Modelling to Evaluate Effectiveness of Variations in Spill Response Strategy

Dagmar Schmidt Etkin
Environmental Research Consulting
Cortlandt Manor, NY, USA
etkin@environmental-research.com

Deborah French McCay and Jill Rowe
Applied Science Associates, Inc.
Narragansett, RI, USA
dfrench@appsci.com

Abstract

This study presents a methodology for evaluating various mechanical containment and recovery-based response strategies for inland waterway spills through the use of a trajectory, fate, and effects model (SIMAP). A sample case study was used to demonstrate different spill outcomes and impacts that may have resulted from several variations of response strategies, focusing on placement of and type of booms and oil removal equipment. The April 2000 PEPCO pipeline spill of 138,600 gallons of No. 2 and No. 6 fuels into Swanson Creek at Chalk Point, Maryland, USA, was modelled with SIMAP, recreating the trajectory and behaviour of the oil with the actual spill response. Three variations on the spill response, including alternative placement and timing of booms, were likewise modelled to estimate different outcomes (oil impacts, natural resource damages, and response costs) that may have occurred with the different responses. This particular case offers valuable lessons learned in that it demonstrates the importance of strategic boom placement and timing. The methodology is applicable to a broad spectrum of spill response planning situations and in evaluating spill responses after actual spills.

1 Introduction

Major oil spill events provide excellent opportunities for in-the-field strategic spill response planning and training as well as post-spill response evaluations. With decreasing frequency of these events (Etkin, 2001a; 2002; 2003a; 2004), it is even more important to derive the greatest benefit from these “spills of opportunity” to increase response effectiveness and maintain well-trained preparedness. The use of SIMAP for simulating the path and behaviour of oil while modelling various spill response methods for actual historical spills and for hypothetical spills allows for a state-of-the-art assessment of alternative spill response strategies for these purposes.

The case study examined in this paper involves the spillage of 138,600 gallons (approximately 481 tonnes) of a combination of No. 2 and No. 6 fuel oils from a pipeline into a salt marsh near the PEPCO facility at Chalk Point, Maryland, USA, at about 9:30am on 7 April 2000. (The details of the spill are described in NOAA, *et al.*, 2002; NTSB, 2001; and US EPA, 2000.) This case is particularly instructive in that it involved extensive impacts to wetlands after failures to follow through on directives set forth by the federal on-scene coordinator (FOSC) for oil booming and recovery, as well as deployment of defective, poorly-maintained boom. Misinformation on spill magnitude, along with the arrival of a storm on the second day after the spill created challenges for responders. Alternative responses to the actual response were modelled to analyze the way in which various boom placements and the deployment of good-condition boom might have decreased wetland impacts, overall shoreline impacts, response costs, and natural resource damages.

2 Methodology

2.1 SIMAP

This study used SIMAP, a computer modelling software application developed by Applied Science Associates (ASA), Inc., that estimates physical fates and biological effects of releases of oil. The specific application of SIMAP in this study is described in another paper in these proceedings (French-McCay, *et al.*, 2006). The actual spill scenario, as described therein, was modified to simulate three additional variations on the actual spill response with regard to boom configurations and mechanical containment and recovery operations.

2.2 Alternative Spill Response Scenario Modelling Assumptions

Four modelled scenarios (Table 1) were: actual response (AR), response using actual boom configurations with good-condition, properly-anchored boom (ARGOOD), actual response with additional booms directed by the FOSC (FOSC), and FOSC scenario with an alternative configuration of one key boom (FOSCALT).

Table 1: Alternative Modelled Spill Scenarios

Scenario	Response
AR	Actual Response
ARGOOD	Actual Response with all boom properly installed; improved oil removal
FOSC	Actual Response plus follow FOSC directives for Swanson Creek booming; ; improved oil removal
FOSCALT	Actual Response plus follow FOSC directives for Swanson Creek booming with alternative location for Boom E (Boom E-alt); improved oil removal

2.3 Booming Configurations

Boom locations are shown in Figures 1 – 2. Table 2 shows the booms deployed in the actual response and booms assumed in the hypothetical alternative responses. "Actual" boom deployment refers to the manner in which the boom was actually reported to have been deployed, including boom condition and deployment effectiveness with regard to use of anchoring, angling, and presence of twists during deployment as reported in the Pollution Reports (PolReps) prepared on scene, in interviews with responders and on- scene coordinators, and in the US EPA's report on the spill (US EPA, 2000). "Good" boom deployment refers to use of well-maintained boom, with proper anchoring and angling, and avoidance of twists.

The timing of boom deployment, the assumed percent retention* of the booms, and current and wave thresholds based on boom specifications are shown in Tables 3 – 6 for the various response scenarios. Boom will not retain oil if current or wave threshold is exceeded. Wave threshold of one foot assumed for 6 – 18" "river-canal" boom and three feet for 18 – 42" "inland environment" boom, as per US Coast Guard (USCG) specifications and known boom capabilities (Potter and Morrison, 2004) for equipment on-scene. Oil would splash over the boom if the wave threshold were exceeded. In the modelling, oil would pass under (entrain) the boom if the current threshold were exceeded.

*Percent of oil contained behind boom. <100% if boom improperly deployed and/or poor-condition.

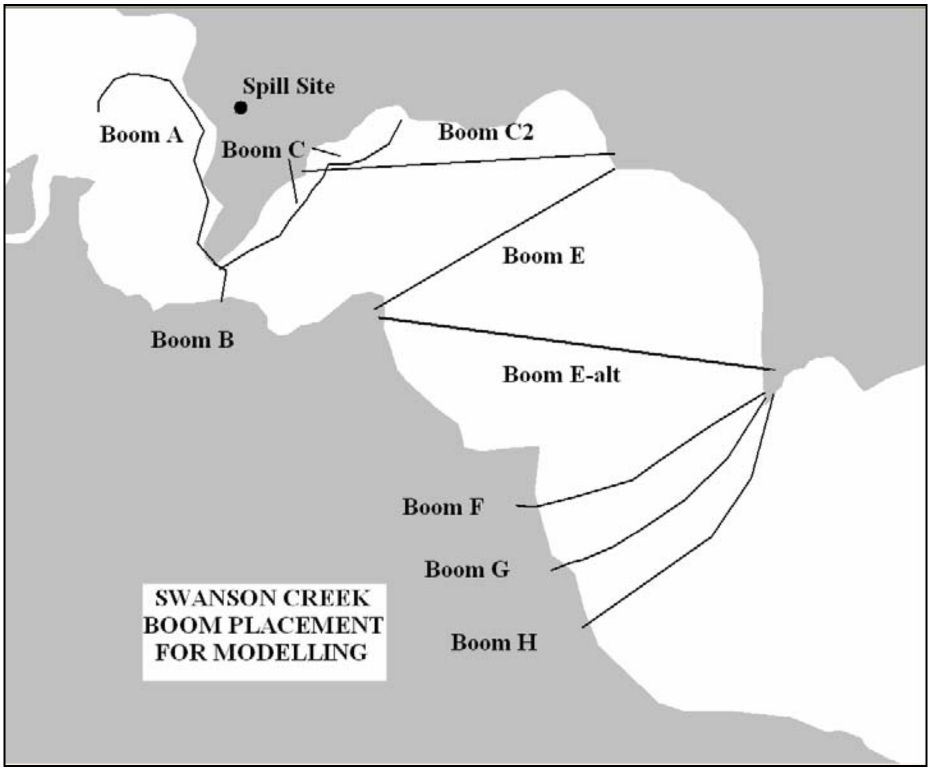

Figure 1: Booms in Swanson Creek. Booms in modelled scenarios deployed as in Table 1 with condition and deployment effectiveness in Table 2.

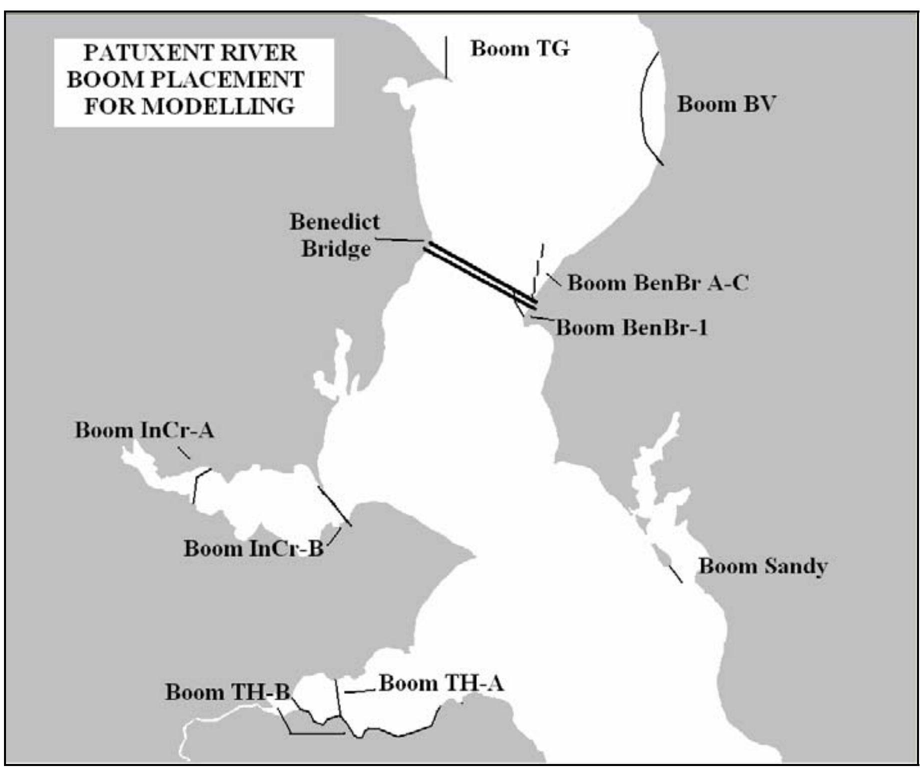

Figure 2: Boom Placement in Patuxent River (downstream from Swanson Creek). Benedict Bridge is shown as double line.

Table 2: Boom and Condition/Deployment Effectiveness by Scenario for Alternative Modelled Spill Scenarios

Boom	Boom Condition and Deployment Effectiveness by Scenario			
	AR	ARGOOD	FOSC	FOSCALT
A	actual	good	actual	actual
B	actual	good	actual	actual
C	actual	good	actual	actual
C2	none	none	good	good
E	actual	good	good	none
E-ALT	none	none	none	good
F	actual	good	actual	actual
G	actual	good	actual	actual
H	none	none	good	good
TG	actual	actual	actual	actual
BV	actual	actual	actual	actual
BenBr-A-C	actual	good	actual	actual
BenBr-1	actual	good	actual	actual
InCr-A	actual	good	actual	actual
InCr-B	actual	good	actual	actual
TH-A	actual	good	actual	actual
TH-B	actual	good	actual	actual
Sandy	actual	actual	actual	actual
Wash	actual	actual	actual	actual
Sher	actual	actual	actual	actual

Table 3: Scenario AR (Actual Response) Boom Deployment Assumptions

Boom	Deployment*	Boom Break	% Retention	Current Threshold (kts)	Wave Threshold (ft)
A	4/7 11:00PM	4/8 6:00PM	25	0.7	3
B	4/7 11:00PM	4/8 2:00PM	25	0.7	3
C	4/7 11:00PM	4/8 2:00PM	25	0.7	1
E	4/8 2:00PM	4/8 6:00PM	25	0.7	3
F	4/7 7:00PM	4/8 6:00PM	50	0.7	1
G	4/8 2:00PM	4/8 6:00PM	50	0.7	3
TG	4/11 11:00AM	*No break*	100	0.7	3
BV	4/9 2:30PM	*No break*	100	0.7	3
BenBr-A-C	4/10 9:30AM	4/10 9:30PM	100	0.7	3
BenBr-1	4/10 9:30AM	4/10 9:30PM	100	0.7	3
InCr-A	4/11 11:30AM	4/11 4:30PM	50	0.7	3
InCr-B	4/11 11:30AM	4/11 4:30PM	50	0.7	3
TH-A	4/11 11:30AM	4/11 4:30PM	50	0.7	3
TH-B	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Sandy	4/10 11:30AM	*No break*	100	0.7	3
Wash	4/11 11:30AM	*No break*	100	0.7	3
Sher	4/11 11:30AM	*No break*	100	0.7	3
Actual boom deployment assumptions based on records of actual boom behaviour and condition from PolReps; NTSB, 2001; US EPA, 2000; and interviews with spill responders and observers.					

***** Oil release began at 9:30am and continued for five hours. The spill was discovered and reported at 6pm on 7 April.

Table 4: Scenario ARGOOD Boom Deployment Assumptions

Boom	Deployment	Boom Break	% Retention	Current Threshold (kts)	Wave Threshold (ft)
A	4/7 11:00PM	*No break*	100	0.7	3
B	4/7 11:00PM	*No break*	100	0.7	3
C	4/7 11:00PM	*No break*	100	0.7	1
E	4/8 2:00PM	*No break*	100	0.7	3
F	4/7 7:00PM	*No break*	100	0.7	1
G	4/8 2:00PM	*No break*	100	0.7	3
TG	4/11 11:00AM	*No break*	100	0.7	3
BV	4/9 2:30PM	*No break*	100	0.7	3
BenBr-A-C	4/10 9:30AM	*No break*	100	0.7	3
BenBr-1	4/10 9:30AM	*No break*	100	0.7	3
InCr-A	4/11 11:30AM	*No break*	100	0.7	3
InCr-B	4/11 11:30AM	*No break*	100	0.7	3
TH-A	4/11 11:30AM	*No break*	100	0.7	3
TH-B	4/11 11:30AM	*No break*	100	0.7	3
Sandy	4/10 11:30AM	*No break*	100	0.7	3
Wash	4/11 11:30AM	*No break*	100	0.7	3
Sher	4/11 11:30AM	*No break*	100	0.7	3

Table 5: Scenario FOSC Boom Deployment Assumptions

Boom	Deployment	Boom Break	% Retention	Current Threshold (kts)	Wave Threshold (ft)
A	4/7 11:00PM	4/8 6:00PM	25	0.7	3
B	4/7 11:00PM	4/8 2:00PM	25	0.7	3
C	4/7 11:00PM	4/8 2:00PM	25	0.7	1
E	4/8 2:00PM	*No break*	100	0.7	3
F	4/8 2:00PM	*No break*	100	0.7	3
G	4/7 7:00PM	4/8 6:00PM	50	0.7	1
TG	4/8 2:00PM	4/8 6:00PM	50	0.7	3
BV	4/8 4:45PM	*No break*	100	0.7	3
BenBr-A-C	4/11 11:00AM	*No break*	100	0.7	3
BenBr-1	4/9 2:30PM	*No break*	100	0.7	3
InCr-A	4/10 9:30AM	4/10 9:30PM	100	0.7	3
InCr-B	4/10 9:30AM	4/10 9:30PM	100	0.7	3
TH-A	4/11 11:30AM	4/11 4:30PM	50	0.7	3
TH-B	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Sandy	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Wash	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Sher	4/10 11:30AM	*No break*	100	0.7	3

There is, of course, the possibility that even "good- condition" boom, properly installed, with strong anchoring would not perform with 100% holding capacity even when the wave and current thresholds were not exceeded. The results presented here for the alternative response scenarios (ARGOOD, FOSC, and FOSCALT) could vary, depending on the amount of oil that actually by-passed each boom. This modelling exercise for alternative responses assumes that the booms perform as per their specifications and USCG classifications.

Table 6: Scenario FOSCALT Boom Deployment Assumptions

Boom	Deployment	Boom Break	% Retention	Current Threshold (kts)	Wave Threshold (ft)
A	4/7 11:00PM	4/8 6:00PM	25	0.7	3
B	4/7 11:00PM	4/8 2:00PM	25	0.7	3
C	4/7 11:00PM	4/8 2:00PM	25	0.7	1
E-ALT	4/8 2:00PM	*No break*	100	0.7	3
F	4/8 2:00PM	*No break*	100	0.7	3
G	4/7 7:00PM	4/8 6:00PM	50	0.7	1
TG	4/8 2:00PM	4/8 6:00PM	50	0.7	3
BV	4/8 4:45PM	*No break*	100	0.7	3
BenBr-A-C	4/11 11:00AM	*No break*	100	0.7	3
BenBr-1	4/9 2:30PM	*No break*	100	0.7	3
InCr-A	4/10 9:30AM	4/10 9:30PM	100	0.7	3
InCr-B	4/10 9:30AM	4/10 9:30PM	100	0.7	3
TH-A	4/11 11:30AM	4/11 4:30PM	50	0.7	3
TH-B	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Sandy	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Wash	4/11 11:30AM	4/11 4:30PM	50	0.7	3
Sher	4/10 11:30AM	*No break*	100	0.7	3

2.4 Oil Removal

In conjunction with boom deployment, mechanical recovery occurred in the actual response and was assumed in the alternative responses in the zones in Figure 3 with the removal rates shown in Tables 7 – 8. Skimming rates were based equipment reported to be present at each location, observed skimming rates during the actual spill response, and information in Potter and Morrison (2004) for the specific equipment on scene. Skimming did not occur to any appreciable extent during darkness, except in removal area R-1 near the spill site where lights were installed for nighttime operations. For the alternative responses, equipment was moved from unaffected areas to increase removal in Swanson Creek and north of the Benedict Bridge.

Table 7: Oil Removal Rates for Actual Response

Name	Start (hrs post-spill)	End (hrs post- spill)	Tonnes/Hr
Swanson	-	-	none
R-1	13.75	69.75	7.54 -0.07
R-3	28.75	64.75	1.25- 0.04
Above Benedict	55	93	4.43-1.48
Ben2	83	93	minimal

Table 8: Oil Removal Rates for Alternative Response Scenarios

Name	Start (hrs post-spill)	End (hrs post- spill)	Tonnes/Hr
Swanson	24.75	120	5.25
R-1	13.75	120	15.07-0.14
R-3	28.75	120	2.5-0.08
Above Benedict	55	120	7.90-1.48
Ben2	83	120	0.15

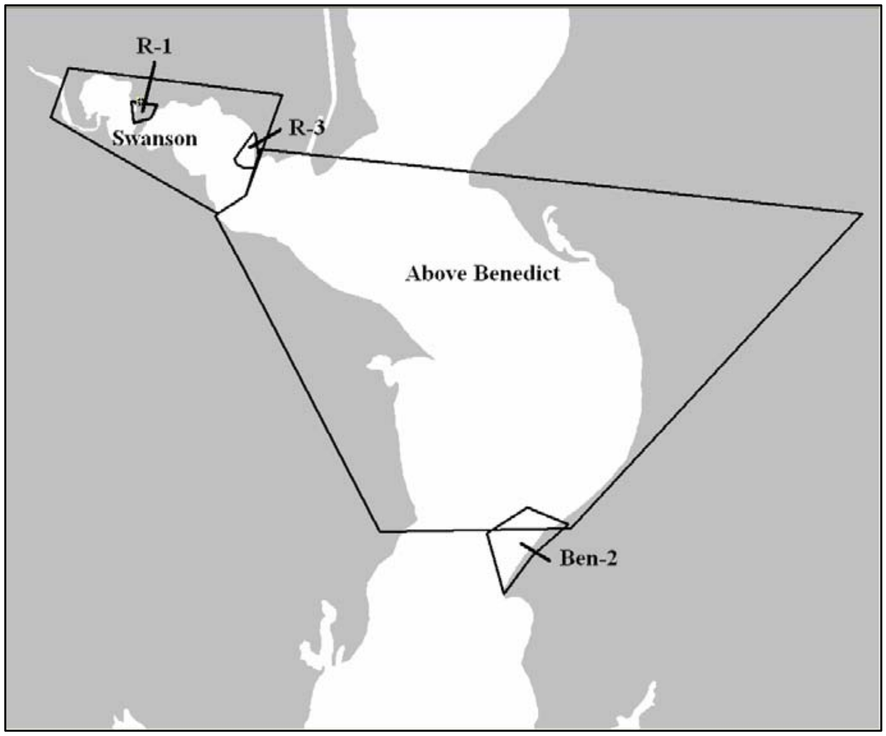

Figure 3: Oil Removal Areas. Oil removal occurred at the marsh near the spill site and in Swanson Creek with vacuum trucks and with Navy skimmers in the Patuxent River north of the Benedict Bridge.

Oil removal was assumed to proceed with decreasing efficiency over time due to the spread of oil and the greater difficulty in retrieving oil, as was also observed in the field during the actual spill response (based on oil removal records). The removal rate specified in the model for the alternative responses was based as closely on actual reported oil removal rates as possible, coupled with a decreasing efficiency rate over time.

Oil removal has been shown in field studies, case histories, and in theoretical studies (Etkin, *et al.*, 2005; Gregory, *et al.*, 1999; and Watkins, 1985) to be considerably less than the "nameplate" efficiency described by manufacturers for specific pieces of skimming equipment. Nameplate efficiency has been "de-rated" in US Coast Guard regulations to Effective Daily Recovery Capacity (EDRC), which is generally 20% of nameplate efficiency based on estimated encounter rates with the oil on the water surface. But even these rates are rarely realized in actual spill response operations where logistical problems, crew changes, oil storage and decanting problems, and the increasingly lower encounter rate with the spreading of oil slicks on water surfaces reduces the oil removal rate with each hour that passes after a spill. The rate of oil recovery over time as a percentage of EDRC is shown in Figure 4. This decreasing rate of oil removal over time was incorporated into the modelling. Modelled oil removal closely matched actual reported removal rates over time.

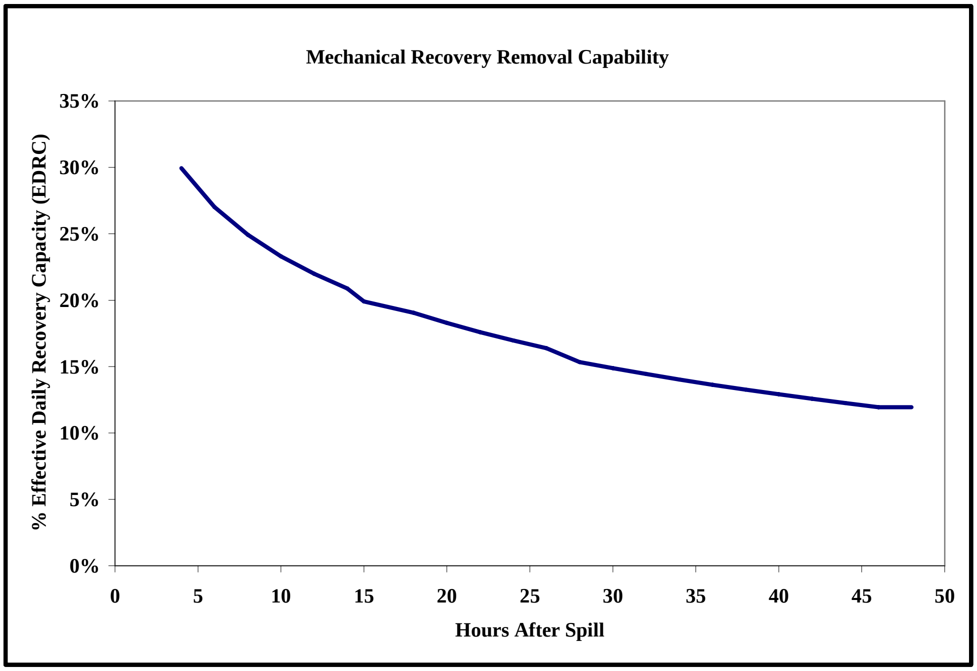

Figure 4: Mechanical Recovery Capability as Percentage of EDRC.

3 Results

3.1 Oil Fate

The fate of the oil was estimated by SIMAP, as described in French-McCay, *et al.* (2006). A synopsis of oil fate results for the actual and three alternative response scenarios is shown in Table 9. Differences in shoreline oiling for the alternative responses compared to the actual response are shown in Table 10. Total shoreline impacts are depicted in Figures 5 – 8. Stochastic variations of the model runs were not performed because actual wind, current, and tidal conditions were known for this case. Actual scenario results corresponded with actual shoreline oiling based on Shoreline Cleanup Assessment Team (SCAT) records (French-McCay, et al. 2006).

Table 9: Shoreline Impact for Actual and Alternative Response Scenarios

Scenario	% Oil Ashore	Shoreline Area (m^2) Impacted by Oil (>0.001 mm thick)			
		Rocky	Sandy	Wetland	Total
AR	20.6%	1,048	4,640	7,466	13,154
ARGOOD	4.9%	21	533	1,463	2,017
FOSC	5.4%	14	304	1,313	1,631
FOSCALT	5.0%	21	250	1,359	1,630

Table 10: Reductions in Shoreline Oiling in Alternative Responses

Scenario	Percent Reduction in Shoreline Impact Compared to Actual (AR) Response			
	Rocky	Sandy	Wetland	Total Shoreline
ARGOOD	98%	89%	80%	85%
FOSC	99%	93%	82%	88%
FOSCALT	98%	95%	82%	88%

Shoreline impacts were reduced by 80 to 98 percent with the alternative responses, with the highest reductions being from the use of good-condition boom and proper anchoring for the actual boom deployment strategy (ARGOOD). With the original booming having failed, the implementation of the FOSC strategy, using either boom configuration for Boom E (E or E-ALT), would have reduced shoreline oiling by at least 41%. Shoreline oiling by zones of impact (Figure 9) are in Table 11.

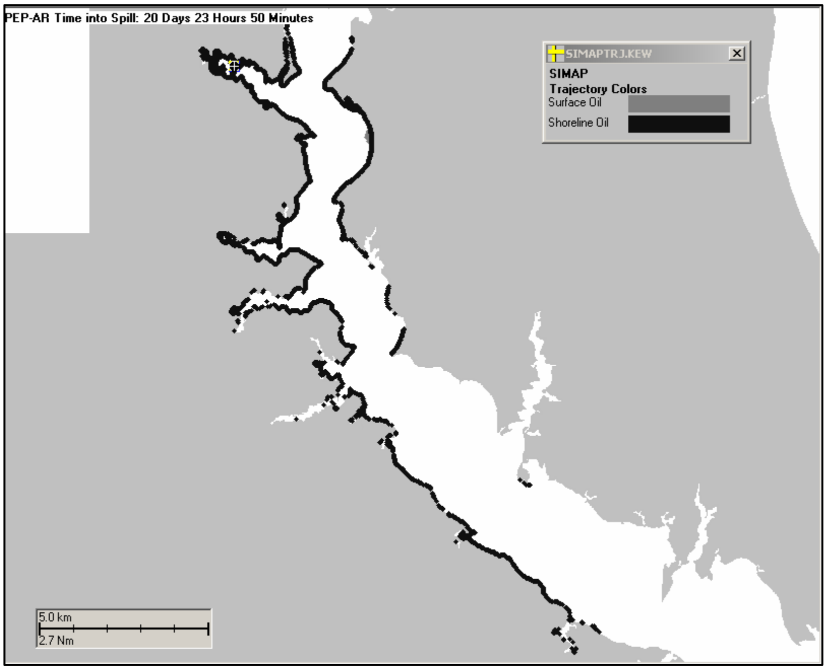

Figure 5: Extent of shoreline oiling for actual response scenario (AR).

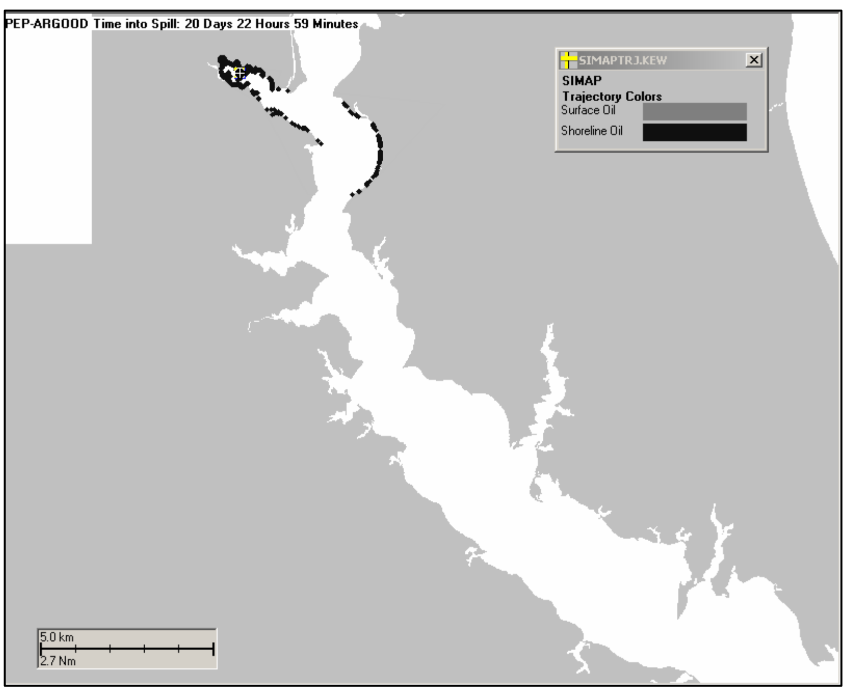

Figure 6: Extent of shoreline oiling for ARGOOD scenario.

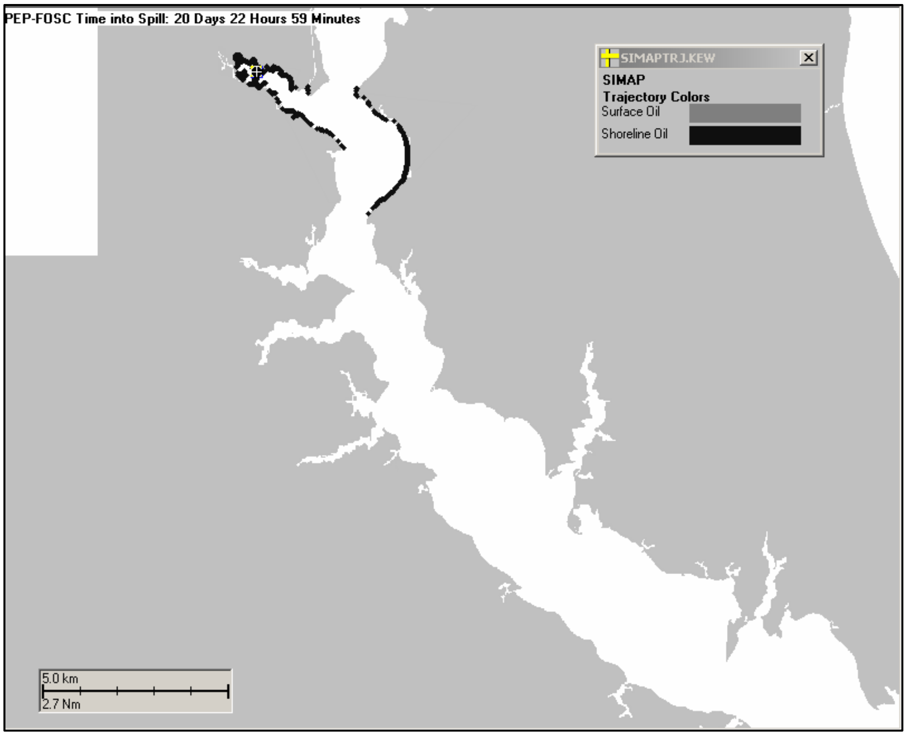

Figure 7: Extent of shoreline oiling for FOSC scenario.

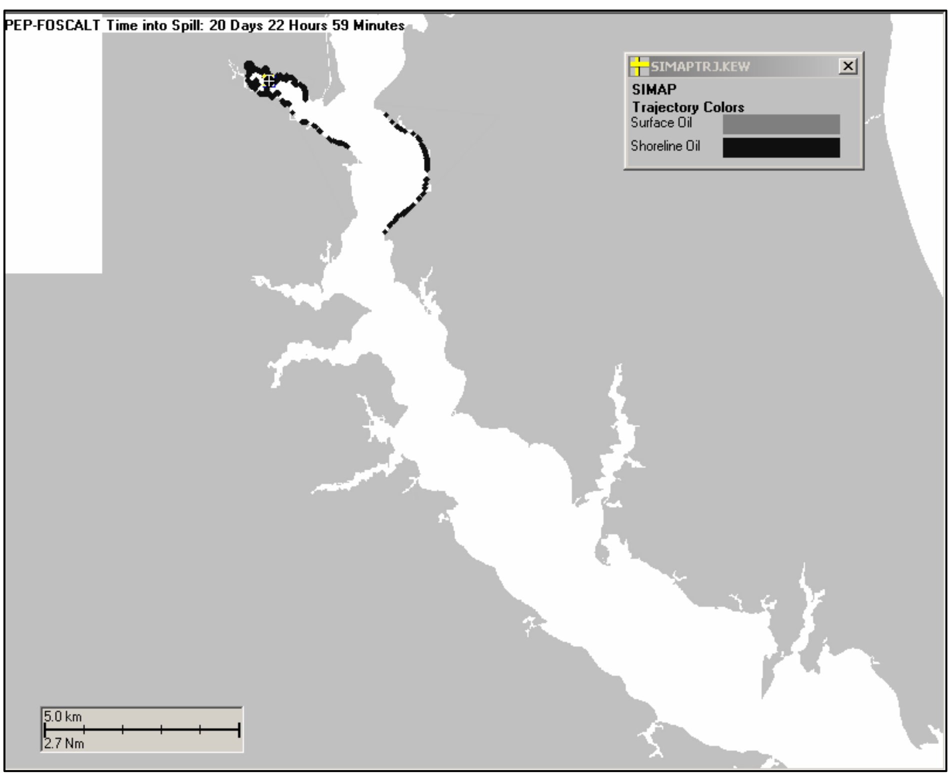

Figure 8: Extent of shoreline oiling for FOSCALT scenario

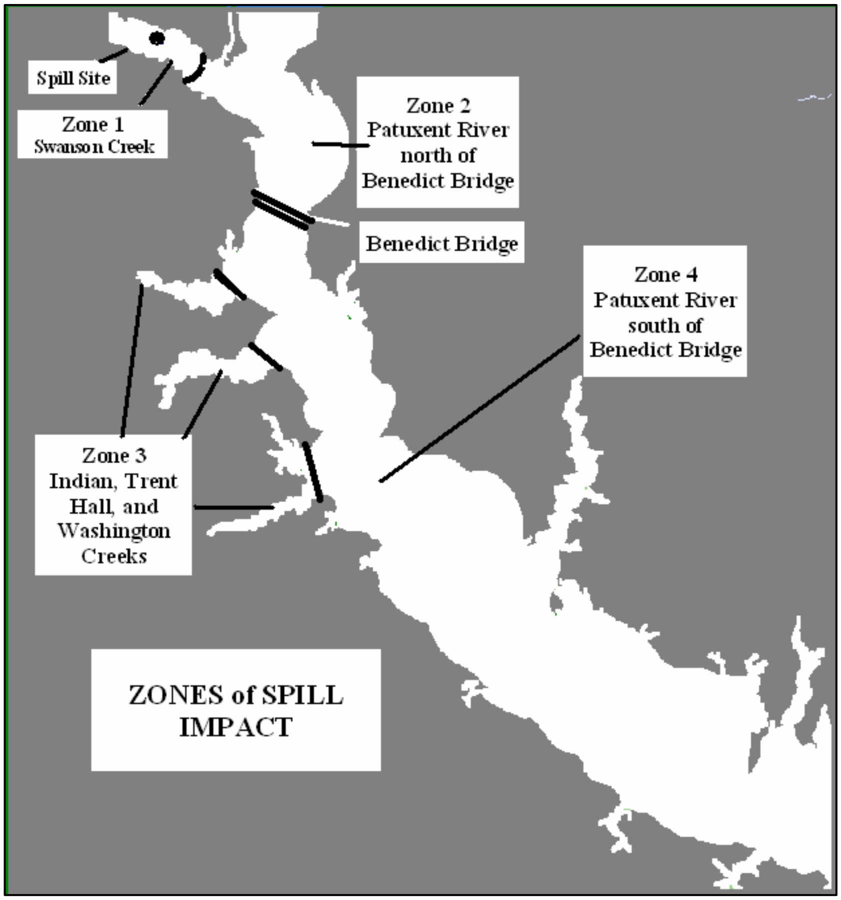

Figure 9: Zones of Shoreline Impact from Spill

Table 11: Shoreline Oiling by Zone in Figure 9 Based on Spill Response

Scenario	Shoreline Impact (m^2) with 0.001 mm oil					Wetland Impact (m^2) with 0.001 mm oil				
	Total	Zone 1	Zone 2	Zone 3	Zone 4	Total	Zone 1	Zone 2	Zone 3	Zone 4
AR	13,154	2,361	3,868	4,489	2,436	7,466	2,361	1,517	1,216	2,372
ARGOOD	2,018	1,274	740	4	0	2,014	1,274	740	0	0
FOSC	1,631	1,227	400	4	0	1,627	1,227	400	0	0
FOSCALT	1,630	1,266	364	0	0	1,630	1,266	364	0	0

Overall, keeping the oil contained within Swanson Creek and increasing oil removal in this zone as in the alternative response scenarios kept significant amounts of oil out of sensitive wetlands further downstream, particularly in Zones 3 and 4. Wetland impacts in Zones 3 and 4 were eliminated. Zone 4 was the most expensive area to clean up, comprising about 48 percent of the entire costs for the US$52 million (2006 US dollars) response operations. Wetland impacts to Zone 4 were reduced by 78 to 91 percent by keeping the oil better contained with Swanson Creek and increasing oil removal in the creek. Impacts to the Swanson Creek area (Zone 1) were also reduced by 46 to 48 percent with the increased oil removal.

Despite the occurrence of a major storm within the first two 48 hours after the spill, at no time should the currents or wave heights have overwhelmed the capacity of the properly-installed, good-condition booms, according to the model.

3.2 Response Costs

Response costs (Table 12) were calculated based on actual detailed cost records (adjusted to remove non-spill response costs, *e.g.*, legal costs, pipeline repair, public relations), and personnel and equipment records for 38 specific work zones impacted by the spill. Differences in shoreline (including wetland) impacts were used to estimate reductions in response costs (Etkin, 2001b; Etkin, 2003) for the alternative hypothetical response scenarios.

Table 12: Spill Response Costs for Actual and Alternative Response Scenarios

Scenario	Total Estimated Response Cost (2006 US$)	Percent Change from AR
AR	$52.4	--
ARGOOD	$20.7	60.5%
FOSC	$20.6	60.6%
FOSCALT	$20.7	60.5%

The alternative response scenarios might have reduced response costs by 60 percent, or a total of US$31 million.

3.3 Natural Resource Damages

Natural resource damages (NRD) for bird injuries were calculated based on the methodology described in French-McCay, *et al.* (2006), which employs a habitat restoration model to scale compensatory restoration, rather than basing calculations on the complex NRD settlement that actually occurred. Results for the actual spill response and the three alternative response scenarios are shown in Tables 13 – 14.

Table 13: Bird injuries (as numbers lost) for the four scenarios.

Scenario	Total Waterfowl	Total Seabirds	Total Wading Birds	Total Shorebirds	Total Raptors	Total Birds
AR	403.1	15.4	2.4	1.5	5.0	427.5
ARGOOD	18.0	0.6	0.5	0.3	0.2	19.5
FOSC	12.4	0.4	0.5	0.3	0.2	13.7
FOSCALT	12.6	0.4	0.5	0.3	0.2	13.9

Table 14: Costs (in millions of 2006 US$) for compensatory restoration for bird injuries resulting from the four scenarios.

Scenario	Total NRD Costs
AR	US$739,340
ARGOOD	US$34,933
FOSC	US$25,433
FOSCALT	US$25,744

Impacts to birds were reduced by 95 to 97 percent with the alternate responses. Over 400 fewer birds might have been injured with a more effective response, which translates into over US$700,000 in reduced natural resource damages

4 Conclusions

The modelling of hypothetical alternative spill responses for the case example of the 2000 PEPCO pipeline spill demonstrates that the outcome of a spill, including response costs and natural resource damages can be dramatically changed with different booming strategies. The use of good-condition boom and the use of proper anchoring are essential to contain oil within the area closest to the spill and to prevent further spreading of the oil.

In this case, the results indicate that had well-maintained boom been deployed initially with anchoring methods that are typically recommended, and had more efficient oil removal operations occurred, US$31 million in response costs might have been saved. Nearly 11,000 square meters of shoreline, 57 percent of which were wetlands might have been spared impact. An estimated 407 fewer birds might have been injured in this scenario, saving over US$705,000 in natural resource damage assessment costs. Had the responders followed the directives of the FOSC and installed additional protective booms in advance of the storm even after the initial failed booming attempts and increased their oil recovery efforts in the creek and above Benedict Bridge, US$31 million in response costs might have been saved and 11,000 square meters of shorelines and wetlands might have been spared major impacts. An estimated 414 fewer birds might have been injured in this scenario, saving over US$714,000 in natural resource damage assessment costs.

The ability to conduct post-mortem examinations of spill responses by modelling alternative responses or examining alternatives to specific aspects of a response provides spill response planners with invaluable information for future contingency planning purposes. The tool can also be used to evaluate options for strategic response planning for hypothetical spills.

5 Acknowledgements

Oil spill response consultant Charlie Huber, and Steve Potter of SL Ross Environmental Research Ltd., provided invaluable assistance in determining specifications and capabilities of the booms and mechanical recovery equipment based on detailed records of on-scene resources, data in SL Ross Environmental Research's *World Catalog of Oil Spill Response Products*, and current research on spill boom capabilities.

6 References

Etkin, D.S., "Analysis of Oil Spill Trends US and Worldwide", in *Proceedings of the. 2001 International Oil Spill Conference,* pp. 1,291 – 1,300, 2001a.

Etkin, D.S., "Methodologies for Estimating Shoreline Cleanup Costs", in *Proceedings of the 24th Arctic & Marine Oilspill Program Technical Seminar,* Environment Canada, Ottawa, ON, pp. 647 – 670, 2001b.

Etkin, D.S., Analysis of Past Marine Oil Spill Rates and Trends for Future Contingency Planning", in *Proceedings 25th Arctic & Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, pp. 227 – 252, 2002.

Etkin, D.S., "Analysis of US Oil Spill Trends to Develop Scenarios for Contingency

Planning", in *Proceedings of the 2003 International Oil Spill Conference*, pp. 47 – 61, 2003a.

Etkin, D.S., "Estimation of Shoreline Response Cost Factors", in *Proceedings of the 2003 International Oil Spill Conference*, pp. 1,243 – 1,253, 2003b.

Etkin, D.S., "Twenty-Year Trend Analysis of Oil Spills in EPA Jurisdiction", in *Proceedings Fifth Biennial Freshwater Spills Symposium*, 2004.

Etkin, D.S., D. French-McCay, J. Rowe, N. Whittier, S. Sankaranarayanan, and L. Pilkey-Jarvis. "Modelling Impacts of Response Method and Capability on Oil Spill Costs and Damages for Washington State Spill Scenarios", in *Proceedings of the 2005 International Oil Spill Conference,* pp. 457 – 462, 2005.

French-McCay, D., S. Sankaranarayanan, D.S. Etkin, and J. Rowe. "Data Needs to Reduce Model Uncertainty, The PEPCO Pipeline Spill of April 2000 as Case Example", in *Proceedings of the 29th Arctic and Marine Oilspill Program Technical Seminar*, Environment Canada, Ottawa, ON, in press. 2006.

Gregory, C.L., A.A. Allen, and D.H. Dale. "Assessment of Potential Oil Spill Recovery Capabilities", in *Proceedings of the 1999 International Oil Spill Conference,* pp. 527 – 534, 1999.

National Oceanic and Atmospheric Administration (NOAA), *et al*., *Restoration Plan and Environmental Assessment for the April 7, 2000, Oil Spill at Chalk Point on the Patuxent River*, *Maryland.* May 2002. Prepared by, National Oceanic and Atmospheric Administration, Maryland Department of Natural Resources, Maryland Department of the Environment, and U.S. Fish and Wildlife Service, 120 p. 2002.

National Transportation Safety Board (NTSB), *Pipeline Accident Report Rupture of Piney Point Oil Pipeline and Release of Fuel Oil Near Chalk Point, Maryland April 7, 2000.* NTSB/PAR-02/01. PB2002-916501. NTSB, Washington, D.C. 62 p., 2001.

Potter, S., and J. Morrison, *World Catalog of Oil Spill Response Products, Eighth Edition.* SL Ross Environmental Research Ltd., Ottawa, Ontario, Canada., 2004.

US Environmental Protection Agency (EPA). *After Action Report for the Emergency Response at the Swanson Creek Marsh Oil Spill Site, Aquasco, Maryland, Prince George's, Charles, Calvery, and St. Mary's Counties, 7 April 2000 to 16 May 2000,* US EPA Region III, Philadelphia, PA. (Prepared by Federal On-Scene Coordinator, Colby E. Stanton, US EPA Region III). 38 p., plus appendices, 2000.

Watkins, R.L. "Effectiveness of Oil Spill Recovery Systems", in *Proceedings of the 1985 International Oil Spill Conference,* pp. 983 – 985, 1985.