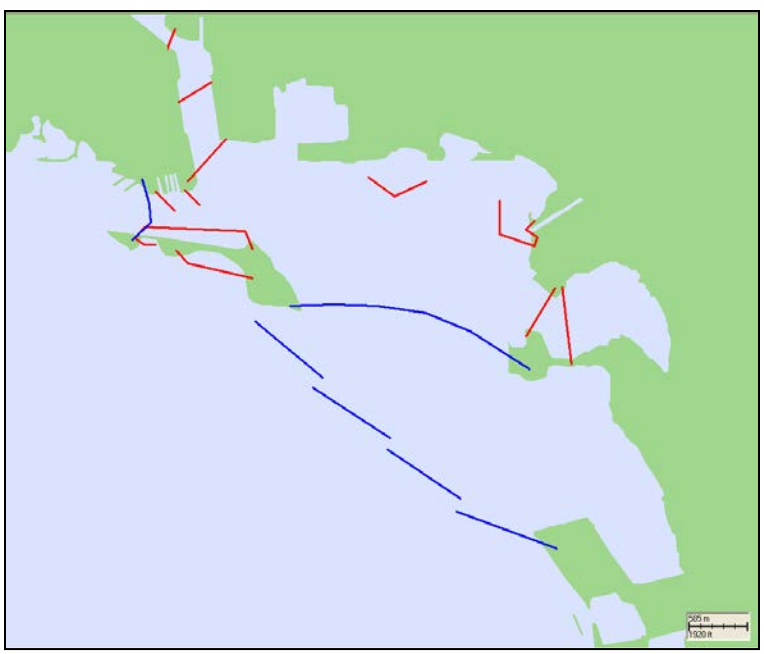


Figure 5: Richmond Inner Harbor booming. ACP booms in red, elective booms in blue.

ACP and alternate (elective) boom

placements for Tiburon and Belvedere Coves (Richardson Bay) are shown in Figure 6. ACP and alternate (elective) boom placements for Grizzly Bay are shown in Figure 7.

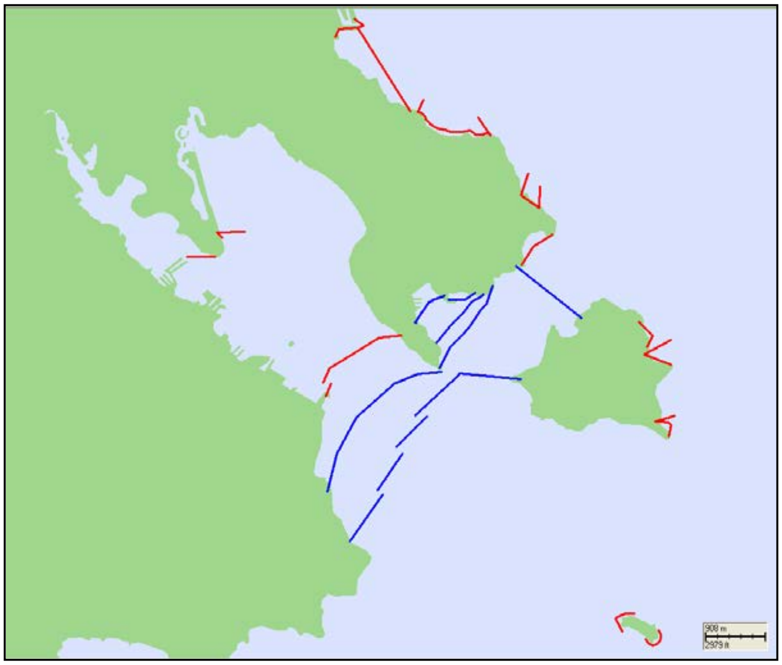


Figure 6: Tiburon Cove and Richardson Bay. ACP booms in red, elective booms in blue.

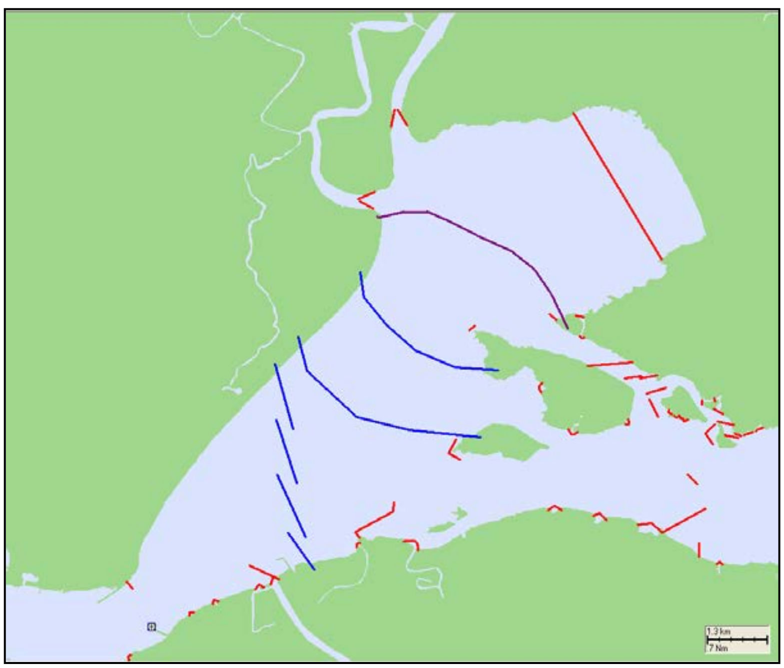


Figure 7: Grizzly Bay. ACP booms in red, elective booms in blue. An additional "inner boom" (purple) is included in this scenario.

For all ACP booming, it is assumed that:

- The booms are in place (completely deployed) at 6 hours, as per the designations in the appropriate sections of the plan;
- Elective booms are in place at 54 hours; and
- All booms are assumed to be 100% effective at deflecting oil only if the current is 0.7 knots or

below, the wind speed is 30 knots or below, and wave height is one foot or less for ACP and additional booms inside the bay, and three feet or less for booms on the outer coast in more exposed areas[12].). Boom height was assumed to be 18 to 42 inches and capable of withstanding a significant wave height of up to three feet. Entrainment (oil escaping under or splashing over the boom) was assumed to occur when wave heights exceeded three feet or current velocity exceeded 1 knot. It was assumed that the booms would have been properly deployed at angles that would allow withstanding of currents up to 1 knot[13].

Phase 1 Modeling Results

Richmond Inner Harbor

For the Richmond Inner Harbor booming strategies the modeled spill scenario was a 100,000-gallon release of heavy fuel oil at the San Francisco Docks (Figure 8).

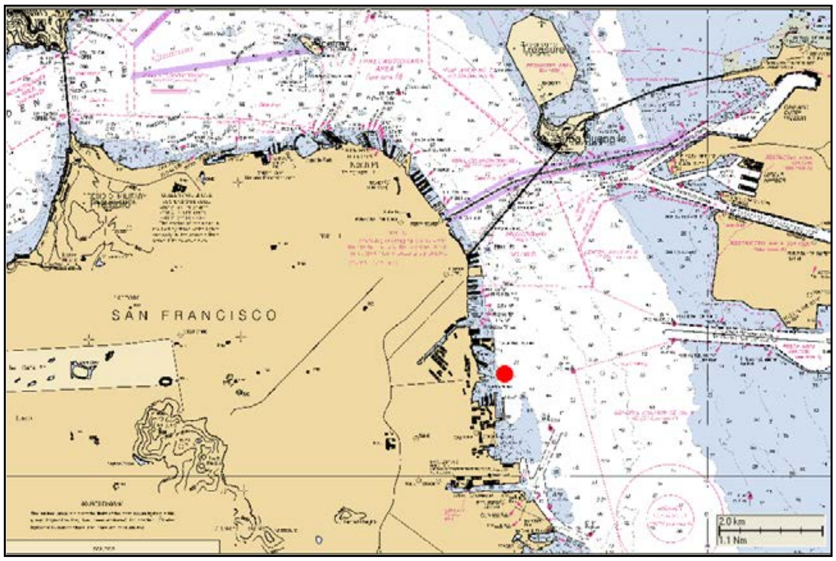


Figure 8: San Francisco Docks spill location

Modeling results for Richmond Inner Harbor are shown in Table 2 and Figures 9 – 11. Total shoreline area and total volume oiled results are for the entire San Francisco Bay.

Table 2: Shoreline Oiling of 100,000-Gallon HFO Spill San Francisco Docks

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Richmond Inner Harbor
No Response	12,208	49,545	1,976
Response A (ACP booms only)	12,426	47,804	1,680
Response B (ACP + alternative booms)	12,228	48,028	0

For this location, the existing ACP appear to offer little protection in that the oiling of the Richmond

[12] 33 CFR 155 (US Coast Guard 1996).
[13] Fingas 2001. See also Appendix A.

Inner Harbor overall is similar with and without the boom. Specific locations within the harbour may have had some better protection. The addition of the larger booms could effectively keep oil out of this area. The relatively low currents in this area allow for effective booming.

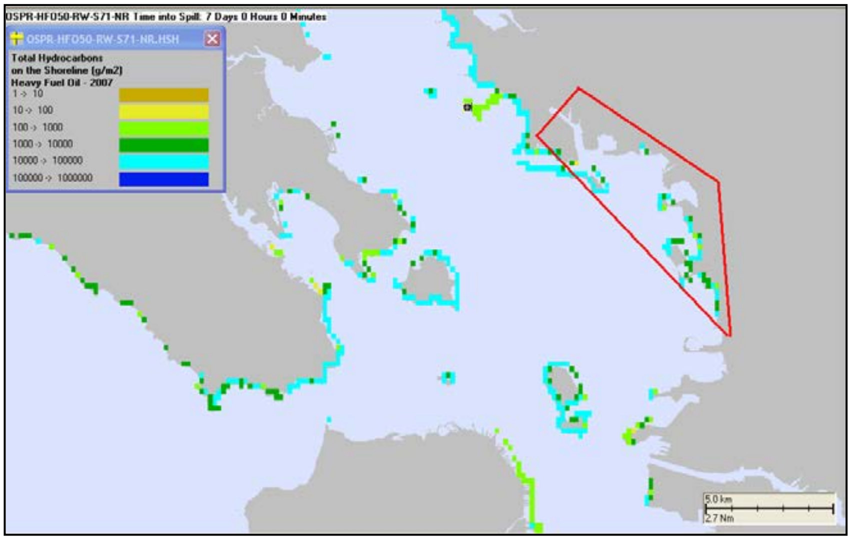


Figure 9: San Francisco Dock 100,000-gallon HFO spill shoreline oiling – no response[14]

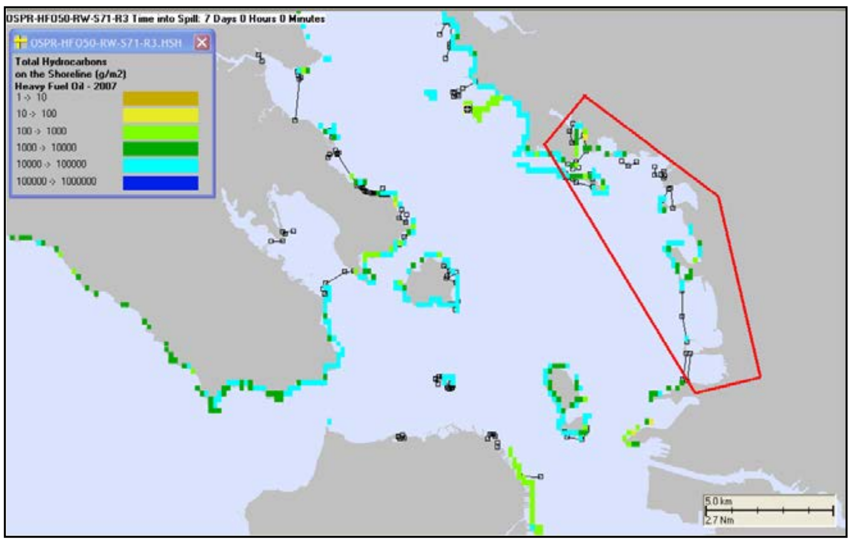
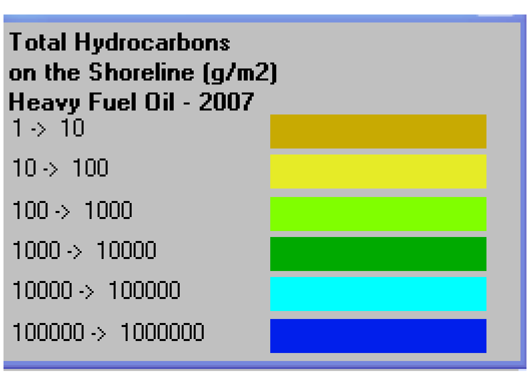


Figure 10: San Francisco Dock 100,000-gallon HFO spill shoreline oiling – Response A

[14] Shoreline oiling is depicted in the SIMAP modeling results as shown below in grams per square meter. The areas with the highest concentrations of shoreline oil are shown in blue and aqua.



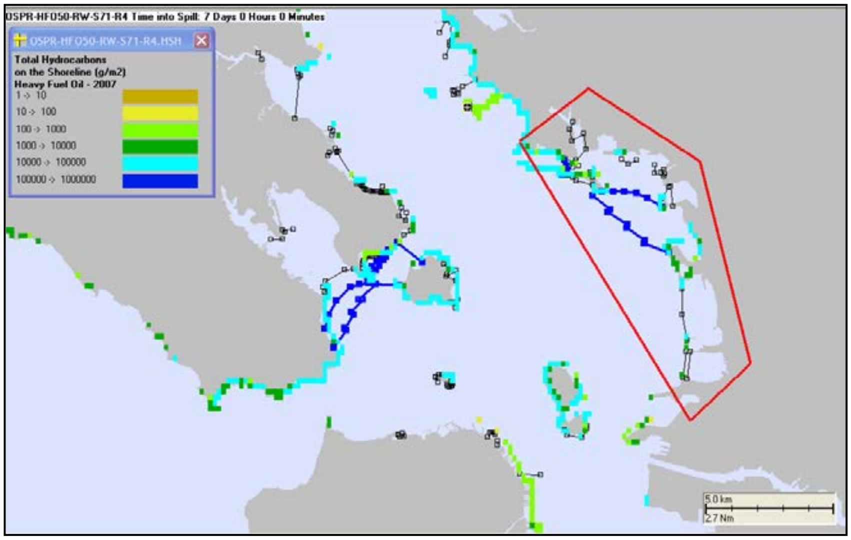


Figure 11: San Francisco Dock 100,000-gallon HFO spill shoreline oiling – Response B

Tiburon/Belvedere Coves and Richardson Bay

For the Tiburon and Belvedere Coves and Richardson Bay booming strategies, the modeled spill as a 100,000-gallon release of heavy fuel oil from the Richmond Long Wharf (Figure 12).

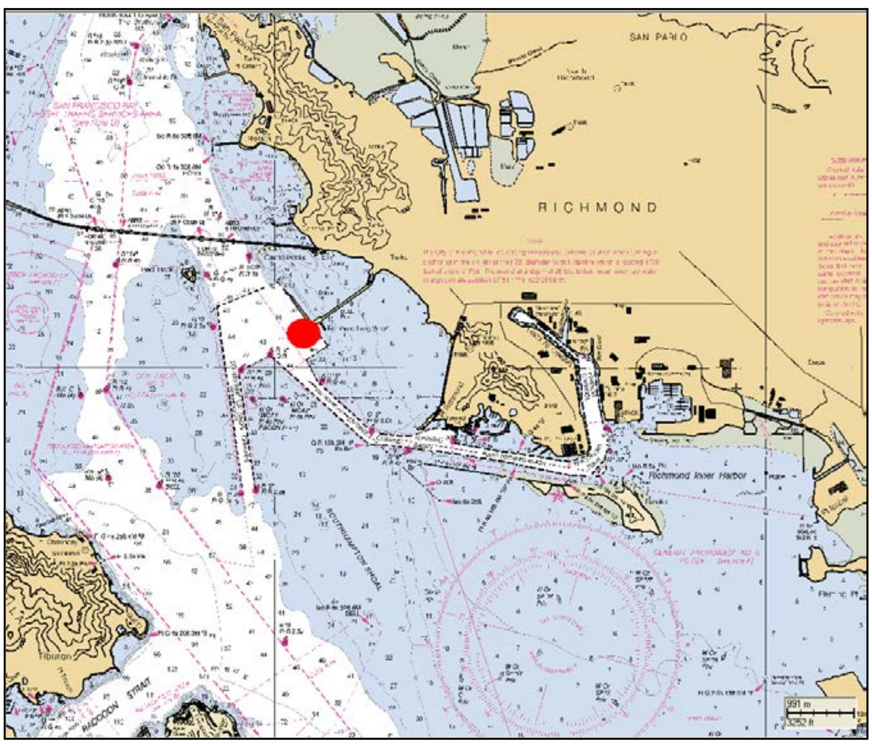


Figure 12: Richmond Long Wharf spill location

Modeling results for the alternative booming strategies for the Tiburon and Belvedere Coves and Richardson Bay are shown in Table 3 and Figures 13 – 15.

Table 3: Shoreline Oiling of 100,000-Gallon HFO Spill Richmond Long Wharf			
Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Belvedere/Tiburon
No Response	21,983	68,666	1,652
Response A (ACP booms only)	20,737	67,561	400
Response B (ACP + alternative booms)	20,321	68,496	282

For this location, the existing ACP booms appear to provide considerable protection, reducing the oiling of these areas by 75 percent. The addition of the elective booms would only reduce oiling of the coves slightly.

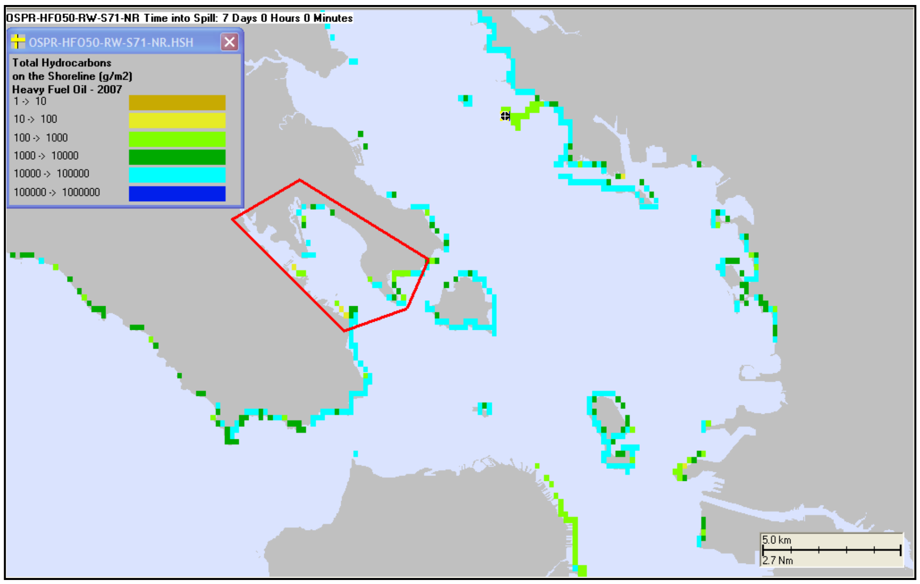


Figure 13: Richmond Long Wharf 100,000-gallon HFO spill – no response

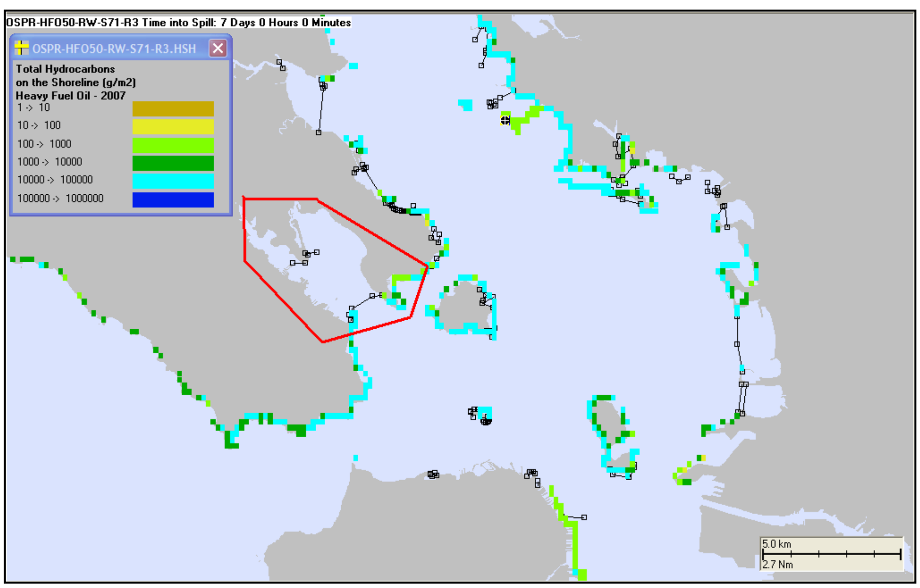


Figure 14: Richmond Long Wharf 100,000-gallon HFO spill – Response A

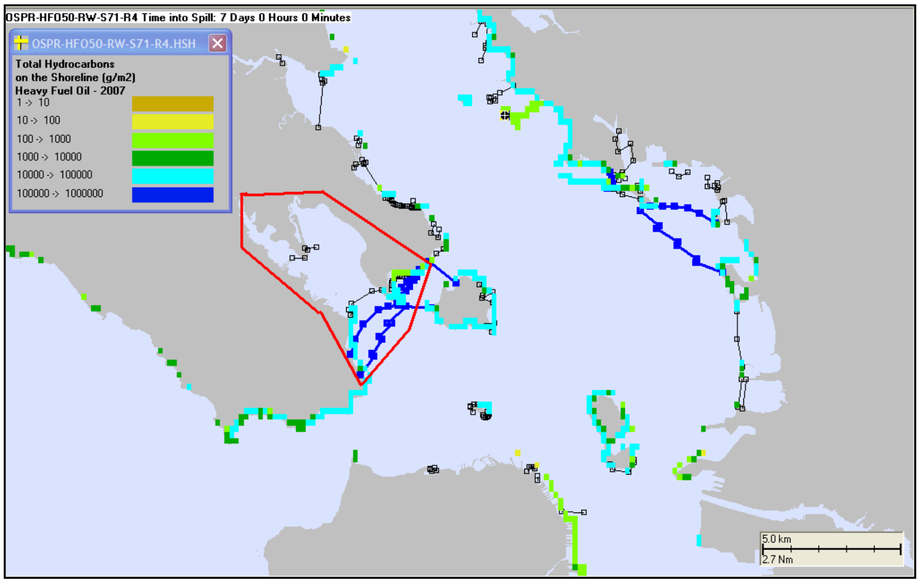


Figure 15: Richmond Long Wharf 100,000-gallon HFO spill – Response B

The high currents in this area, as shown in Figure 16, present significant challenges for booming. Any booming strategies would need to take into account the high currents, which would involve continuous re-adjustment of the angling of the booms with regard to the currents. This likely would not be worthwhile with regard to benefits in oil reduction.

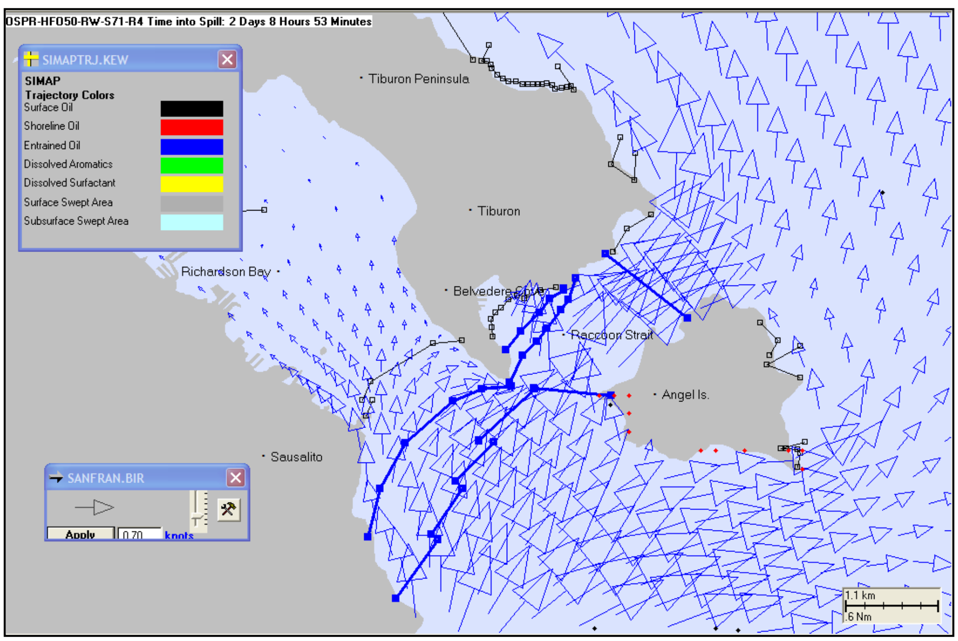


Figure 16: Currents at Belvedere and Tiburon Coves and Richardson Bay[15]

Grizzly Bay

For the Grizzly Bay boom strategy analysis, the modeled spill scenario was a 100,000-gallon heavy fuel oil release at a refinery in Martinez (Figure 17).

[15] Vector arrows indicate the direction and intensity of the current.

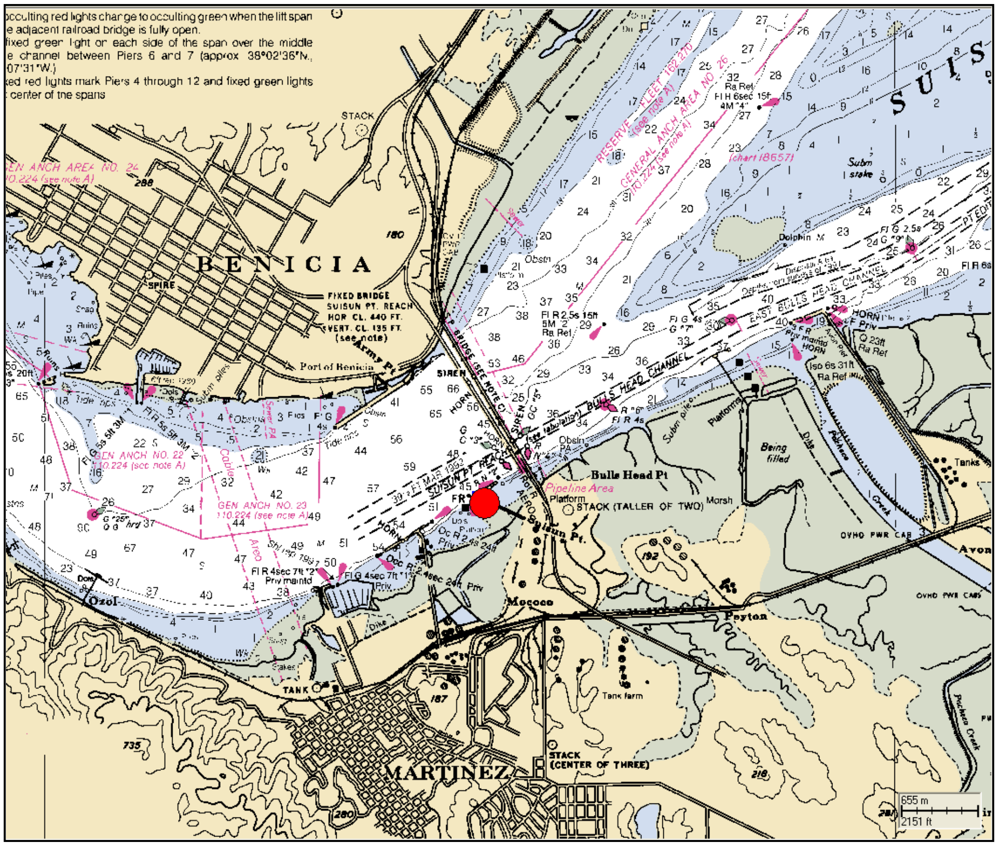


Figure 17: Martinez spill location

Modeling results for Grizzly Bay booming strategies are shown in Table 4 and Figures 18 – 21. For this location, the ACP booms reduce oiling to the shoreline within Grizzly Bay by 44 percent, but the addition of the elective booms do not appear to improve protection for this area. This seems to be due to high currents in this area, as shown in Figure 22. The addition of the “inner boom” (added to the ACP boom and the elective boom), which is not subject to high currents, does, however, appear to reduce oiling further. Oiling to Grizzly Bay is reduced by 83 percent with this boom.

Table 4: Shoreline Oiling of 100,000-Gallon HFO Spill Martinez Refinery

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Grizzly Bay
No Response	7,440	51,568	7,762
Response A (ACP booms only)	7,183	49,058	4,322
Response B (ACP + alternative booms)	7,163	49,098	4,028
Response C (Response B + Inner Boom)	7,657	51,244	1,323

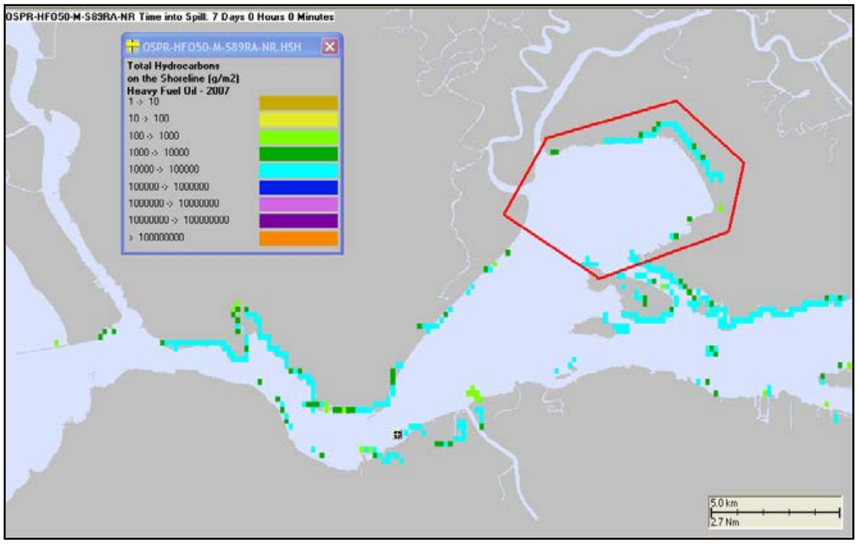


Figure 18: 100,000-gallon HFO spill at Martinez – no response

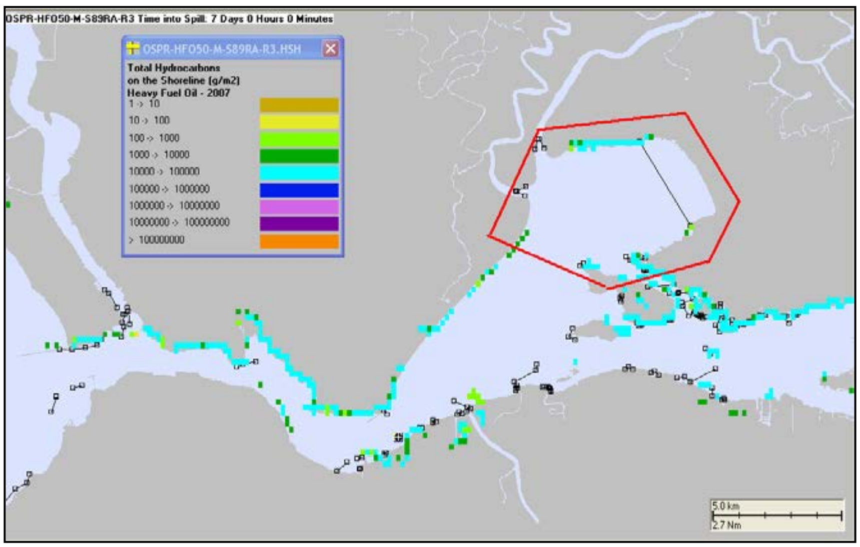


Figure 19: 100,000-gallon HFO spill at Martinez – Response A

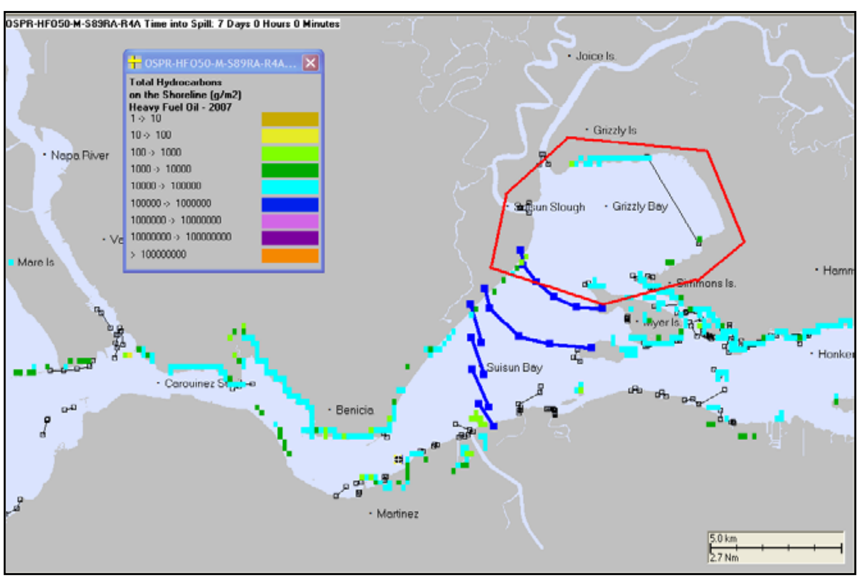


Figure 20: 100,000-gallon HFO spill at Martinez – Response B

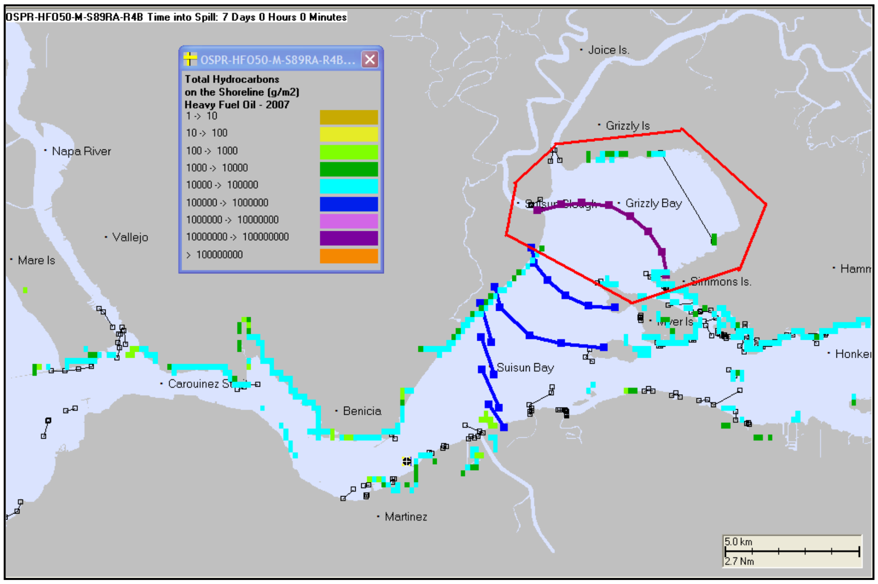


Figure 21: 100,000-gallon HFO spill at Martinez – Response C

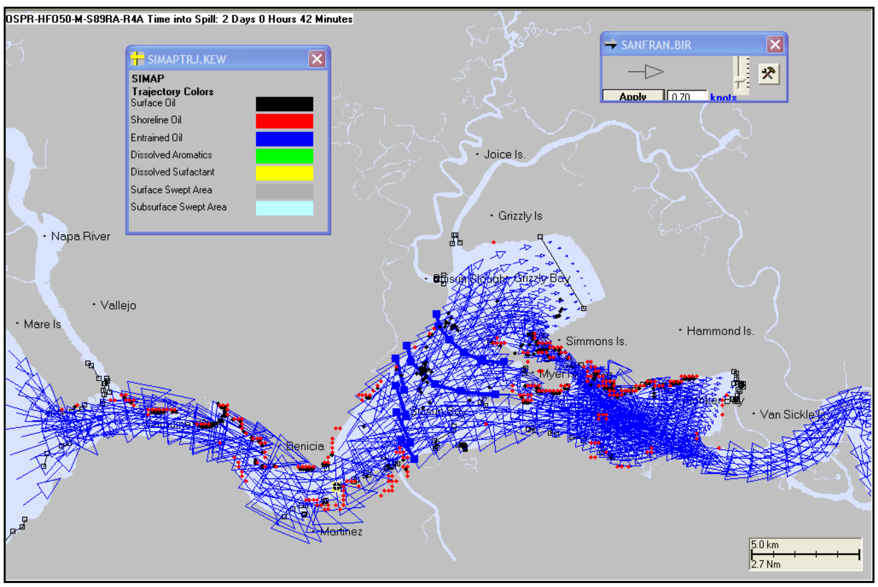


Figure 22: Current challenges at Grizzly Bay and Carquinez Strait

Phase 1 Conclusions on Boom Effectiveness

California OSPR's concept of adding "elective" large-area exclusionary booms is based on the premise that these booms might deflect oil from particularly sensitive areas to other locations in which the impacts may be somewhat lower. This could be a plausible strategy for an area in which the currents generally preclude highly effective on-water oil removal. However, there are a number of significant issues that are raised in this approach.

First, as demonstrated by the Phase 1 modeling results, the same high currents that present challenges for on-water mechanical containment and recovery operations also will likely present problems in protective booming. It would be best to limit the elective booming strategies to locations in which there are likely to be lower currents so that booming effectiveness can be maximized. Some potential areas in which these strategies might be explored are shown in Figure 23.

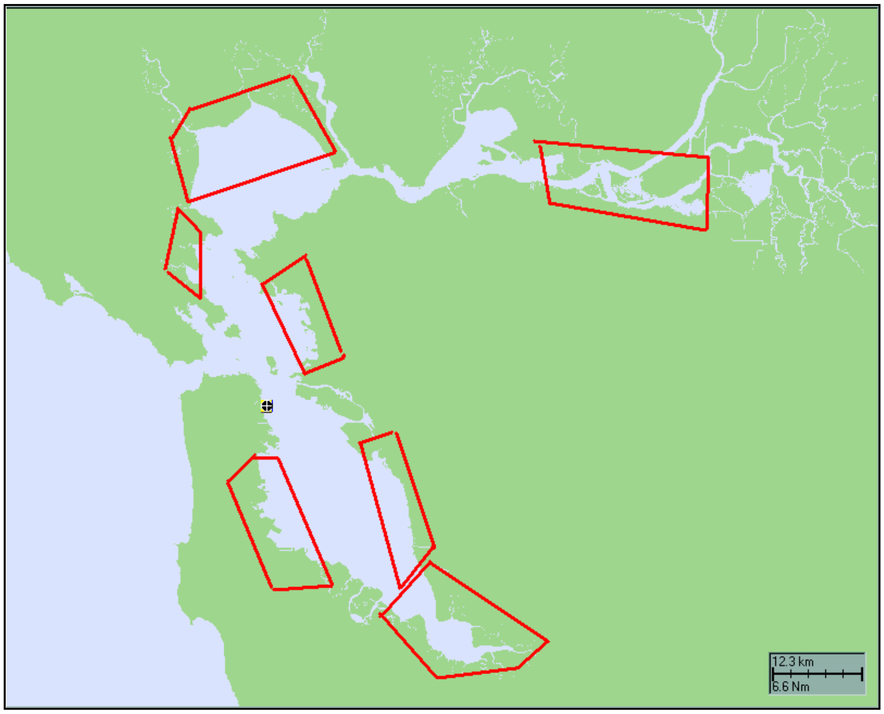


Figure 23: Areas of lower currents in San Francisco Bay where elective booming strategies might be effective.

The effectiveness of the elective booms, as well as the ACP booms, depends on the timing of deployments. The booms need to be in place in advance of the oil. In this modeling study, the majority of spill runs showed oil reaching the areas of interest considerably in advance of the 54-hour time frame designated by OSPR as permissible with regard to the addition of the elective booms. The time frame was considered to be reasonable with regard to potentially achievable and acceptable goals for the spill response organizations that would be involved in the boom deployments.

The effectiveness of the elective booms will be limited by the time frame of deployment. The deployment process itself could take considerable time.

The time to shoreline impact will be longer for spills from a site more remote to the area(s) of concern. These spill scenarios may better lend themselves to these alternative booming strategies.

In addition to timing issues, there are also a number of significant logistical and technical issues involved in the deployment of booms of the lengths required to cover large areas. Boom strength is decreased when the booms are deployed in long segments. Anchoring or cascading needs to be employed to strengthen the booms with respect to the stresses of the currents. In addition, deployment of greater lengths of boom requires sufficient properly trained personnel, boats, and equipment.

Phase 2 Scenarios

Additional booming scenarios were modeled in the second phase of the study to test variations in strategic boom placement in Grizzly Bay and to examine booming strategies in Honker Bay (near Grizzly Bay) and in the Central Bay area. The spill locations selected were San Francisco Bay Docks and Martinez, as previously depicted in Figures 8 and 17. The spill volume remained at 100,000 gallons, but in addition to spills of heavy fuel oil, spills of diesel fuel and crude oil of this volume were also modeled in the second phase of the study.

Phase 2 Booming Strategies

Booming strategies for the Phase 2 modeling involved the same general specifications as in Phase 1 (see Table 5). To distinguish from the previous responses (Response A, B, and C), the Phase 2 responses were designated as Response D and Response E, for the ACP booms only, and ACP booms plus elective alternate booms scenarios, respectively. As in Phase 1, the on-water removal was not modeled in order to distinguish the specific effects of the alternate booming on oil impacts to the areas of concern.

Table 5: Phase 2 Modeled Oil Spill Response Scenarios

Response	ACP Booms	Elective Alternate Booms
No Response	no	no
Response D	yes	no
Response E	yes	yes

Grizzly Bay

The Grizzly Bay booms for the Phase 2 modeling were adjusted as shown in Figure 24. The other non-ACP booms for Grizzly Bay were eliminated in this phase.

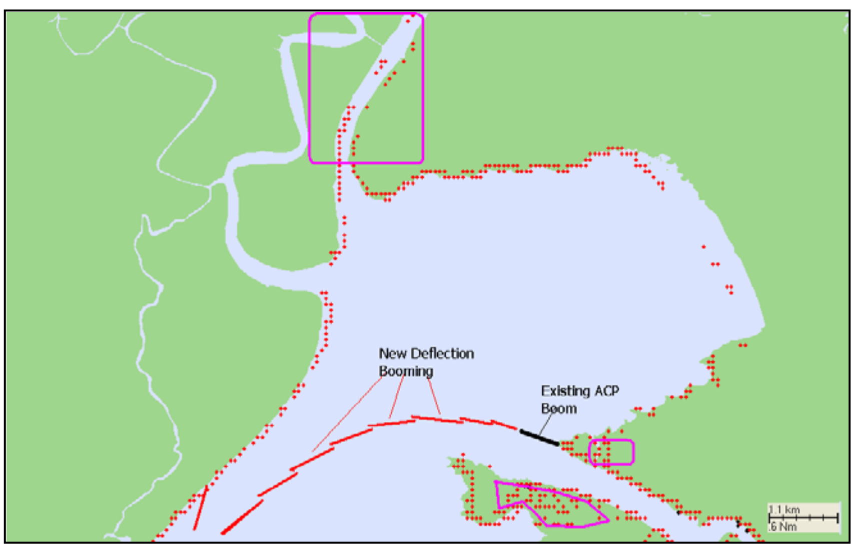


Figure 24: New elective deflection boom added in Grizzly Bay

Honker Bay

Additional booms were added around Ryer Island and Freeman Island in Honker Bay, as shown in Figure 25.

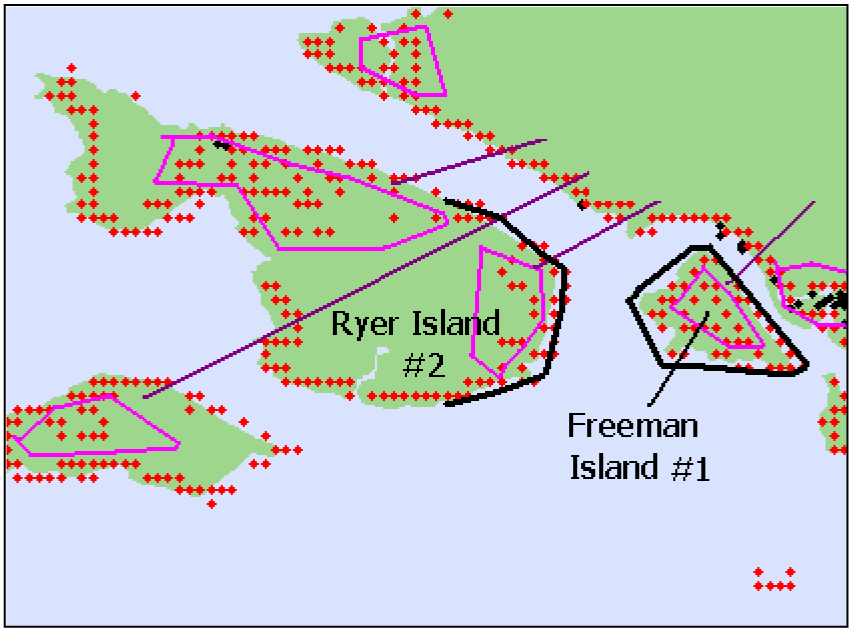


Figure 25: Additional booming around sensitive sites in Honker Bay

Central Bay

The booms in the Central Bay were adjusted to include only elective booms at Berkeley, Oakland Outer Harbor, and Bay Farm Island, as shown in Figure 26.

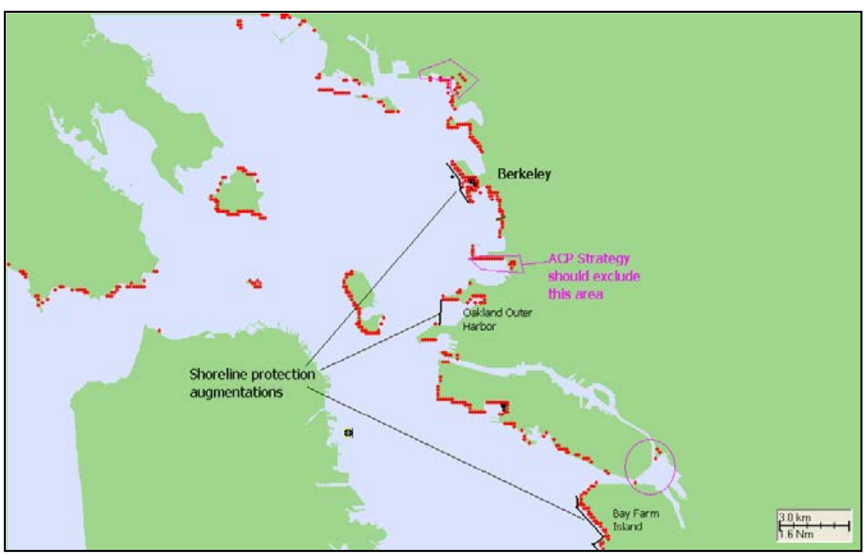


Figure 26: Additional booming applied at Berkeley, Oakland Outer Harbor, and Bay Farm Island in Central Bay

Phase 2 Modeling Results – Martinez Spills

HFO Spill at Martinez

The shoreline oiling in the Grizzly Bay and Honker Bay areas from a 100,000-gallon spill of HFO at Martinez is shown in Figure 27 for the no response scenario, in Figure 28 for the ACP-boom response, and in Figure 29 for the alternative boom response[16].

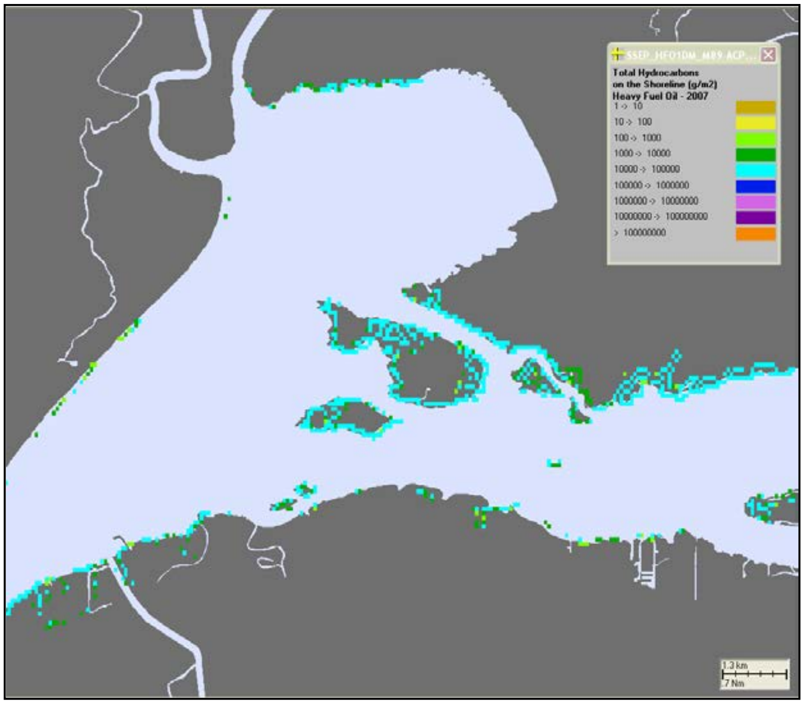


Figure 27: 100,000-gallon HFO spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with no response

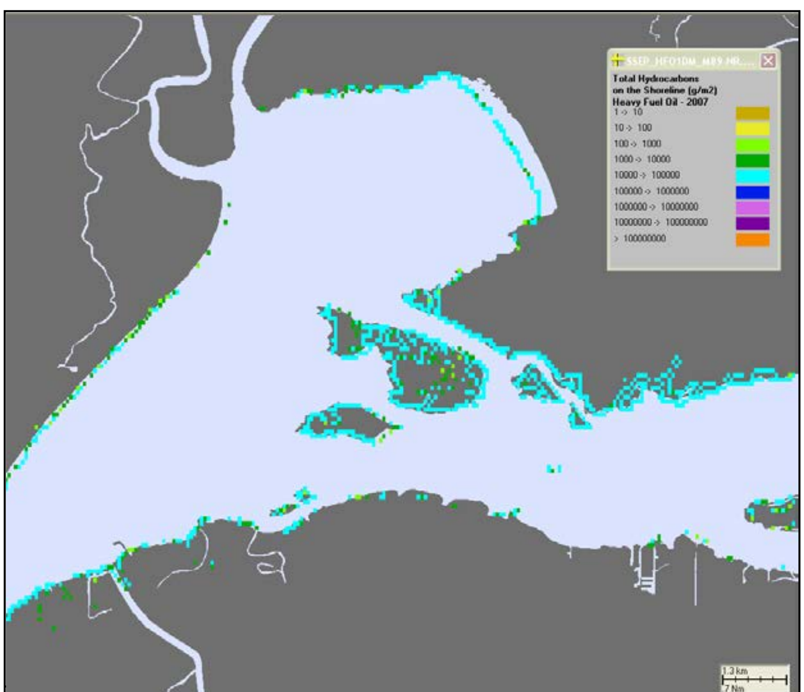


Figure 28: 100,000-gallon HFO spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with ACP boom response

[16] The alternative boom response includes all ACP booming.

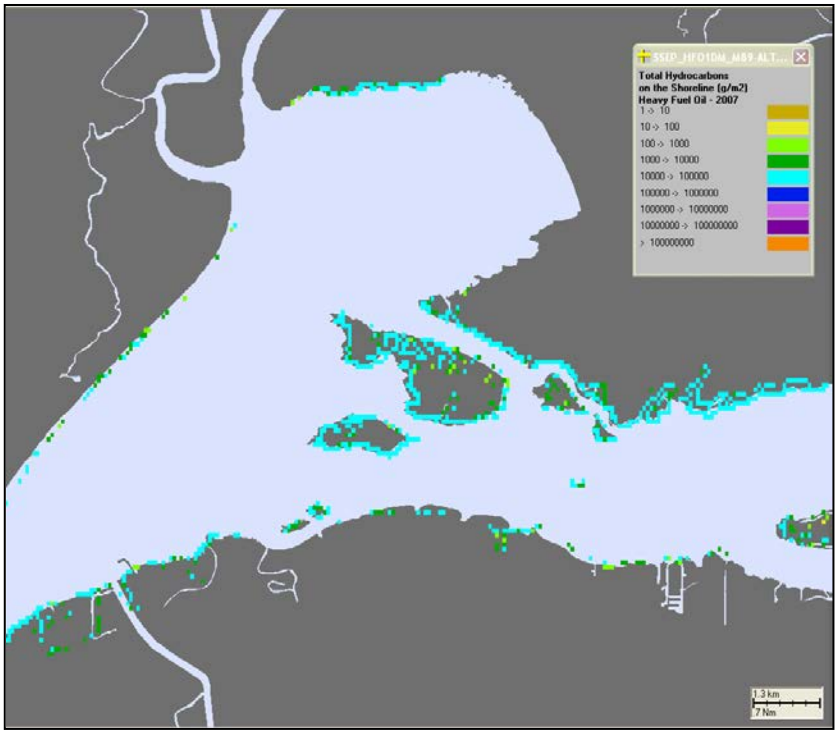


Figure 29: 100,000-gallon HFO spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with ACP boom response

Tables 6, 7, and 8 summarize the shoreline oiling at Grizzly Bay, and Ryer and Freeman Islands in Honker Bay, respectively.

Table 6: Phase 2 Shoreline Oiling HFO Spill Martinez – Grizzly Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Grizzly Bay
No Response	12,096	69,963	6,456
Response D (ACP Booms Only)	10,113	50,924	2,537
Response E (ACP + Alternative Booms)	10,291	50,042	2,540

Table 7: Phase 2 Shoreline Oiling HFO Spill Martinez – Ryer Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Ryer Island
No Response	12,096	69,963	4,851
Response D (ACP Booms Only)	10,113	50,924	3,778
Response E (ACP + Alternative Booms)	10,291	50,042	2,355

Table 8: Phase 2 Shoreline Oiling HFO Spill Martinez – Freeman Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Freeman Island
No Response	12,096	69,963	2,702
Response D (ACP Booms Only)	10,113	50,924	1,150
Response E (ACP + Alternative Booms)	10,291	50,042	488

Diesel Spill at Martinez

The shoreline oiling in the Grizzly Bay and Honker Bay areas from a 100,000-gallon spill of diesel at Martinez is shown in Figure 30 for the no response scenario, in Figure 31 for the ACP-boom response, and in Figure 32 for the alternative boom response[17].

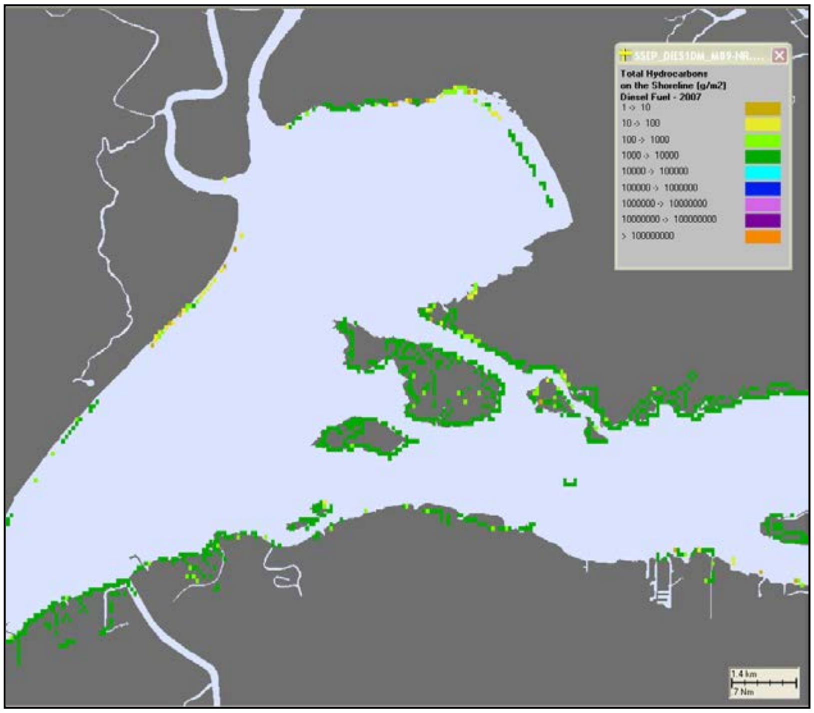


Figure 30: 100,000-gallon diesel spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with no response

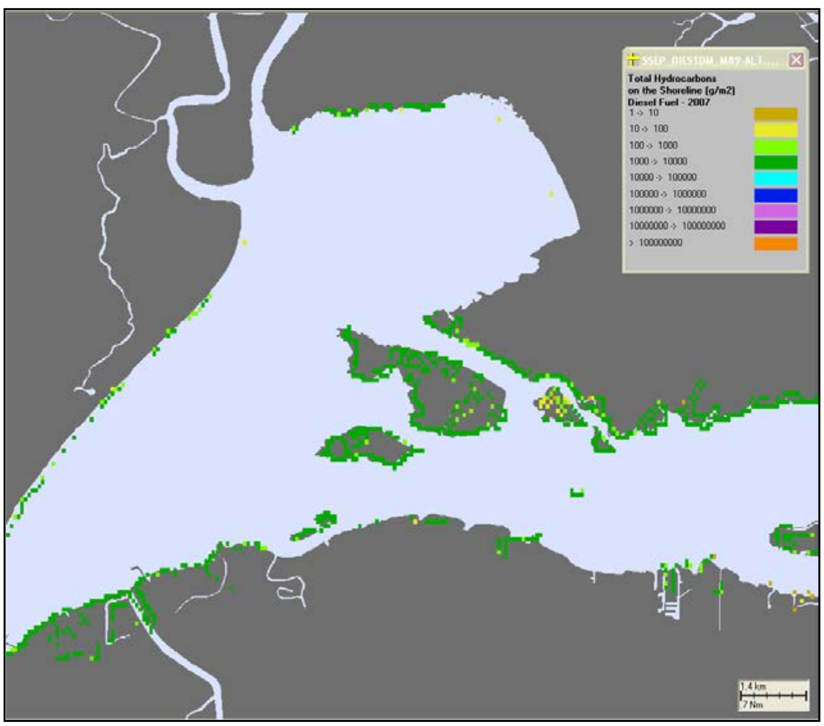


Figure 31: 100,000-gallon diesel spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with ACP boom response

[17] The alternative boom response includes all ACP booming.

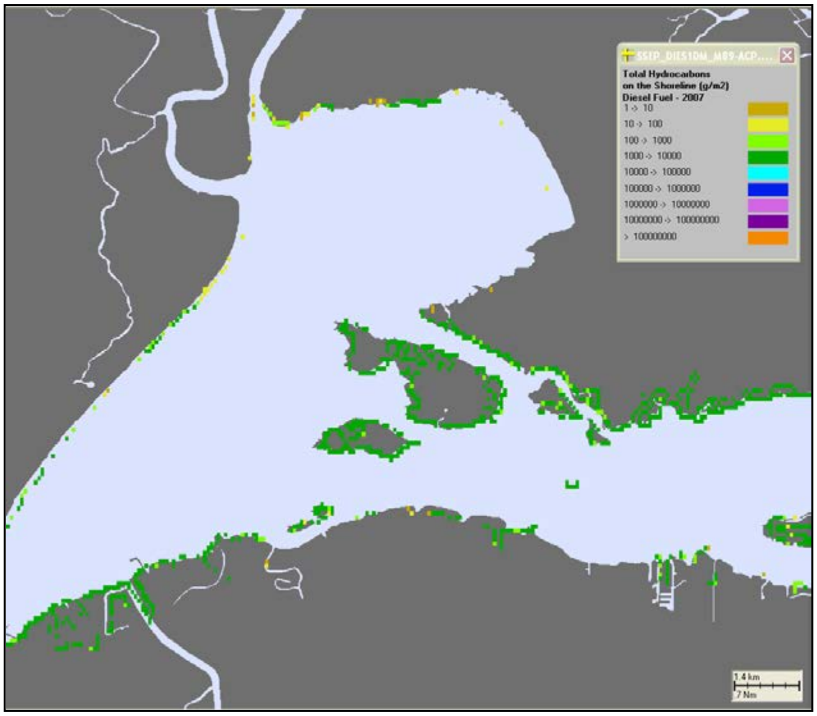


Figure 32: 100,000-gallon diesel spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with alternative boom response

Tables 9, 10, and 11 summarize the shoreline oiling at Grizzly Bay, and Ryer and Freeman Islands in Honker Bay, respectively.

Table 9: Phase 2 Shoreline Oiling Diesel Spill Martinez – Grizzly Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Grizzly Bay
No Response	8,968	11,637	297
Response D (ACP Booms Only)	8,290	11,704	203
Response E (ACP + Alternative Booms)	8,027	11,931	203

Table 10: Phase 2 Shoreline Oiling Diesel Spill Martinez – Ryer Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Ryer Island
No Response	8,968	11,637	1,003
Response D (ACP Booms Only)	8,290	11,704	711
Response E (ACP + Alternative Booms)	8,027	11,931	241

Table 11: Phase 2 Shoreline Oiling Diesel Spill Martinez – Freeman Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Freeman Island
No Response	8,968	11,637	612
Response D (ACP Booms Only)	8,290	11,704	482
Response E (ACP + Alternative Booms)	8,027	11,931	550

Crude Spill at Martinez

The shoreline oiling in the Grizzly Bay and Honker Bay areas from a 100,000-gallon spill of crude at Martinez is shown in Figure 33 for the no response scenario, in Figure 34 for the ACP-boom response, and in Figure 35 for the alternative boom response[18].

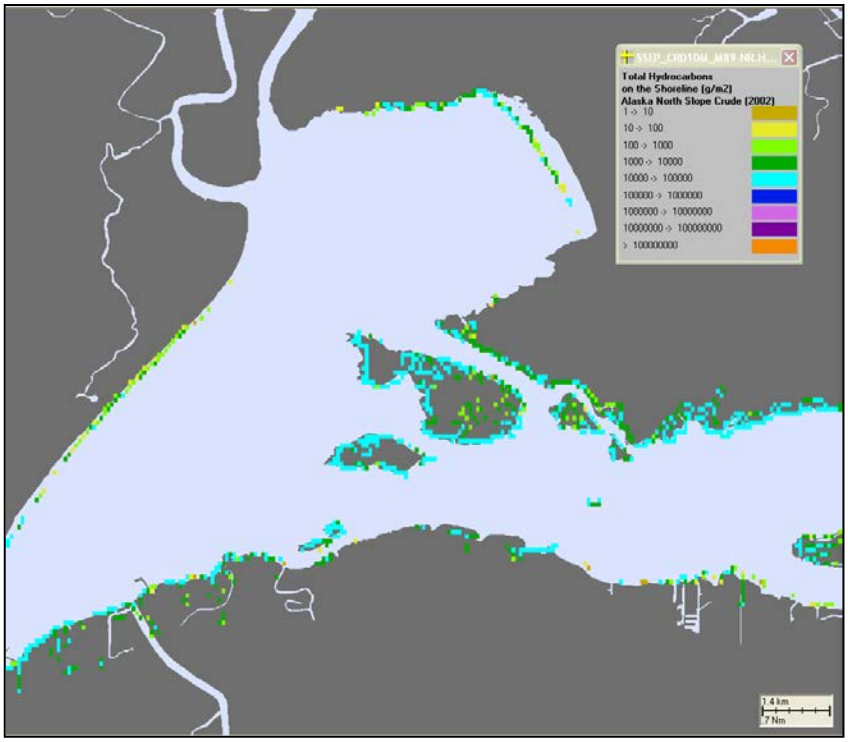


Figure 33: 100,000-gallon crude spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with no response

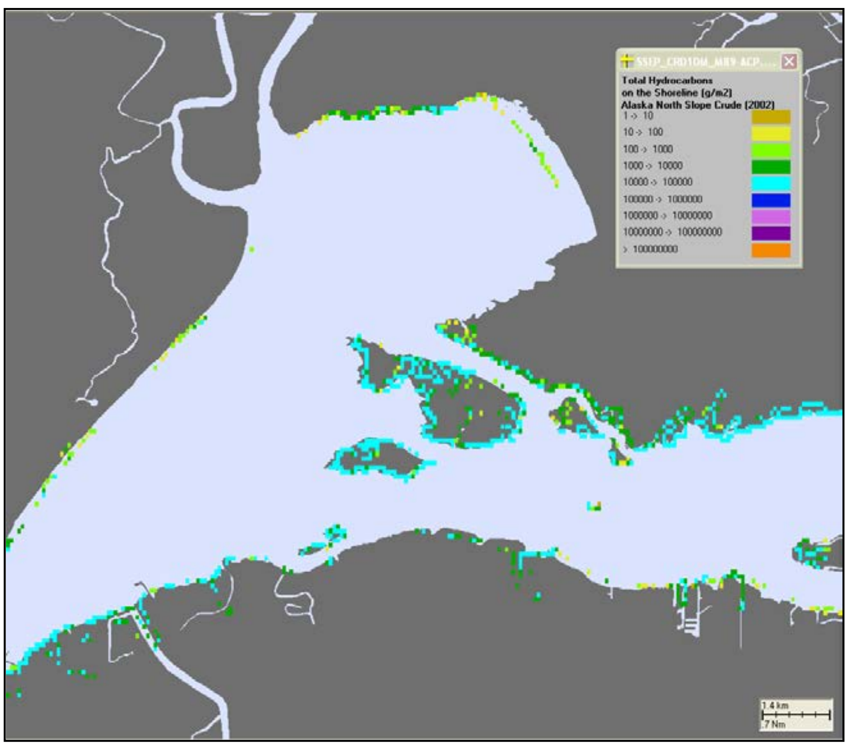


Figure 34: 100,000-gallon crude spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with ACP boom response

[18] The alternative boom response includes all ACP booming.

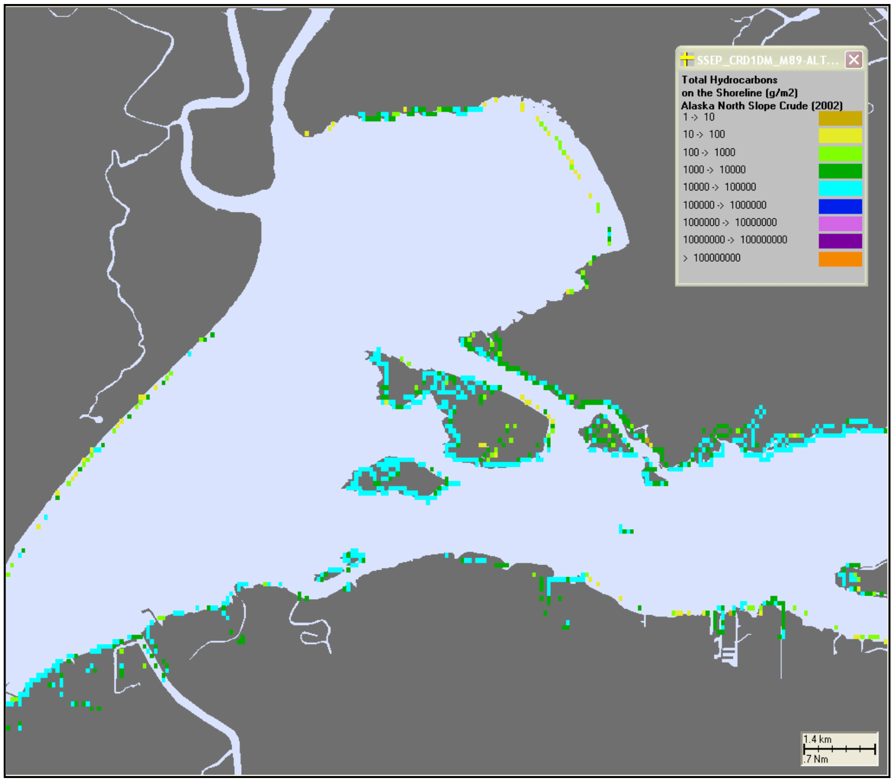


Figure 35: 100,000-gallon crude spill impacts to Grizzly Bay and Honker Bay (Freeman and Ryer Islands) with alternate boom response

Tables 12, 13, and 14 summarize the shoreline oiling at Grizzly Bay, and Ryer and Freeman Islands in Honker Bay, respectively.

Table 12: Phase 2 Shoreline Oiling Crude Spill Martinez – Grizzly Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Grizzly Bay
No Response	10,884	29,988	1,291
Response D (ACP Booms Only)	10,519	28,553	750
Response E (ACP + Alternative Booms)	10,044	27,395	947

Table 13: Phase 2 Shoreline Oiling Crude Spill Martinez – Ryer Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Ryer Island
No Response	10,884	29,988	2,190
Response D (ACP Booms Only)	10,519	28,553	1,911
Response E (ACP + Alternative Booms)	10,044	27,395	1,326

Table 14: Phase 2 Shoreline Oiling Crude Spill Martinez – Freeman Island/Honker Bay

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Freeman Island
No Response	10,884	29,988	653
Response D (ACP Booms Only)	10,519	28,553	420
Response E (ACP + Alternative Booms)	10,044	27,395	415

Phase 2 Modeling Results – San Francisco Docks Spills

HFO Spill at San Francisco Docks

The shoreline oiling in Central Bay from a 100,000-gallon spill of HFO at San Francisco Docks is shown in Figure 36 for the no response scenario, in Figure 37 for the ACP-boom response, and in Figure 38 for the alternative boom response[19].

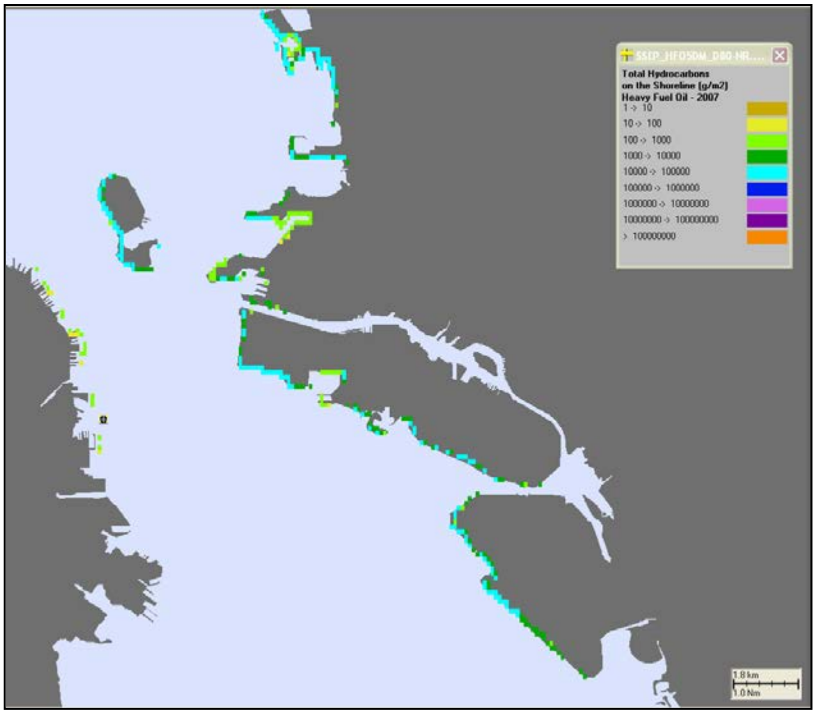


Figure 36: 100,000-gallon HFO spill at San Francisco Docks with no response

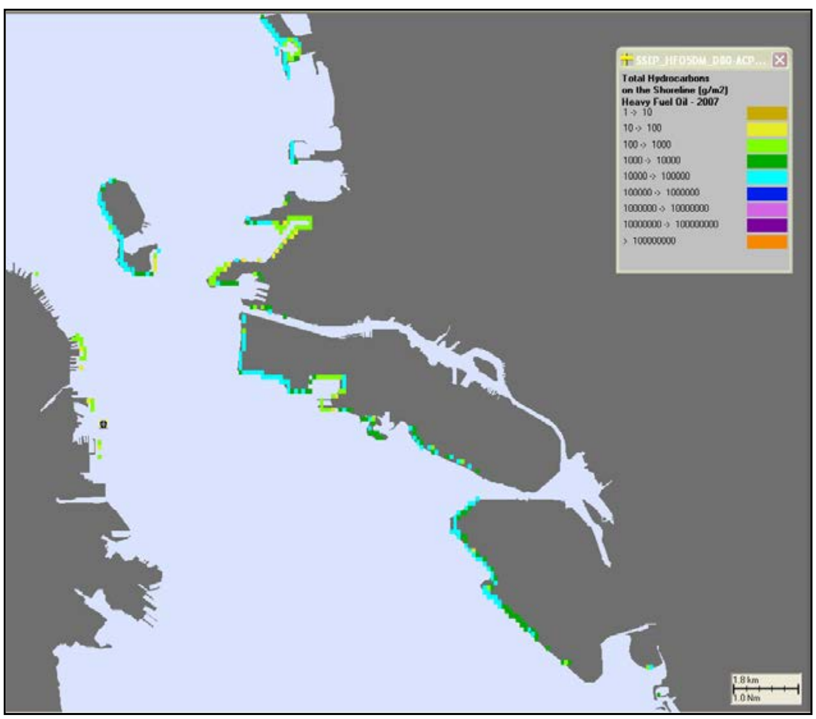


Figure 37: 100,000-gallon HFO spill at San Francisco Docks with ACP boom response

[19] The alternative boom response includes all ACP booming.

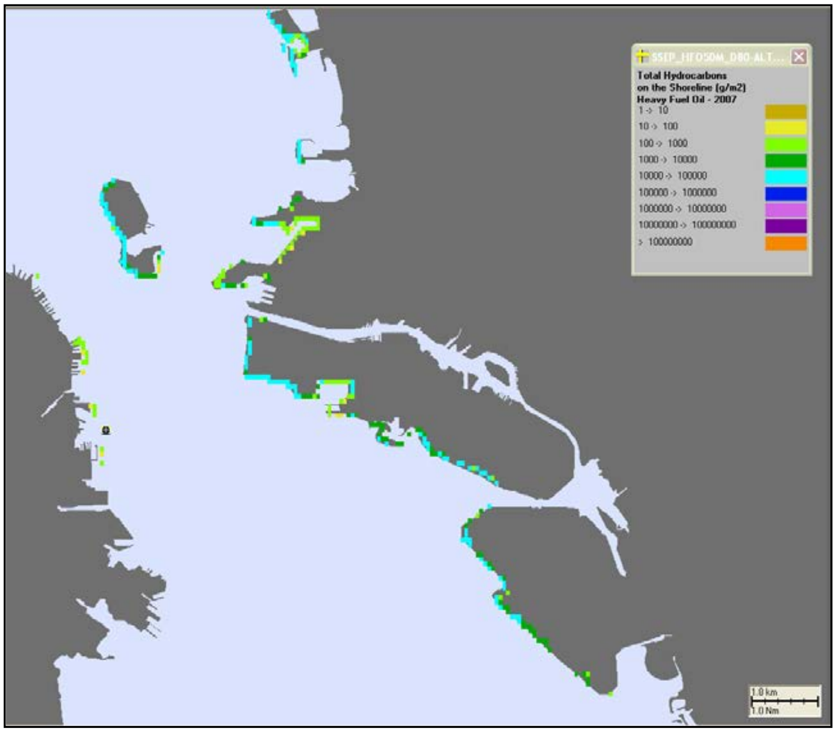


Figure 38: 100,000-gallon HFO spill at San Francisco Docks with alternative boom response

Tables 15, 16, and 17 summarize the shoreline oiling at Berkeley, Oakland Harbor, and Bay Farm Island, respectively.

Table 15: Phase 2 Shoreline Oiling HFO Spill San Francisco Docks – Berkeley

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Berkeley
No Response	34,735	58,377	3,581
Response D (ACP Booms Only)	32,058	54,587	7,241
Response E (ACP + Alternative Booms)	32,119	38,382	3,210

Table 16: Phase 2 Shoreline Oiling HFO Spill San Francisco Docks – Oakland Harbor

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Oakland Outer Harbor
No Response	34,735	58,377	447
Response D (ACP Booms Only)	32,058	54,587	550
Response E (ACP + Alternative Booms)	32,119	38,382	606

Table 17: Phase 2 Shoreline Oiling HFO Spill San Francisco Docks – Bay Farm Island

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Bay Farm Island
No Response	34,735	58,377	7,194
Response D (ACP Booms Only)	32,058	54,587	7,562
Response E (ACP + Alternative Booms)	32,119	38,382	4,875

Diesel Spill at San Francisco Docks

The shoreline oiling in Central Bay from a 100,000-gallon spill of diesel at San Francisco Docks is shown in Figure 39 for the no response scenario, in Figure 40 for the ACP-boom response, and in Figure 41 for the alternative boom response[20].

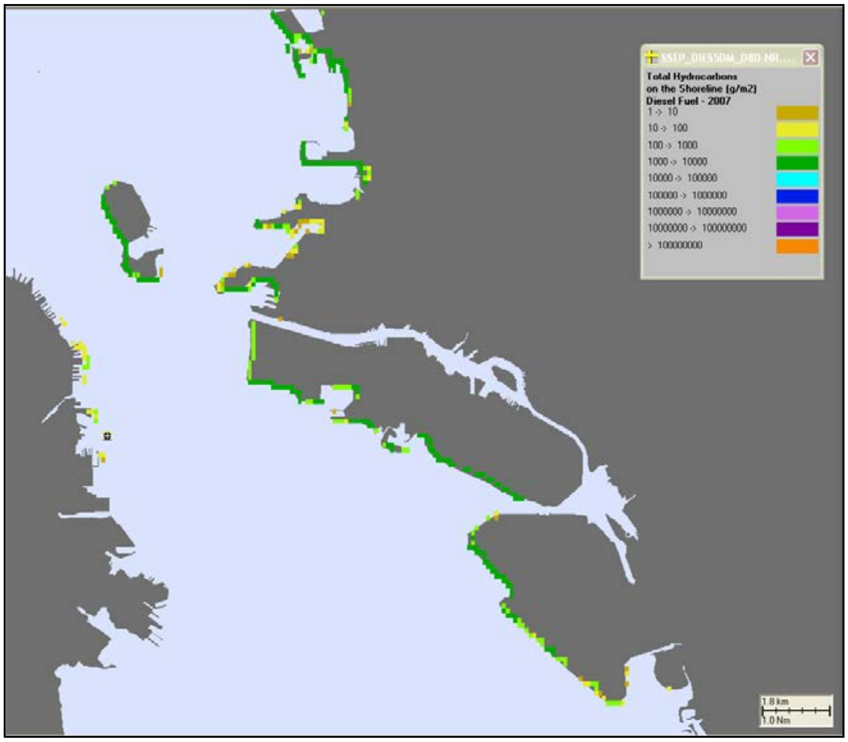


Figure 39: 100,000-gallon diesel spill at San Francisco Docks with no response

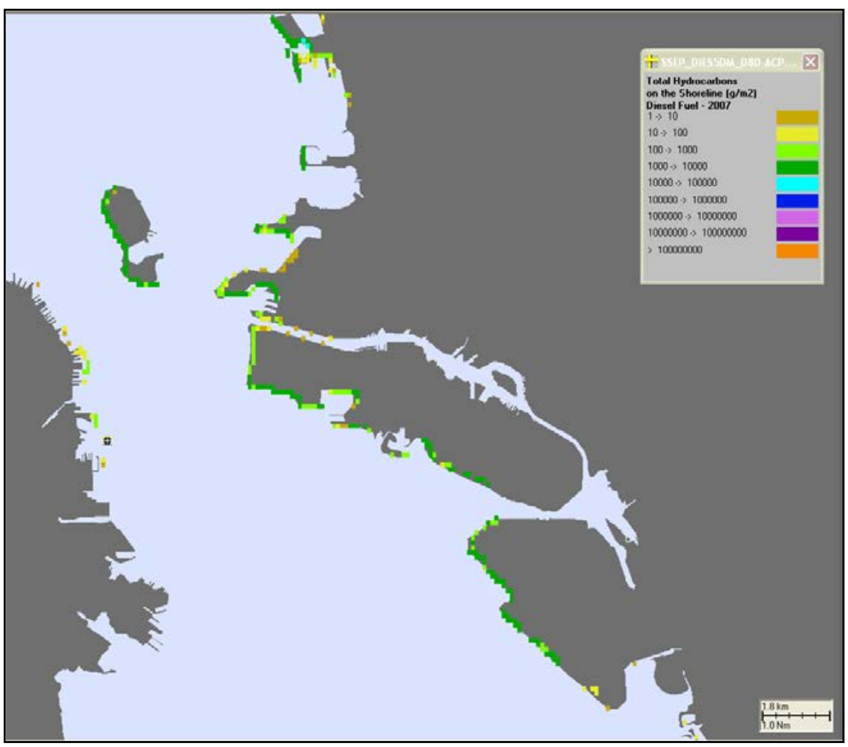


Figure 40: 100,000-gallon diesel spill at San Francisco Docks with ACP boom response

[20] The alternative boom response includes all ACP booming.

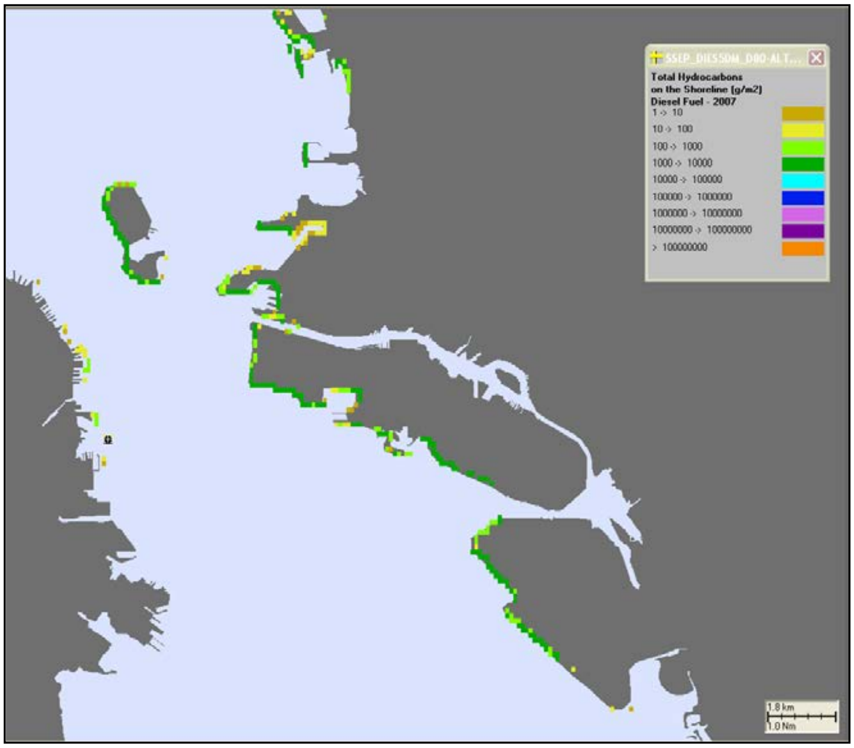


Figure 41: 100,000-gallon diesel spill at San Francisco Docks with alternate boom response

Tables 18, 19, and 20 summarize the shoreline oiling at Berkeley, Oakland Harbor, and Bay Farm Island, respectively.

Table 18: Phase 2 Shoreline Oiling Diesel Spill San Francisco Docks – Berkeley

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Berkeley
No Response	56,695	13,453	138
Response D (ACP Booms Only)	47,875	13,239	229
Response E (ACP + Alternative Booms)	47,388	11,701	126

Table 19: Phase 2 Shoreline Oiling Diesel Spill San Francisco Docks – Oakland Harbor

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Oakland Outer Harbor
No Response	56,695	13,453	41
Response D (ACP Booms Only)	47,875	13,239	44
Response E (ACP + Alternative Booms)	47,388	11,701	47

Table 20: Phase 2 Shoreline Oiling Diesel Spill San Francisco Docks – Bay Farm Island

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Bay Farm Island
No Response	56,695	13,453	1,264
Response D (ACP Booms Only)	47,875	13,239	1,185
Response E (ACP + Alternative Booms)	47,388	11,701	1,173

Crude Spill at San Francisco Docks

The shoreline oiling in Central Bay from a 100,000-gallon spill of crude at San Francisco Docks is shown in Figure 42 for the no response scenario, in Figure 43 for the ACP-boom response, and in Figure 44 for the alternative boom response[21].

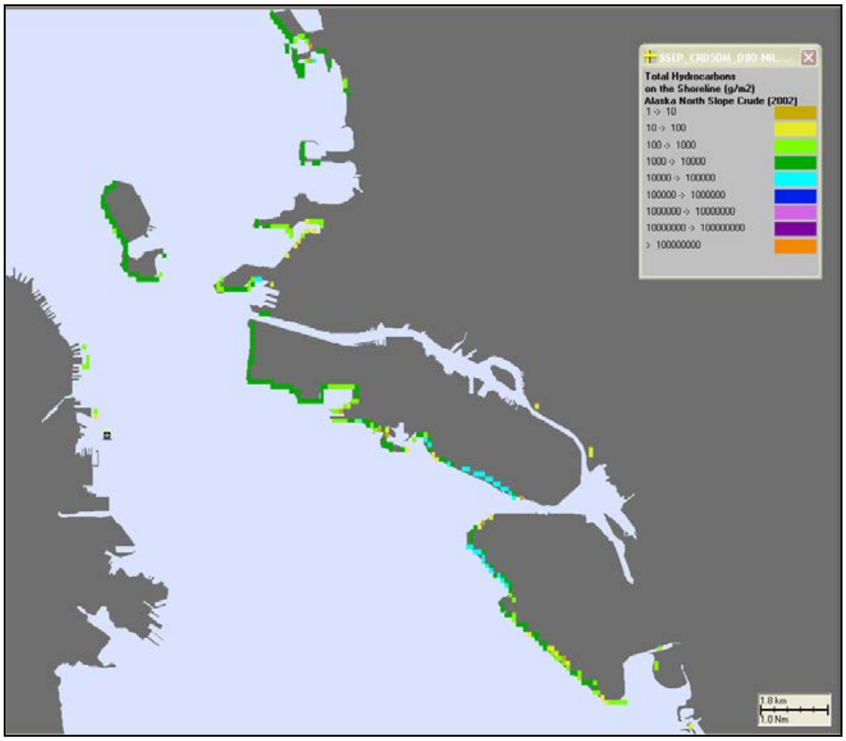


Figure 42: 100,000-gallon crude spill at San Francisco Docks with no response

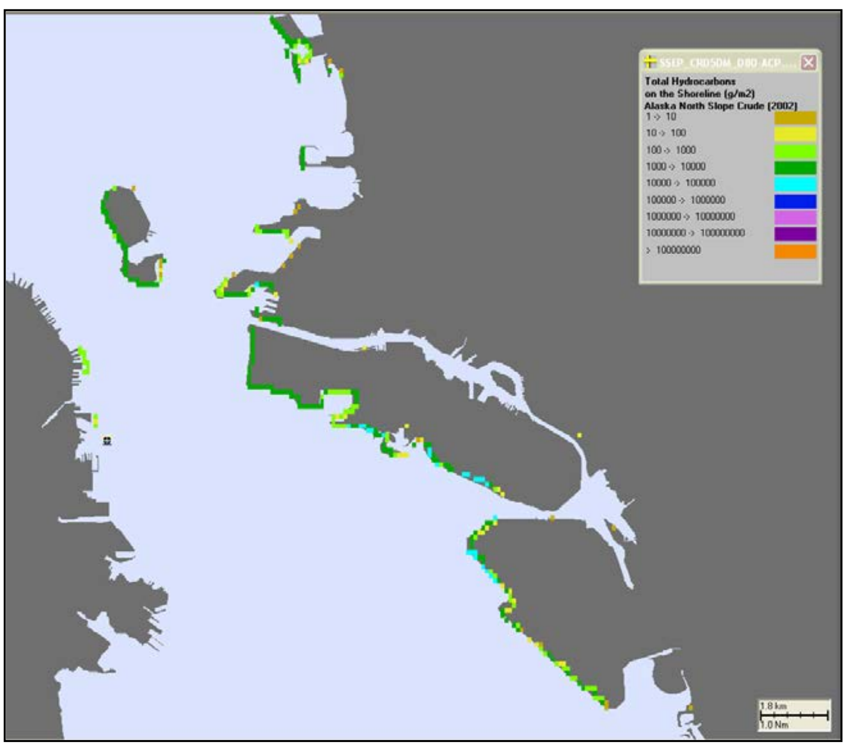


Figure 43: 100,000-gallon crude spill at San Francisco Docks with ACP boom response

[21] The alternative boom response includes all ACP booming.

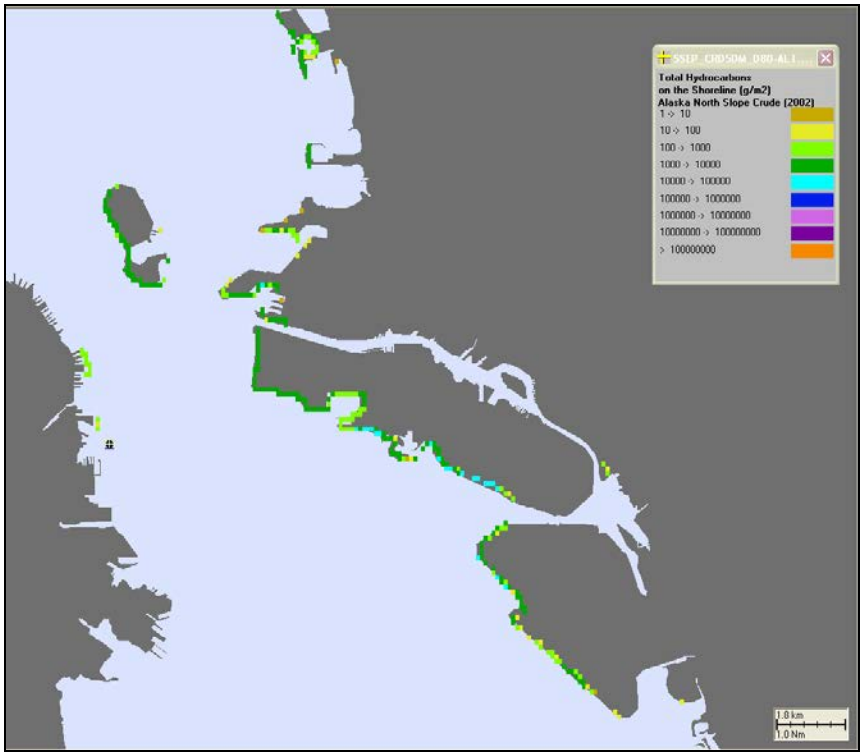


Figure 44: 100,000-gallon crude spill at San Francisco Docks with alternative boom response

Tables 21, 22, and 23 summarize the shoreline oiling at Berkeley, Oakland Harbor, and Bay Farm Island, respectively.

Table 21: Phase 2 Shoreline Oiling Crude Spill San Francisco Docks – Berkeley

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Berkeley
No Response	39,905	35,492	641
Response D (ACP Booms Only)	38,506	34,313	1,111
Response E (ACP + Alternative Booms)	36,803	33,960	659

Table 22: Phase 2 Shoreline Oiling Crude Spill San Francisco Docks – Oakland Harbor

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Oakland Outer Harbor
No Response	39,905	35,492	168
Response D (ACP Booms Only)	38,506	34,313	221
Response E (ACP + Alternative Booms)	36,803	33,960	209

Table 23: Phase 2 Shoreline Oiling Crude Spill San Francisco Docks – Bay Farm Island

Response	Total Shoreline Oiling (m^2)	Shoreline Oiling (gallons)	
		Total	Bay Farm Island
No Response	39,905	35,492	3,466
Response D (ACP Booms Only)	38,506	34,313	2,796
Response E (ACP + Alternative Booms)	36,803	33,960	1,385

Phase 2 Boom Effectiveness – Martinez Spills

The results of the modeling scenarios for all three oil types were analyzed with regard to the potential reduction in shoreline oiling with the ACP booming (Response D) and ACP plus alternative booming (Response E) strategies.

Grizzly Bay

Table 24 shows the relative change in shoreline oiling (by oil volume) compared with no response in Grizzly Bay for the three oil types.[22] The currents in this area, as shown in Figure 21 are too swift to allow effective booming in Grizzly Bay except for the innermost ACP boom where the current is relatively low.

Table 24: Shoreline Oil Change (by Volume) in Grizzly Bay by Booming Type

Response[23]	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Grizzly Bay	All Areas	Grizzly Bay	All Areas	Grizzly Bay
Response D	-27%	-61%	0%	-32%	-5%	-42%
Response E	-28%	-61%	+3%	-32%	-9%	-27%
Improvement	-	none	-	none	-	none

Ryer Island/Honker Bay

Table 25 shows the relative change in shoreline oiling (by oil volume) compared with no response at Ryer Island in Honker Bay for the three oil types. Relative improvements in the area of concern with alternative boom added to the ACP boom compared are highlighted.

Table 25: Shoreline Oil Change (by Volume) at Ryer Island by Booming Type

Response	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Ryer Island	All Areas	Ryer Island	All Areas	Ryer Island
Response D	-27%	-22%	0%	-29%	-5%	-13%
Response E	-28%	-51%	+3%	-76%	-9%	-39%
Improvement	-	-38%	-	-66%	-	-31%

Freeman Island/Honker Bay

Table 26 shows the relative change in shoreline oiling (by oil volume) compared with no response at Freeman Island in Honker Bay for the three oil types. Relative improvements in the area of concern with alternative boom added to the ACP boom compared are highlighted.

Table 26: Shoreline Oil Change (by Volume) at Freeman Island by Booming Type

Response	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Freeman Island	All Areas	Freeman Island	All Areas	Freeman Island
Response D	-27%	-57%	0%	-21%	-5%	-36%
Response E	-28%	-82%	+3%	-10%	-9%	-36%
Improvement	-	-58%	-	none	-	none

[22] Negative percentages indicate a reduction in oiling, positive percentages an increase.
[23] Response D and E show the relative change in oiling compared to "no response". Improvement is the relative change with the addition of the alternate boom to the ACP boom in the area of concern.

Phase 2 Boom Effectiveness – San Francisco Docks Spills

The results of the modeling scenarios for all three oil types were analyzed with regard to the potential reduction in shoreline oiling with the ACP booming (Response D) and ACP plus alternative booming (Response E) strategies.

Berkeley

Table 27 shows the relative change in shoreline oiling (by oil volume) compared with no response in Berkeley for the three oil types.[24] Relative improvements in the area of concern with alternative boom added to the ACP boom compared are highlighted.

Table 27: Shoreline Oil Change (by Volume) in Berkeley by Booming Type

Response	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Berkeley	All Areas	Berkeley	All Areas	Berkeley
Response D	-6%	+102	-2%	+66%	-3%	+73%
Response E	-34%	-10%	-13%	-9%	-4%	+3%
Improvement	-	-56%	-	-45%	-	-41%

Oakland Harbor

Table 28 shows the relative change in shoreline oiling (by oil volume) compared with no response at Oakland Harbor for the three oil types. The existing ACP boom seems to provide the same benefit as the alternative booming arrangement.

Table 28: Shoreline Oil Change (by Volume) at Oakland Harbor by Booming Type

Response	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Oakland	All Areas	Oakland	All Areas	Oakland
Response D	-6%	+3%	-2%	+7%	-3%	+32%
Response E	-34%	+6%	-13%	+15%	-4%	+24%
Improvement	-	none	-	none	-	-5%

Bay Farm Island

Table 29 shows the relative change in shoreline oiling (by oil volume) compared with no response at Bay Farm Island for the three oil types. Relative improvements in the area of concern with alternative boom added to the ACP boom compared are highlighted.

Table 29: Shoreline Oil Change (by Volume) at Bay Farm Island by Booming Type

Response	HFO Spill		Diesel Spill		Crude Spill	
	All Areas	Bay Farm Island	All Areas	Bay Farm Island	All Areas	Bay Farm Island
Response D	-6%	+5%	-2%	-6%	-3%	-19%
Response E	-34%	-32%	-13%	-7%	-4%	-60%
Improvement	-	-36%	-	-1%	-	-50%

[24] Negative percentages indicate a reduction in oiling, positive percentages an increase.

General Conclusions on Phase 2 Booming Results

Booming effectiveness is highly dependent on the currents in the particular location of boom installation. As discussed in the Phase 1 analysis, many areas of San Francisco Bay experience currents over 1.0 knots, which allow for oil entrainment and other types of boom failure.[25] Higher currents can be overcome to some extent with the placement of boom at angles to the current. Locations in which currents are relatively low of boom or the flow is that the boom can be placed at an appropriate angle will afford the greatest effectiveness in keeping oil out of the sensitive areas of concern. The areas shown in Figure 23 are locations in which protective booming strategies might be effective.

In some instances, the oiling in a particular area of concern is higher with booming than without any booming, as would occur in the hypothetical "no response" situation. In the "no response" case, the oil spreads across the shorelines in the bay undeterred by any deflection by protective or deflection booms. The oil may therefore cover the particular area of concern in the current study in a greater way if booms are placed in other parts of the bay, including in the area of concern than if the oil were to spread freely across the shorelines in the bay.

Of course, the "no response" strategy would generally not be considered a true "option" for response except under the most extreme circumstances in which no response were possible due to safety or other emergency circumstances. The placement of booms in one location will deflect the oil to another location unless significant efforts are made to remove oil off the water surface. Oil recovery efforts that involve mechanical containment will also be limited in large part by the relative effectiveness of the boom as related to current velocity. This is the reason that spill response is particularly challenging in San Francisco Bay.

This modeling study did not include mechanical containment and recovery modeling because the purpose of the study was to determine whether alternative booming strategies would be effective in reducing the oiling to particular areas of concern. Adding modeling of oil removal would have added additional variables that would not allow for proper testing of the booming hypotheses. Any improvement in protection of the sensitive sites could be related either to the effectiveness of the alternative boom placement or it could be related to the way in which oil removal operations in the vicinity of the area, or perhaps even at some distance from the sensitive site, had been conducted.

In general, oil removal is rarely more effective than 10 – 25% even under optimum conditions, with lighter fuels, such as diesel, recovery is considerably lower than that due to dissolution and evaporation of the oil and the difficulty in locating the oil on the water surface. Heavier oils, such as HFO, can sometimes be recovered at a higher rate, such as was reported for the Cosco Busan spill.[26]

Booming strategies are usually "tradeoffs" in which oil is deflected out of a particular area of concern at the expense of another shoreline location. Effective contingency planning includes evaluating and prioritizing sensitive areas and determines which to protect and where best to deflect oil. The sites to which oil is deflected should be areas that are easier to clean or have less value as natural or socioeconomic resources. In many cases, political or cultural issues become deciding factors as well.

[25] Boom failure is discussed in more detail in Appendix A.
[26] Rates of recovery exceeding 30% were reported, though much of that recovered oil was recovered from shorelines rather than from the water surface.

Phase 2 Cost Analyses

The booming strategies were also evaluated with regard to relative shoreline cleanup[27] cost reductions for the specific areas of concern and for the bay as a whole. Estimated costs of additional booming in the ACP plus alternative booming strategies were contrasted to potential benefits with regard to reduced oiling and reductions in cleanup costs. Additional benefits with regard to potential reductions in natural resource damages[28] (e.g., fewer birds oiled) or socioeconomic impacts (e.g., less oiling of marinas) were not specifically quantified.

Basis of Protective Boom Costs

Boom costs are based on the amount of boom deployed, as in Table 30 for the ACP booms scenarios. The additional boom required for the alternative elective boom scenarios, above and beyond the ACP scenarios, are shown in Table 31.

Table 30: Best Achievable Practice Boom Response Resources in San Francisco Bay[29]

Post-Spill Time Period	Central Bay[30] (ft of boom)			Suisun Bay[31] (ft of boom)		
	Harbor Boom	River Boom	Other Boom	Harbor Boom	River Boom	Other Boom
0 – 6 hours	12,100	500	0	11,300	2,600	0
7 – 12 hours	2,500	2,500	4,000	6,000	4,250	0
13 – 24 hours	27,900	4,150	0	-	-	-
25 – 48 hours	38,200	7,300	3,600	-	-	-
Total	**80,700**	**14,450**	**7,600**	**17,300**	**6,850**	**0**

Table 31: Additional Elective Boom for Phase 2 Scenarios

Post-Spill Time Period	San Francisco Docks Spill			Martinez Spill		
				Grizzly Bay (ft of boom)	Honker Bay	
	Berkeley (ft of boom)	Oakland Outer Harbor (ft of boom)	Bay Farm Island (ft of boom)		Ryer Island (ft of boom)	Freeman Island (ft of boom)
6 hours	5,300	3,400	12,700	23,800	6,900	9,200

It is assumed that additional boom would need to be procured for the alternative booming strategies based on the amounts of boom reported to be in the San Francisco Bay area (Table 31), unless this boom were taken from another location. This is unlikely to occur at the early time of six hours as it would likely still be unclear where the oil might spread. In the case of the Phase 1 booming scenarios, in which the

[27] Calculations for overall cleanup operations were not evaluated in this study because the relative differences in overall costs would likely be insignificant. The costs and impacts to the specific areas of concern (e.g., Grizzly Bay or Bay Farm Island) were examined. The costs of cleanup for different hypothetical spills in San Francisco Bay can be found in Etkin et al. 2002 and French-McCay et al. 2002.
[28] For more information on natural resource impacts, refer to French-McCay and Rowe 2009.
[29] Based on Jochums et al. 2005.
[30] Includes Richmond Inner Harbor, Tiburon/Belvedere Coves.
[31] Includes Grizzly Bay and Honker Bay areas of Carquinez Strait.

alternative boom was not installed until about 54 hours, there may be opportunities to move boom from one location to another.

The estimated costs of the additional booms are shown in Table 32. The costs are based on typical commercial costs for boom on a per-foot daily basis for the estimated time that booms would be in transit to and from the spill site and in place on site. "No response" scenarios are assumed to have no protective booming in place. These scenarios act as a baseline to demonstrate the general effectiveness of the booming in keeping oil out of sensitive areas through the use of the ACP boom and the alternate elective booms.

Table 32: Rental Cost of Additional Elective Boom for Phase 2 Scenarios

Post-Spill Time Period	San Francisco Docks Spill			Martinez Spill		
					Honker Bay	
	Berkeley (ft of boom)	Oakland Outer Harbor (ft of boom)	Bay Farm Island (ft of boom)	Grizzly Bay (ft of boom)	Ryer Island (ft of boom)	Freeman Island (ft of boom)
6 hours	$148,400	$95,200	$355,600	$666,400	$193,200	$257,600

Basis of Response Crew Costs

In addition to the costs for the rental of the booms, there will be additional costs for the response crews that will need to install the booms.

The pay scales for workers are based on a comprehensive survey of Basic Ordering Agreements made with the US Coast Guard (USCG) Office of Maintenance and Logistics for the 11th US Coast Guard District updated to 2009 dollars and adjusted for commercial rates. Wages are assumed paid as: 67% straight wages, 20% premium wages, and 13% overtime wages. Cleanup crews work for 12-hour workdays. Crews are assumed to consist of: 1% project managers, 3% supervisors, 67% skilled laborers, and 29% unskilled laborers[32].

Worker numbers and ratios of worker types were verified by a review of Area Contingency Plans[33], Incident Action Plans from past spills[34], and oil company contingency plans. Equipment rental rates are based on a comprehensive survey of Basic Ordering Agreements made with the USCG Office of Maintenance and Logistics for the 11th US Coast Guard District updated to 2009 dollars and adjusted for commercial rates (Table 33). [35]

[32] Etkin 2000; National Research Council 2001.
[33] e.g., North Coast California; Central Coast California; San Francisco Bay & Delta, Baltimore; Long Angeles/Long Beach; San Diego
[34] M/V Cape Mohican; PEPCO Pipeline; M/V New Carissa; T/B Morris J. Berman.
[35] Etkin 1998; Etkin 2000; National Research Council 2001.

Table 33: Contractor Labor Costs for San Francisco Bay Area			
Labor Type	**Relative Percentage of Workers**	**Hourly Wages**	**Daily Wages**
Project Managers	1.4%	$114	$1,370
Supervisors	2.5%	$85	$1,024
Skilled Laborers	65.6%	$72	$859
Unskilled Laborers	28.0%	$61	$735
Workboat Operators	2.1%	$62	$740
Biologist	0.4%	$85	$1,018

The alternative boom installation operations are assumed to involve a crew of about 10 people (in the proportions outlined in Table 33) for seven days, i.e., a cost of about $117,000 for each of the alternative booming areas in Phase 2. If it were necessary to keep the boom in place for as long as two or more weeks, these costs could double.

Total costs for the boom installations, including boom rental costs and labor costs, are shown in Table 34. Note that these costs do not take into account the long-term maintenance costs of the boom per se, but it is assumed that the commercial oil spill response organizations (OSROs) that procure and maintain these booms include their own maintenance costs into the rental fees charged for the use of the boom so that they can continue to make a reasonable profit. Again, if the booms were left in place for more than a week, the costs would increase.

Table 34: Total Cost of Additional Elective Boom for Phase 2 Scenarios						
Post-Spill Time Period	**San Francisco Docks Spill**			**Martinez Spill**		
					Honker Bay	
	Berkeley (ft of boom)	**Oakland Outer Harbor (ft of boom)**	**Bay Farm Island (ft of boom)**	**Grizzly Bay (ft of boom)**	**Ryer Island (ft of boom)**	**Freeman Island (ft of boom)**
6 hours	$265,400	$212,200	$472,600	$783,400	$310,200	$374,600

Basis of Averted Shoreline Cleanup Costs

The alternative boom installations were intended to keep oil out of sensitive areas to reduce shoreline oiling (and marsh or wetland impact) and to keep oil out of areas that are deemed to be particularly sensitive with regard to natural and/or socioeconomic resources. The relative benefits of the booms for reducing impacts to natural resources, such as birds, is not covered in this analysis. Potential bird impacts and other natural resource impacts are discussed in the companion report (French-McCay and Rowe 2009).

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

Shoreline cleanup costs are based on area of oil impact by shoreline type and oil type[36] (Etkin 2001*d*, 2003*b*). The characteristics of oil (as in Table 35) and the characteristics of the substrate (rocky, gravel, wetland, sand, *etc.*) influence the degree of penetration, persistence, and adhesion. All these factors determine the amount of labor necessary to remove the oil from impacted shorelines. In addition, some shoreline types – notably wetlands and mudflats – are extremely sensitive to the impacts of the spill response itself (moving of machinery and personnel) so that extraordinary measures need to be taken, making these shoreline types more expensive to clean up.

Shoreline cleanup cost factors on a per area basis by oil type and shoreline type are shown in Table 36. Note that these costs *include* the disposal of oily debris and solid waste collected.

Table 35: Influence of Oil Properties on Oil Impact in Environment[37]

Oil Type	Viscosity	Adhesion	Penetration	Degradation
Gasoline	1	1	5	4
Diesel	2	2	4	1
Crude	4	4	2	3
Heavy fuel oil	5	5	1	5

Table 36: Shoreline Cleanup Cost Factors[38]

Oil Type	Heavy Fuel Oil ($/m^2)		Diesel ($/m^2)		ANS Crude	
Shoreline Type	**<1 mm**	**>1 mm**	**<1 mm**	**>1 mm**	**<1 mm**	**>1 mm**
Rocky shoreline	$368	$510	$340	$344	$352	$424
Gravel beach	$380	$650	$342	$348	$358	$492
Sand beach	$390	$510	$342	$350	$362	$424
Mud flat	$492	$686	$358	$376	$414	$510
Wetland	$516	$722	$360	$384	$426	$528
Artificial	$354	$440	$338	$340	$344	$388

Costs for the disposal of oily debris recovered from oil-impacted shorelines are included in this category. Oil disposal rates are based on a comprehensive survey of Basic Ordering Agreements made with the US Coast Guard Office of Maintenance and Logistics for the all US Coast Guard Districts updated to 2009 dollars. The costs are $242 per barrel of oil recovered mechanically (on water) and $168 per m^2 shoreline impact of greater than 0.1mm. The costs *assume an emulsification factor of four – i.e.*, for each barrel of oil recovered, there are four barrels for disposal/separation due to emulsification and excess water recovery[39] (Etkin 1995).

[36] Etkin 2001d, 2003b
[37] Lower numbers indicate more favorable conditions to the environment and faster recovery after a spill (based on Fingas 2001).
[38] In 2009 dollars. Includes $168 per m^2 of shoreline impact over 0.01 mm for disposal.
[39] Etkin 1995.

Calculated Averted Shoreline Response Costs

The estimated difference in shoreline cleanup costs for the alternative booming responses (Response E) for each of the oil types and locations for the Martinez spills are shown in Table 37, and for the San Francisco Docks spills in Table 38. Averted shoreline cleanup costs were not calculated if there was no clear benefit in that there was no substantive reduction in oiling or if the alternative booming strategy appeared to increase rather than decrease oiling. The relative differences in costs are shown in Tables 39 and 40.

Table 37: Estimated Shoreline Cleanup Costs in Areas of Concern for Martinez Spills[40]

Area of Concern	HFO		Diesel		Crude	
	Response D	Response E	Response D	Response E	Response D	Response E
Grizzly Bay	-	-	-	-	-	-
Ryer Island	$504,290	$326,212	$200,910	$74,313	$482,621	$200,016
Freeman Island	$149,924	$69,407	-	-	-	-

Table 38: Estimated Shoreline Cleanup Costs in Areas of Concern for SF Docks Spills

Area of Concern	HFO		Diesel		Crude	
	Response D	Response E	Response D	Response E	Response D	Response E
Berkeley	$2,210,167	$583,018	$287,166	$182,837	$210,665	$122,557
Oakland Harbor	-	-	-	-	-	-
Bay Farm Island	$2,346,177	$881,467	-	-	$533,246	$264,465

Table 39: Estimated Shoreline Cleanup Costs Averted with Alternative Booming Strategies in Areas of Concern for Martinez Spills

Area of Concern	HFO	Diesel	Crude
Grizzly Bay	-	-	-
Ryer Island	$178,078	$126,597	$282,605
Freeman Island	$80,517	-	-

Table 40: Estimated Shoreline Cleanup Costs Averted with Alternative Booming Strategies in Areas of Concern for San Francisco Docks Spills

Area of Concern	HFO	Diesel	Crude
Berkeley	$1,627,149	$104,330	$88,108
Oakland Harbor	-	-	-
Bay Farm Island	$1,464,710	-	$268,780

[40] Response E is with ACP booms only. Response F is with ACP booms augmented by alternative booms.

Benefits Analysis Conclusions

Cost-benefit matrices were developed for each of the areas of concern to compare the estimated costs of the alternative booming (in addition to the costs of ACP booming in the area of concern and other aspects of the overall spill cleanup cost) with the potential benefits in terms of averted shoreline oiling, averted shoreline cleanup costs, and other qualitative benefits, such as reductions in impacts to natural resource and socioeconomic resources.

In the matrices, if the benefits exceeded the costs of booming, the benefit is shown to be positive, if the costs of booming appear to exceed the benefits, the benefit is negative. Note that only shoreline cleanup cost is compared in that analysis. Averted shoreline cleanup costs were not calculated if there was no clear benefit in that there was no substantive reduction in oiling or if the alternative booming strategy appeared to increase rather than decrease oiling.

Other potential benefits should be evaluated, such as the potential reduction of oiling of natural resource and socioeconomic resources. These benefits may be seasonal or situational. For example, if there are migrating or nesting birds in an area or if there is a marina that is in full use, there may be a particular benefit to protecting those sites at that time.

Martinez Spills

The potential benefits for alternative booming for 100,000-gallon spills that originate in Martinez are shown for Grizzly Bay, Ryer Island, and Freeman Island in Tables 41, 42, and 43, respectively.

Table 41: Cost-Benefit Matrix of Grizzly Bay Alternative Booming Strategies

Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$783,400	0	-	-	None
Diesel	$783,400	0	-	-	None
Crude	$783,400	Increase in oiling	-	-	None

Table 42: Cost-Benefit Matrix of Ryer Island Alternative Booming Strategies

Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$310,200	1,423	$178,078	Birds (coating) Marsh habitats	Possible[41]
Diesel	$310,200	470	$126,597	Marsh habitats Toxic impacts	Possible[42]
Crude	$310,200	585	$282,605	Birds (coating) Marsh habitats	Probable

[41] Benefits may be realized if there are significant natural resources at stake, particularly migratory or nesting birds.
[42] Benefits may be realized if there are significant natural resources at stake that may be impacted by the toxicity of diesel.

Table 43: Cost-Benefit Matrix of Freeman Island Alternative Booming Strategies					
Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$374,600	662	$80,517	Birds (coating) Marsh habitats	Possible[43]
Diesel	$374,600	Increase in oiling	-	-	None
Crude	$374,600	5 gallons	-	-	Minimal

San Francisco Docks Spills

The potential benefits for alternative booming for 100,000-gallon spills that originate at the San Francisco Docks are shown for Berkeley, Oakland Harbor, and Bay Farm Island in Tables 44, 45, and 46, respectively.

Table 44: Cost-Benefit Matrix of Berkeley Alternative Booming Strategies					
Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$265,400	4,031	$1,627,149	Marinas (coating) Birds?	Definite
Diesel	$265,400	103	$104,330	Marinas (coating) Birds?	Possible
Crude	$265,400	452	$88,108	Marinas (coating) Birds?	Possible

Table 45: Cost-Benefit Matrix of Oakland Harbor Alternative Booming Strategies					
Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$212,200	Increase in oiling	-	-	None
Diesel	$212,200	Increase in oiling	-	-	None
Crude	$212,200	12	-	-	Minimal

Table 46: Cost-Benefit Matrix of Bay Farm Island Alternative Booming Strategies					
Oil Type	Costs	Potential Benefits			
	Booming Cost	Averted Shoreline Oiling (gallons)	Averted Shoreline Cleanup Costs	Other Potential Damage Averted	Benefit
HFO	$472,600	2,687	$1,464,710	Birds (coating) Marsh habitats	Definite
Diesel	$472,600	12	-	-	Minimal
Crude	$472,600	1,411	$268,780	Birds (coating) Marsh habitats	Definite

[43] Benefits may be realized if there are significant natural resources at stake, particularly migratory or nesting birds.

General Observations

There were mixed results with regard to the effectiveness of the alternative booming strategies over the existing booming strategies specified in the Area Contingency Plan (ACP).

San Francisco Bay has many sensitive sites, as well as a particularly challenging current system that will not allow booms, both as protection and for containment purposes during on-water recovery operations. In some of the hypothetical spill scenarios (e.g., Grizzly Bay) there was clearly no benefit to the alternative booming unless it could be conducted in such a way so as to overcome the currents that reduced boom effectiveness and allowed entrainment and other boom failures.

In some of the individual scenarios, the oil type played a role in determining the results. For example, at Bay Farm Island, for the diesel spill the alternative booming gave virtually no benefit in protection due to the relatively small amount of oil that would be kept out of the area (an estimated 12 gallons). On the other hand, there appeared to be a definite benefit for HFO and crude oil spills that might impact this site.

For the scenarios in Oakland Harbor, the additional alternative booming did not have any enhancing effect on the protection already provided by ACP booms.

The Berkeley alternative booming offered enhanced protection and thus netted benefits over the existing ACP booming strategy, particularly for HFO spills.

The alternative booming at Ryer Island and Freeman Island might provide some benefits if the spill occurred during a time in which there were particularly susceptible natural resources at risk, particularly migratory or nesting birds.

Overall, the decision to add additional alternative booms at these locations should depend on the particular seasonal resources at risk at the time of the spill, as well as whether the trajectory of the spill appears to indicate a direct or nearly direct hit on these sites. There may also be benefits that cannot be quantified, such as political and social concerns.

It is important to keep in mind that this study examined the specific benefits of alternative booming strategies for specific scenarios. It did not examine the benefits of overall effectiveness in on-water removal operations, which are rarely more than 10 – 25% effective, particularly in areas of high current such as San Francisco Bay.

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Appendix A: Components of Boom Effectiveness

Boom "effectiveness", i.e., the ability of a boom to deflect or contain oil by providing a barrier to the oil on and under the water surface, is dependent on a number of factors:

- Boom condition[44]
- Boom configuration
- Timing of boom deployment
- Boom angle(s) with respect to current vector(s)[45]
- Boom deployment quality (e.g., proper anchoring, tight connections, proper angling)[46]
- Current velocity and direction over time
- Wave height over time
- Amount of oil

If it is assumed that the boom is in good condition and the response personnel have deployed it in a correct manner, then the effectiveness of the boom will be completely dependent on physical and environmental conditions. If it is completely effective, a boom could, theoretically, be considered the equivalent of a shoreline beyond which no oil can pass. But, in reality, as observed in countless field applications, booms are not always impermeable barriers. Even when properly deployed and in excellent condition, there are number of ways in which booms might fail by allowing oil to pass, including[47]:

Entrainment

Oil goes under boom skirt if current exceeds critical velocity[48] of 0.5 m/s (1 kt) except as corrected by angle of boom to current (Figure A-1).

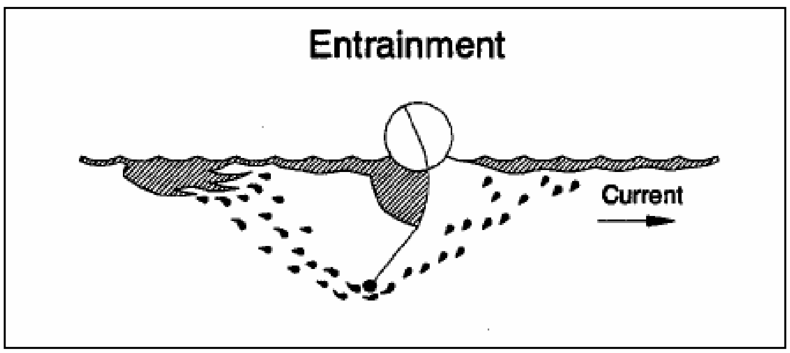

Figure A-1: Entrainment under a boom

The most important factor with regard to oil spill modeling is entrainment. This is the factor that leads to the most boom failure, assuming that the boom is properly deployed and in excellent condition. Regardless of the size of the boom, the length of its skirt, or its composition, it is virtually impossible to create an impermeable floating boom barrier to overcome the physics of entrainment. When the current velocity exceeds 0.35 m/s (0.7 kts), oil begins to move under the boom[49].

[44] Boom maintenance and age are important in determining the effectiveness of booming.
[45] The angle at each point along its length will be important in determining effectiveness.
[46] See Fang and Wong 2001.
[47] See also An, et al. 1997; Wong and Witmer 1995.
[48] Some entrainment begins at 0.35 m/s (0.7 kts)
[49] Some of the first descriptions of this phenomenon are in Brown, Bartlett, and Lamb 1973, and Wicks 1969.

The only way to overcome this is the angle the boom with regard to the direction of current[50]. This allows the boom to be effective under higher current velocities. Figure A-2 shows the angles of the boom with respect to the current that are required to prevent entrainment. The formula is derived by curve-fitting of the empirical data points[51]. Note a longer boom with a more complex configuration or with a curve may have a number of angles with respect to the current. Entrainment could occur in some locations on the boom but not others.

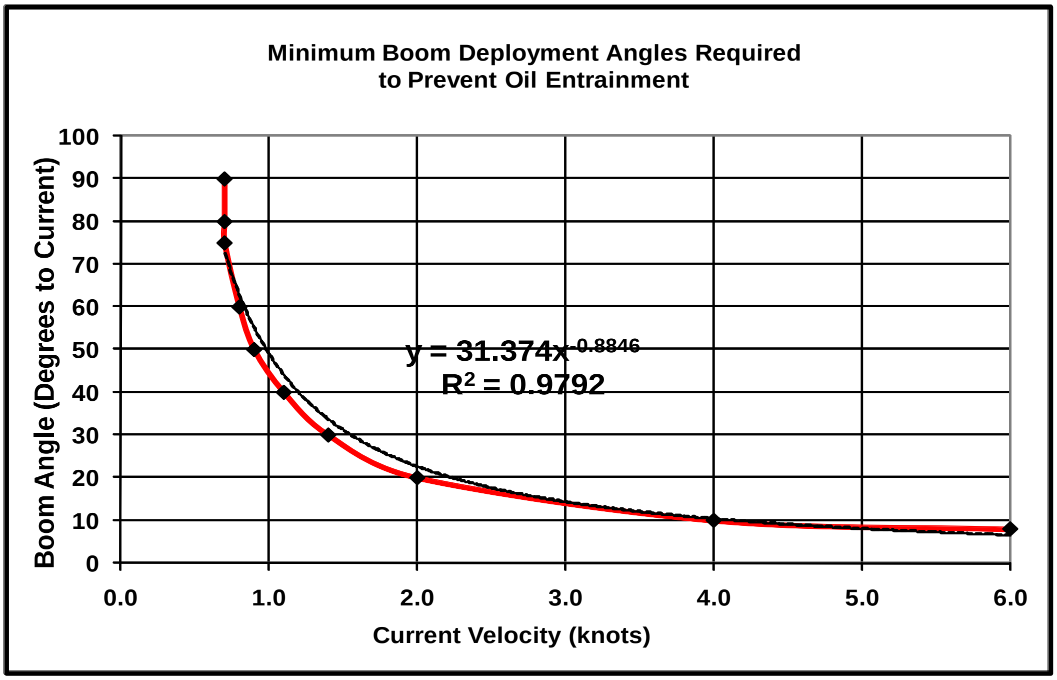

Figure A-2: Minimum boom deployment angles to prevent oil entrainment

Drainage

Oil collects at the boom interface and is swept under boom by current exceeding critical velocity (Figure A-3).

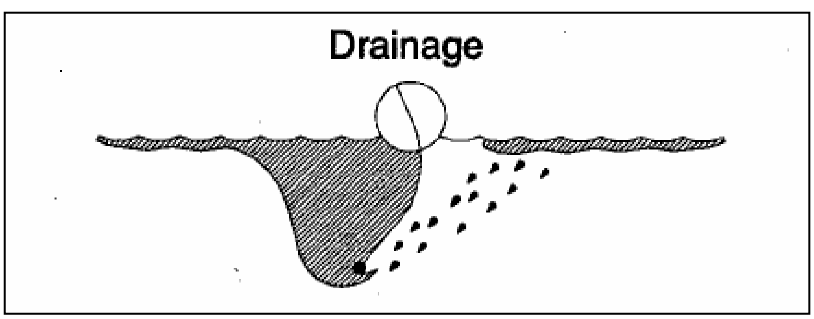

Figure A-3: Drainage at a boom

[50] There have been some research and development programs in fast-water booming techniques that have made some progress in improving booming effectiveness in higher currents, but most of these are related to maintaining the angles of deployment under the higher current velocities. These are reviewed in: Coe 1999; Brown, Goodman, and An 1999; DeVitis and Hanon 1995; and Hansen 2001.

[51] Boom failures observed in field applications are reviewed in Swift et al. 2000.

Splash-over

During splash-over, the oil splashes over when waves are higher than the boom's freeboard (Figure A-4).

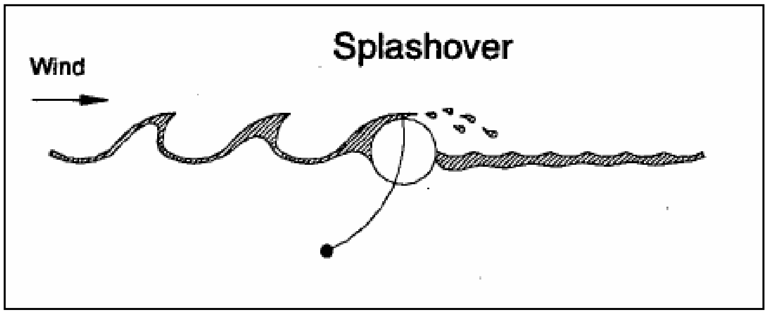

Figure A-4: Splashover at boom interface

Submergence Failure

During submergence failure, the boom becomes submerged due to poor heave response.

Planing

During planing, the boom moves from a vertical to a horizontal position in water due to poor design of tension members or if the boom is towed in currents exceeding critical velocity.

Structural or Stability Failure[52]

Structural or stability failure occurs when the boom components fail usually due to floating debris (Figure A-5).

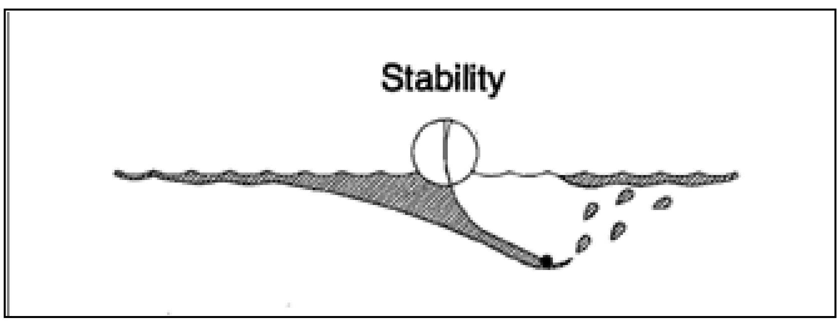

Figure A-5: Stability failure in a boom

Critical Accumulation

Critical accumulation occurs when heavier oils accumulated at the boom interface are swept under the boom when certain critical amount of oil accumulates.

Shallow Water Blockage

Rapid currents form under the boom in shallow water causing blockage.

[52] See Fang and Wong 2000.

Appendix B: Variability and Randomness in Modeling Results

In both Phases 1 and 2 of this study, the use of modeling to simulate hypothetical spill scenarios introduces certain degrees of inherent variability and "randomness" that may impact the results and outcomes. In many respects, this "randomness" is analogous to what happens in actual spills and is not necessarily a sign of "incorrect" or "inaccurate" outcomes from the modeling.

For example, because the oil transport model in SIMAP[53] includes stochastic randomized movements to represent turbulent motions at spatial and time scales smaller that the resolution of the current and wind data used as input to the model, there is variability in the movements of oil spillets[54] in the simulation. That randomization may be enough to move oil closer to a shoreline in one simulation, while in another using the same wind and current data inputs, the random motion might move oil away from the shore. This randomization results in variation in the specific water areas and shoreline locations oiled and in some cases the shore types oiled. This randomization simulates the natural variability in the environment and uncertainty in predicting exactly where oil might be transported.

In addition, protective booming input to the model deflects oil offshore from the boomed site. In many cases, the booms are located to protect inlets, coves, and wetlands with small shoreline length. In the model, oil deflected off booms moves offshore and along the shore (down wind and with the currents) and may oil other shorelines. Thus, the deflected oil becomes more dispersed, allowing it to impact a larger area. The other shorelines oiled may be of a different type with less ability to "hold" oil (such as a sand beach, which holds less oil per length than a wetland), and so the length of shore oiled may actually be *increased* by the inclusion of booms in the model. In an actual spill, protective booming would often be accompanied by localized efforts to remove oil. However, simulation of this response detail was not included in the modeling reported here.

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[53] The SIMAP (Spill Impact Model Application Package) modification of the Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) model (developed by Applied Science Associates (ASA) for use by the Department of the Interior in CERCLA NRDA type A regulations and for oil spill assessments under OPA) was used for this study. This model is comprised of three-dimensional oil fate and biological effects models that access impacts and provide data to estimate NRD, response, and socioeconomic costs of spills in marine and freshwater environments. The model was run in stochastic mode to produce results and statistics for multiple model runs under various possible environmental conditions. The model uses wind data, current data, and transport and weathering algorithms to calculate mass balance in various environmental compartments (water surface, shoreline, water column, atmosphere, sediments, *etc*.), surface oil distribution over time (trajectory), and concentrations of the oil components in water and sediments. Geographical data (habitat mapping and shoreline location) were obtained from existing Geographical Information System (GIS) databases based on Environmental Sensitivity Indices (ESI). Water depth was obtained from National Oceanic and Atmospheric Administration (NOAA) National Ocean Service (NOS) soundings databases. Hourly wind speed and direction data over a long historical period were obtained from nearby meteorological stations. Tidal and other currents were modeled based on known water heights, using a hydrodynamic model based on physical laws (*i.e*., conserving mass and momentum). (The use of SIMAP is described in greater detail in French-McCay, *et al.* 2005 Volume I)

[54] Lagrangian elements (spillets) are used to simulate the movements of oil components in three dimensions over time. Surface floating oil, subsurface droplets, and dissolved components are tracked in separate spillets or discrete smaller volumes of oil that in total make up the entire amount of oil spilled.

In the simulations, the differences between runs[55] are in many cases *less* than the randomized variability in the model and are not significant. However, in some cases, the timing of installation of shoreline protective boom along shorelines changes the impacts to various sensitive sites and to the area as a whole. These differences are the most important for evaluating the benefits of various response planning standards.

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