Barge Morris J. Berman Spill
NOAA's Scientific Response

EDITOR...

LCDR Gary Petrae

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Hazardous Materials Response and Assessment Division
Office of Ocean Resources Conservation and Assessment
National Oceanic and Atmospheric Administration

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INTRODUCTION

The *T/B Morris J. Berman* oil spill was the first major spill since the Oil Pollution Act (OPA) of 1990 for which the United States Coast Guard became the sole executors of the response effort. Response activities and response management were directed by the federally designated On-Scene Coordinator. This was also the first major U.S. oil spill under OPA since the development of area contingency plans.

Many important environmental issues were addressed during this response. NOAA's Hazardous Materials Response and Assessment Division provided the FOSC with scientific and technical support to deal effectively with the environmental aspects of the response. NOAA's Scientific Support Coordinator and support team collaborated with other local and Federal government agencies and members of the scientific community to provide the FOSC with the best scientific information available.

This report will discuss major response issues related to the scientific aspects of this spill, and will document processes and response actions that worked well and those that were later judged to be less successful. This report can serve as a reference source for planning and for future spill responses, especially when similar issues are addressed.

INCIDENT SUMMARY

At approximately 0400 Atlantic Standard Time on January 7, 1994, the tank barge *Morris J. Berman* grounded on a hard bottom of rocky substrate and scattered coral in the surf zone 300 yards off Escambron Beach in San Juan, Puerto Rico. The barge drifted ashore after the towing cable parted from its tug, the *Emily S*.

The barge had a capacity of three million gallons but was reportedly only half full. The cargo, a heavy No. 6 fuel oil, began discharging immediately, impacting nearby shoreline and shallow intertidal habitats. Due to strong northerly winds, the surf at the grounding site created a hazardous situation with heavy waves pounding the deck of the vessel.

The responsible party initially assumed responsibility for the spill, but very quickly expended its insurance policy's ten-million dollar limit Full Federal funding of the spill began at 0600 on January 14, when the responsible party turned over direct management of the response to the U.S. Coast Guard (USCG).

Soon after being notified of the spill, the USCG Federal On-Scene Coordinator (FOSC) requested support from the USCG Gulf Strike Team. Once on-scene, the Strike Team began lightering the barge. The grounded barge could not be boomed because of intense surf action. Crews worked in extremely hazardous conditions to lighter oil from the *Morris J. Berman* to another barge. As time progressed, the oil became more viscous and difficult to pump, making lightering ineffective. However, lightering efforts continued until the barge was prepared for towing to the scuttle site.

Combined skimming and lightering operations were effective and removed an estimated 743,000 gallons of oil from the water and leaking barge.

Shoreline cleanup and assessment began almost immediately. Little progress was made, however, because the barge continued to leak fresh oil, which meant that cleaned areas were re-oiled and areas not yet cleaned were more heavily impacted. Protection strategies were employed for areas at risk that were not yet oiled. Intensive shoreline cleanup for the most heavily impacted areas was postponed until the sources of re-oiling could be stopped. Two shallow lagoons near the grounding site acted as natural catchment areas. Oil accumulated on the surface and, in the form of large mats, on the bottom of the lagoons. This submerged oil posed a major cleanup problem during the response. It was eventually removed by divers using manual techniques, vacuum transfer units, pumps, and a dredge. Waste and oily water from dredging operations were collected and separated in a series of swimming pools arranged to decant and filter the effluent from the dredge before returning the filtered water to the sea.

On January 15, the barge was refloated, towed to a scuttling site 20 nautical miles northeast of San Juan, and sunk. This operation was carefully evaluated by the FOSC, U.S. Navy Supervisor of Salvage, the Gulf Strike Team, and NOAA. The Caribbean Regional Response Team (CRRT) was consulted and on-scene trustee representatives were given an opportunity to discuss the operation and voice their concerns. These groups agreed that the sinking of the barge represented the best alternative because continued re-oiling of the nearshore environment from the unrecoverable oil left on board was delaying cleanup and preventing resource recovery. Moreover, resource concerns offshore were minimal and it was believed that the small amount of residual oil left on the barge at the time of sinking would have little impact. Extensive trajectory analysis before the barge was scuttled identified the risk of shoreline oil impacts along northwestern Puerto Rico, Isla Mona, and the Dominican Republic.

With the barge removed, shoreline cleaning continued in earnest and proved to be much more successful. Surface and buried oil along sand beaches were removed in accordance with cleanup guidelines. Beachrock, rip rap, and seawalls were cleaned with pressure washing and chemical cleaners as approved. Some areas were left to natural cleaning due to inaccessibility, low levels of human use, or their exposure to high energy. A Heritage Resource Team was formed to address problems related to oiled historical structures. Through this team, trustees developed and approved cleanup guidelines for oiled historical structures.

On February 3, oil impacts were reported along northwestern Puerto Rico. A convergence zone at the northwest corner of the island concentrated debris and oil that had been released when the barge was scuttled. Impacts were primarily along 12 miles of shoreline, from Isabella to Borinquen. Some of this oil was buried as oily sand layers and submerged as oil and sand mats in the protected areas or crenulate bays. A separate command post was established on the west end of the island and assessments and cleanup operations began immediately. Crews removed the stranded oil as soon as possible to prevent additional burial. Cleanup efforts were intense in this area as attempts were made to minimize risks to nesting sea turtles, due to arrive in a few weeks.

All necessary cleanup guidelines and inspection criteria were in place by mid-February. To help manage and track shoreline cleanup, the impacted shoreline was divided into 18 shoreline segments, or zones. Most of these zones were cleaned, inspected in accordance with the “how clean is clean” guidelines, and approved by the FOSC by April 4. All other zones were signed off by April 25, with the exception of zone 18, which was completed on May 27. Once approved as clean, each zone entered a monitoring and maintenance phase to address any further re-oiling.

CHEMICAL CHARACTERIZATION OF THE OIL

Characteristics

The oil released from the barge *Morris J. Berman* was characterized by the spiller as a Fuel Oil No. 6 with an American Petroleum Institute (API) gravity of 9.5, a pour point of 4.4°C, and viscosity of 369° at 50°C. The oil floated because its specific gravity, when spilled, was lower than the surrounding waters. The oil had a high concentration of heavy aromatics making it acutely toxic to large numbers of territorial reef fish and benthic organisms near the grounding site. This was evident by the fish kills and high numbers of mollusc and echinoderm mortalities observed during the first few days of the release.

Chemical Analyses

Samples of the spilled oil were forwarded to Louisiana State University’s (LSU) Institute for Environmental Studies. Here, chemical analysis helped characterize the spilled oil and identify samples recovered from various sites to distinguish the *Berman’s* cargo and oil from other sources. Interpretation of the gas chromatograph/mass spectrograph (GC/MS) analytical data suggested that the oil was consistent with heavy, No. 6 fuel oil and enriched with aromatic hydrocarbons relative to the saturate compounds. This heavy oil would persist in the environment, with little evaporation or natural dispersion. However, any evaporation and dissolution would significantly reduce the concentration of naphthalenes and the alkylated naphthalene homologs. Naphthalenes have the highest acute toxicity in marine fuel oils; therefore, the spilled oil would become less acutely toxic as it weathered. Furthermore, analysis indicated that submerged oil found in the nearshore areas weathered at slower rates than stranded beach oil. This preliminary assessment was consistent with physical properties of a Low-API Oil (LAPIO).

A comparison was then conducted between a sample taken from this spill and that of a previous spill: the *Bouchard B155* spill in Tampa Bay, Florida (Genwest 1993).

One of the spilled products from the *Bouchard B155* was a heavy residual fuel oil blend near the LAPIO range that exhibited LAPIO-like characteristics when spilled. Figure 1 shows that the range and abundance of the aromatic hydrocarbons are comparable between the two oils. Data extrapolated from weathered samples collected during the *Bouchard B155* spill and comparisons of environmental conditions between Tampa Bay, Florida in August and San Juan, Puerto Rico in January were used to estimate the chemical characterization of the weathered oil. Figure 2 shows the predicted aromatic hydrocarbon chemical composition of the spilled oil stranded on a beach after 48 hours. The submerged oil was expected to weather at significantly slower rates.

OIL FATE, MOVEMENT, AND TRAJECTORY FORECASTING

Oil Fate

Based on previous experiences with heavy refined products, particularly the *Bouchard B155* spill in Tampa Bay, Florida, NOAA accurately predicted that the floating oil released from the *Morris J. Berman* would likely fragment into smaller patches of oil that varied in diameter from less than one meter (tarballs) to tens of meters (pancakes). Visual and remote-sensing techniques to track the spill would be extremely difficult to use, since little or no visible sheen would be associated with the highly scattered patches of weathered oil. In addition, the tarballs and pancakes would remain buoyant and, therefore, confined to the water surface. In areas where there was a convergence of surface water, the oil would collect in a long line. This would happen where there was a sharp change in bathymetry or water properties, or when waves were deflected off rocky headlands, exposed offshore rocks, and reefs. This would make it possible for the scattered slicks to reconstitute as a threat even after the tarballs and pancakes had dispersed to very low concentration levels. This factor, combined with the overall persistence of the tarballs, suggested that the oil spill would continue to be a threat for hundreds of kilometers of coastline over several weeks.

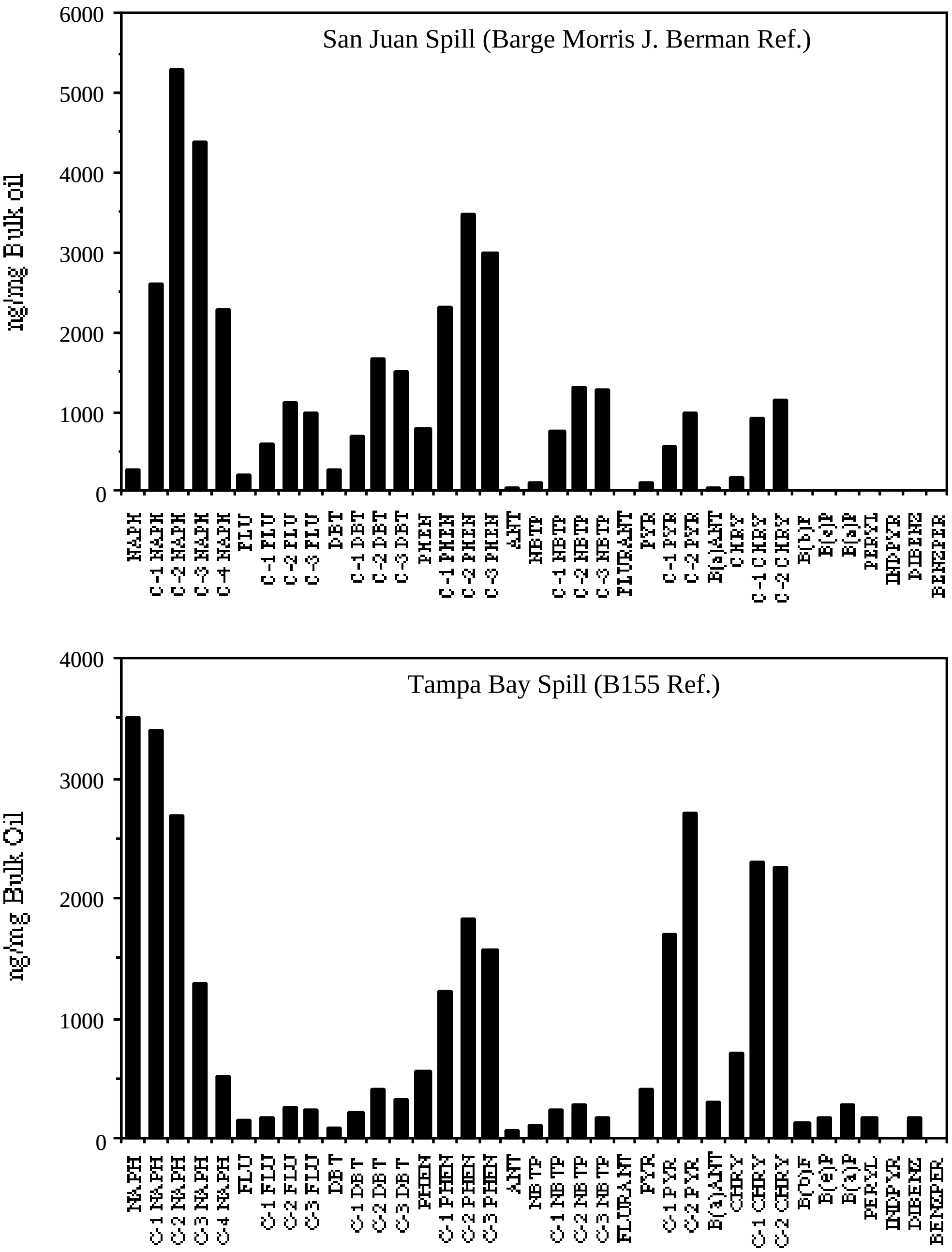

Figure 1. Aromatic hydrocarbon profile comparison of spilled oil to oil spilled in the 1993 Bouchard B155 incident in Tampa Bay. While the target aromatic hydrocarbon fraction represents only 3.0% and 3.5% of the bulk oil for the San Juan and Tampa Bay spilled oils, respectively, it is this fraction that is generally associated with the chemical toxicity of heavy residual oils.

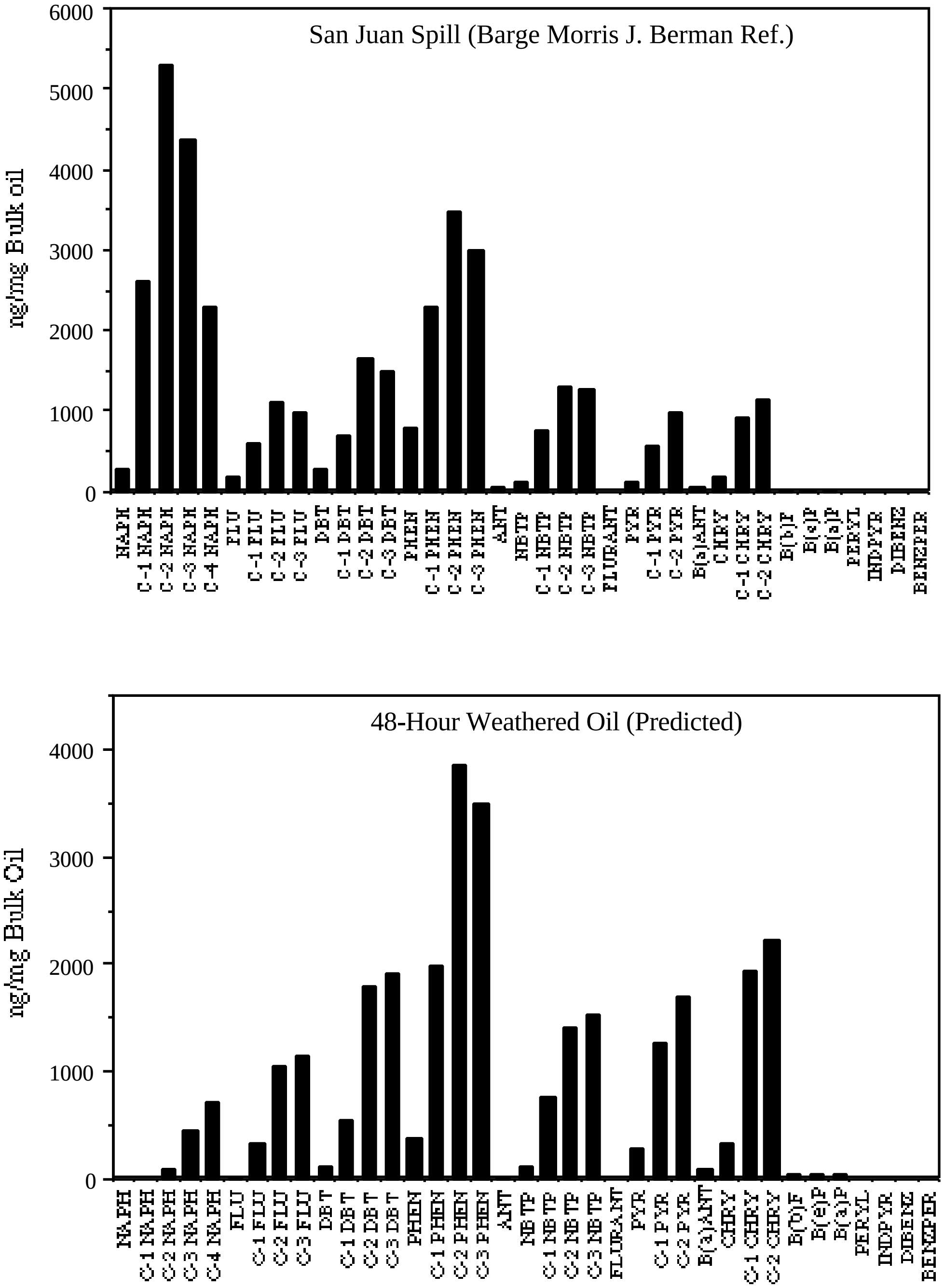

Figure 2. Aromatic hydrocarbon profile comparison of the unweathered reference oil to predicted aromatic hydrocarbon values of stranded oil after 48 hours of weathering. Data extrapolated from the Bouchard B 155 spill were used to estimate these changes. This plot is intended only to provide a perspective on changes in the chemical composition of the bulk oil due to weathering.

NOAA oceanographers entered the physical-property data of the spilled oil into the oil weathering model, Automated Data Inquiry for Oil Spills (ADIOS™; NOAA 1994a). After entering on-scene wind and sea conditions, the model was run using a release of 10,000 barrels (42,000 gallons). The ADIOS™ results suggested that the spilled oil was fairly persistent in the marine environment with little or no evaporation or dispersion and, consequently, little loss of floating oil. The model also indicated that chemical dispersion of the floating oil would not be practicable due to the oil's high viscosity. Further ADIOS™ analysis indicated that 50 to 60% of the oil would likely remain floating on the sea surface five days after the initial release.

Observations confirmed these predictions. However, submerged oil was also observed in the shallow nearshore areas. Several factors provide some insight as to why this oil may have accumulated as submerged tarmats, patches, clumps, or tarballs. The barge had been loaded shortly before sailing at a nearby refinery, where a heavy residual Group V oil was mixed with another product or products as it was loaded onto the barge. If the raw residual oil and the cutterstock were incompatible they may have separated when discharged. If the raw residual had a specific gravity near that of the surrounding water, part of the spilled product could submerge, particularly in nearshore areas where it might pick up sand.

The nearshore, high-energy, surf zone location was an important factor in the fate of the spilled oil. Wave action mixed this oil throughout the water column, causing the oil to pick up sand and become heavier. Calculations show that as little as 2% sand by weight could have been enough to cause this oil to sink. Whether the oil manifested itself in large mats, patches, clumps, or tarballs is most likely related to the physical forces, wave type, wave intensity, and duration of exposure to which it was subjected.

Refloating of some of the submerged oil was observed daily. The oil would tend to rise from the bottom in small globules (like a lava lamp), break free, surface, and create a sheen. This phenomenon was most noticeable in the afternoons in shallow lagoons. There are three theories to explain the mechanism by which this occurred:

- Downward sand migration through the oil allowed portions of the submerged oil to become lighter and refloat. This theory was tested and observed in a jar containing seawater and the source oil mixed with sand. The oil/sand mixture would, over time, separate and allow the oil to refloat.
- Increased sun angle and higher temperatures caused the oil to refloat, as was often observed in the afternoons in the shallow lagoons.
- Increased water column mixing or turbulence refloated the oil because of wave-induced currents related to sea breeze effects. This effect would be more pronounced in the afternoon.

A combination of all three might be valid for specific conditions.

Meteorological Factors

Northeast trade winds dominate in the Greater Antilles area during January (Martyn 1992). However, weather frontal passages often interrupt normal trade winds. Other localized wind effects include a land breeze-sea breeze system that, coupled with an easterly wind, contributes to an offshore wind component at night and an onshore component during the day. When this phenomenon occurred, the wind tended to hold the floating oil against the shore during the day. When the easterly winds relaxed in the evening and the offshore land breeze developed, the oil was moved away from the shore.

Oceanographic Factors

The general description of the large-scale oceanic circulation indicates that the surface waters off northern Puerto Rico flow to the west as part of the Antilles Current (Pickard and Emery 1990). However, historical buoy data suggest that areas north of Puerto Rico are not entirely influenced by a steady westerly current since both large- and small-scale eddies often occupy the Antilles Current (O'Connor 1983). Nearshore, the irregular shoreline (e.g., cusps, reefs, beaches, and inlets) contributes to a complicated longshore current flow. In particular, on-scene observers noted that a moderate swell approaching Peñon de San Jorge bifurcated near the grounded barge, causing the nearshore currents to split and extend both east and west from Punta Escambron.

Oil Observations

During the initial phase of the spill response, information about the release was extremely sketchy, and visual observations from aircraft became a critical source of information. The oil formed a slick that extended from the vessel to a few miles northeast of Punta Salinas. At the leading edge of the slick, the oil evaporated and feathered into widely dispersed pancakes and tarballs.

Overflights were generally conducted twice daily and maps describing the distribution of the floating oil (in both English and Spanish; Figure 12) were distributed to the responders and the wider community. The positions of the slicks were determined using a hand-held Global Positioning System (GPS) unit. This information was then used both to forecast oil movement for the first two weeks of the spill and to help direct appropriate oil spill countermeasures.

Within several days of the initial release, the oil dispersed over a much larger area and additional remote sensing techniques were used to complement visual observations. The first technique used was a combination GPS-microcomputer device called the Laplogger (Lehr and Simecek-Beatty 1994). The Laplogger is a hand-held instrument connecting a Rockwell NavCore GPS receiver with an Intel 80186 processor, four-line display screen, and keyboard in a water-resistant box. It stores observer notes and flight path information for later downloading and display on desktop computers. The Laplogger was used with some success during the oil spill but also demonstrated an unacceptable hardware failure rate.

The second technique, developed by the USCG, is an airborne, real-time remote sensing system used to identify and document the distribution of oil floating on the sea surface (Smith and Venne 1986/1987). Designated AIREYE, the system includes the AN/APS-131 side-looking airborne radar (SLAR) and an IRS-18C infrared/ultraviolet line scanner (IR/UV-LS) mounted in a USCG HU-25B Falcon 20 jet. During the spill response, the Falcon often flew remote-sensing missions twice daily. The flights fulfilled four tasks: 1) confirmed the presence of oil; 2) provided a strategic overview of the spill; 3) identified oceanographic features such as convergence zones that might affect the distribution and movement of oil; and
4) directed low-flying helicopters and/or vessels to areas of interest.

On January 15, 1994, the leaking barge was refloated and towed to an offshore dump site where it was sunk with the remaining oil still aboard. Figure 3 is a SLAR image for January 23 showing a large tarball field west of the scuttling site. Briefing

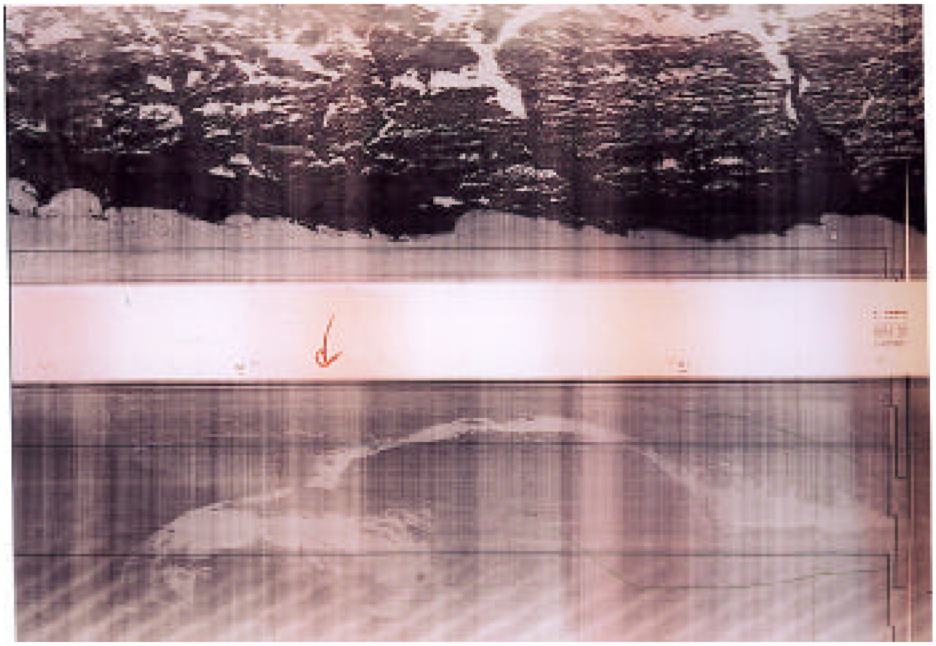

Figure 3. SLAR image for January 23, 1994. A large area of sheen containing widely scattered tarballs is visible as the lighter area shown in the upper half of the figure

maps were generated that displayed the outline of the oil distribution from the visual overflights and the interpretation of the SLAR and UV/IR images by the AIREYE crew and NOAA personnel. Figure 4 shows the briefing map generated for the January 23, 1994 SLAR image and visual overflight. The briefing map shows the remains of the release observed when the barge was initially scuttled and a smaller sheen at the scuttling site. The larger sheen consisted of widely scattered areas of emulsified oil and pancakes or tarballs. A small, continuous rainbow and silver sheen was also observed over the scuttling site.

The third technique used for spill observation was helicopter-based infrared (IR) imaging. This was accomplished using both hand-held and aircraft-mounted IR units. IR systems detect oil slicks on water by sensing the radiometric contrast (seen as an apparent temperature difference) between floating oil and the surrounding sea surface. This technique is useful for monitoring the oil at night when visual means are unavailable. The hand-held IR imager was operated by USCG personnel in both an HH-65A USCG helicopter and a San Juan Police Department helicopter.

The police helicopter was also equipped with a forward-looking IR (FLIR) system installed in a remotely operated, gimbaled turret. While the hand-held IR imager was unconstrained by aircraft installation requirements, the gimbal-mounted sensor (when available) provided a more stable and consistent-quality image and offered both wide-angle and zoom fields of view.

FLIR missions were flown at night in an attempt to direct the Marine Spill Response Corporation (MSRC) skimming vessel, *Caribbean Responder*. The results were mixed. The IR images clearly indicated when oil was escaping from the grounded barge, and provided information on slick movement toward the nearby beaches and harbor. Figures 5 and 6 are false-color images taken at night with the gimbal-mounted FLIR several days after the initial grounding, when seas began to build. Figure 5 shows spray from the breaking waves at one end of the barge and oil escaping from the opposite end. Figure 6 shows this oil slick moving towards beaches and San Juan Harbor.

As portions of the oil slick incorporated sand and sank or separated from the clearly defined source near the wreck site, it was not always possible to positively identify thermal anomalies as oil slicks without additional surface-truthing or daylight observations. The need for a clear linkage with the spill source or other means of confirming oil presence is a well-known limitation of IR imaging. Cleanup operations were complicated because oil identified by the IR imagers during skimmer-directing flights was located in waters too shallow for the *Caribbean Responder* to operate. In addition, the videotape output suffered from rapid contrast changes and lacked positioning information (e.g., verbal description of the area or a

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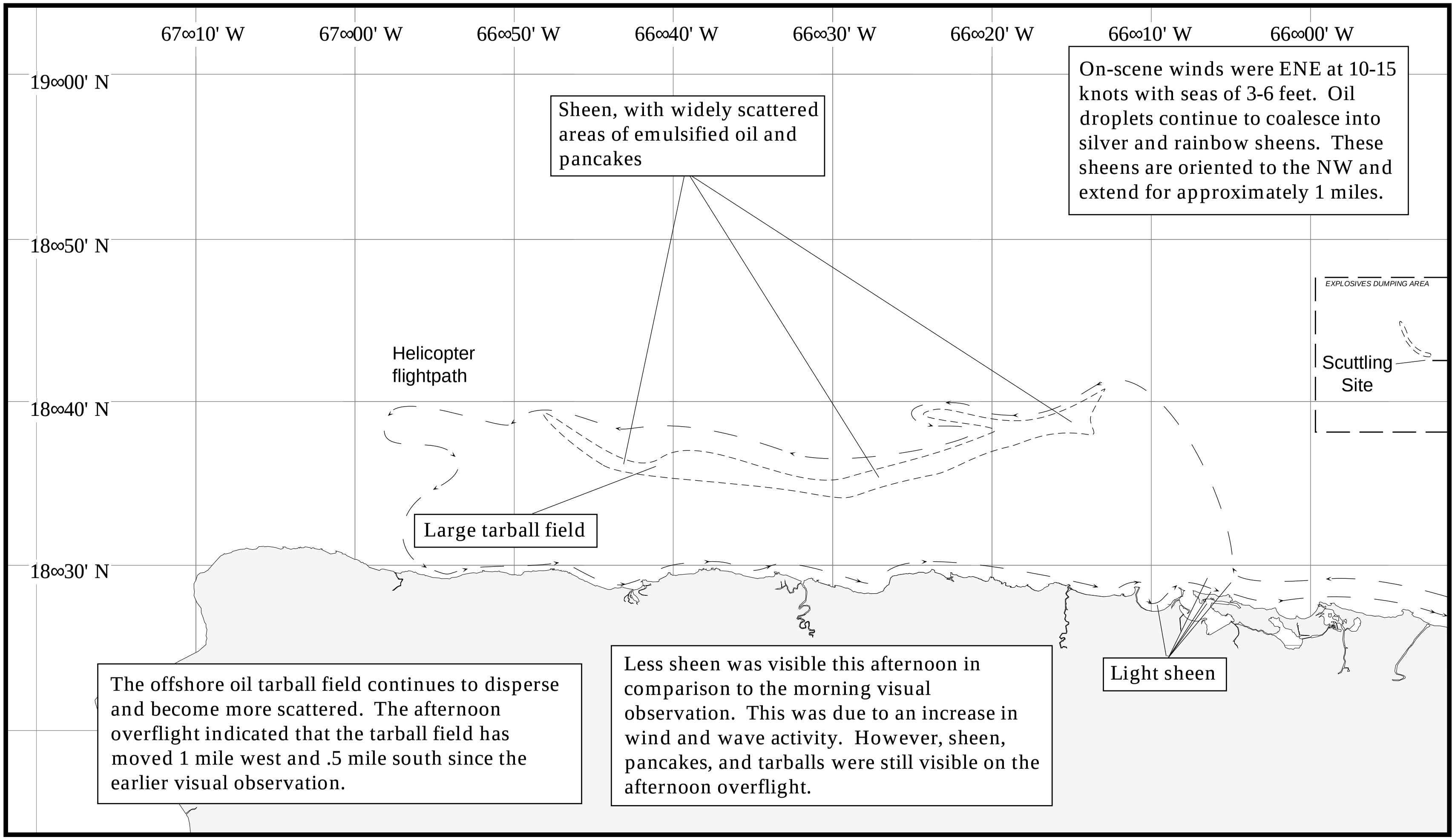
Helicopter, USCG Falcon AIREYE SLAR and
USCG H65 Overflight Map
prepared by NOAA
USE ONLY AS A GENERAL REFERENCE

Date/Time: 23 JAN 94, 1400-1600
Platform: Helicopter
Observers: Hardy (USCG), Lankford, Shigenaka, Montello (NOAA), Morris (USFWS)
Graphic does not represent precise amounts or locations of oil.



Sheen, with widely scattered areas of emulsified oil and pancakes

On-scene winds were ENE at 10-15 knots with seas of 3-6 feet. Oil droplets continue to coalesce into silver and rainbow sheens. These sheens are oriented to the NW and extend for approximately 1 miles.

The offshore oil tarball field continues to disperse and become more scattered. The afternoon overflight indicated that the tarball field has moved 1 mile west and .5 mile south since the earlier visual observation.

Less sheen was visible this afternoon in comparison to the morning visual observation. This was due to an increase in wind and wave activity. However, sheen, pancakes, and tarballs were still visible on the afternoon overflight.

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Figure 4. Briefing map generated for January 23, 1994 SLAR image and visual overflight.

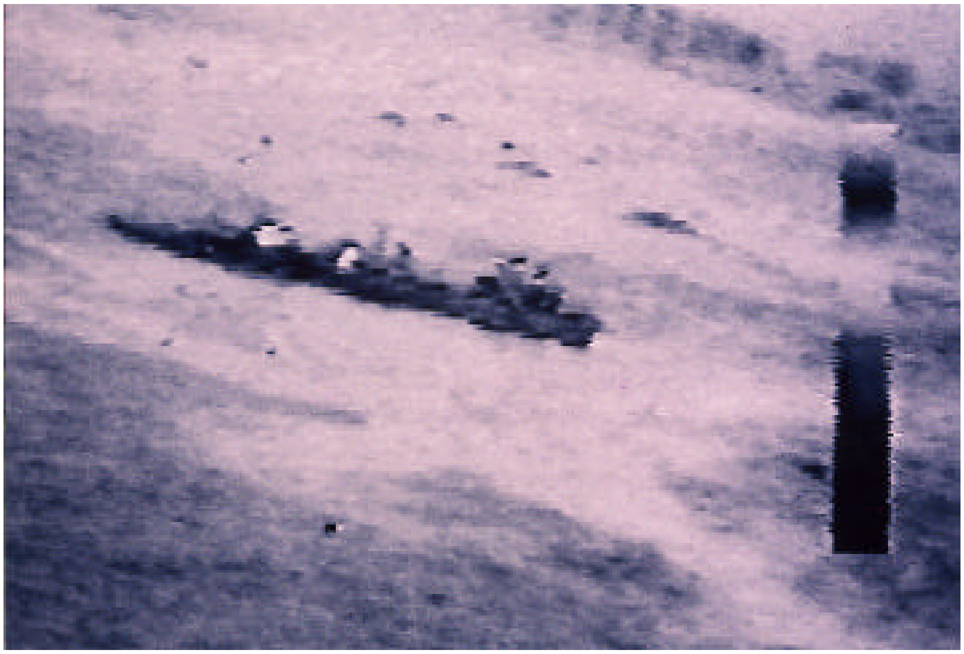

Figure 5. False-color IR image taken at night showing an oil slick surrounding the barge at the initial grounding site. Oil appears as the lighter portions of the figure but in this case it is difficult to distinguish from natural phenomena.

Figure 6. False-color IR image taken at night showing oil trailing from the barge (at the initial grounding site) to the beaches. Oil is shown in the center of the figure in the surf zone as the darker portions of the image, and at the top of the figure on the shoreline.

latitude and longitude). As a result, the viewer could not easily determine the area being observed unless identifiable objects (such as the barge or shore points) were also visible in the image.

A fourth remote sensing technique used was satellite-tracked surface buoys, which were provided by the U.S. Department of the Interior's Minerals Management Service (MMS). In light of recent technological advances, MMS is investigating the use of surface drifters for tracking oil spills and providing test data for oil-spill trajectory models (Reed 1993). Two drifters, both of the Low-Cost Drifter (LCD) type, were deployed by NOAA to determine surface currents during the spill. Both drifters transmitted four or more times a day with a location error of ±1 kilometer. The drifter locations were determined by the ARGOS satellite service, downloaded by MMS, and overlaid on the visual and SLAR overflight maps.

To better define the surface circulation in the immediate spill area, the first drifter was successfully deployed from a helicopter on January 10, 1994 about 1.5 nautical miles north of Punta del Morro in an area containing the heavier concentrations of oil. The drifter moved to the west-northwest and eventually came ashore northwest of Levittown, Puerto Rico. Although this drifter provided a good indication of the location of the oil slick, it was particularly useful as an indicator of surface current flow. The second drifter was deployed on January 11, in an abandoned ammunitions dump site (18° 43' N, 65° 54' W) to determine the direction and speed of the surface currents should the barge be scuttled in that area. Moving in a prevailing northwest direction, the drifter described a gyre-like path, consistent with observations reported in the literature (O'Connor 1983).

Oil Movement

Early in the spill, the oil was released from the grounded barge at a relatively constant rate. Initially, the oil was influenced by light winds (relative to the persistent trade winds) from the northeast to north-northeast and a moderate swell that caused the longshore current to bifurcate. The light winds tended to move the oil directly towards the shoreline and, with the currents moving to the east and west, beach impacts were almost immediate from the Dos Hermanos bridge north and west of Escambron Beach.

The first overflights on January 8, 1994 show the oil impacting the eastern part of San Juan Island, Laguna del Condado, and the San Antonio channel with light sheen in the harbor area. Oil windrows trailed northwest from the accident site. Over the next few days, some of these windrows came ashore in the entrance of San Juan Harbor, Punta Salinas, and as far west as Punta Boca Juana, ten nautical miles away. The floating oil distribution remained almost in steady state while the barge continued to spill as it remained grounded at the original spill site. Oil would be found slightly to the east of the accident and as far west as Río de la Plata, with patches alternatively being next to shore or a few miles offshore depending on the local winds (Figure 7).

When the barge was moved on January 15, a trail of heavy rainbow sheen followed it to the scuttling site. The slicks near shore diminished in size as natural weathering processes removed the oil. On the evening of January 16, the Coast Guard and NOAA observed a new slick at the scuttle site. This slick moved to the west of the scuttle site at about two-thirds of a knot, forming windrows and large brown pancakes. A smaller slick at the scuttling site also trailed to the west. By January 20, the sheen boundary of the western slick had decreased significantly and it was difficult to visually observe pancakes and tarballs unless the observer was both directly overhead at low elevation. The slick at the scuttle site was reduced to approximately 100 yards of light sheen.

Over the next several days, the oil from the original grounding and the scuttle site became a collection of westward-moving, widely scattered tarballs. The area of the sheen at the scuttling site periodically increased or decreased, depending upon sea state. A February 3 overflight reported tarballs mixed with debris near shore at the northwest corner of Puerto Rico. Subsequent flights showed oil on shore at Isabella, 58 nautical miles west of the spill site, with streamers and tarballs west of the island. The movement of these tarballs matched earlier predictions by NOAA’s oil spill trajectory model. The last recorded overflight of the scuttle site on February 23 reported tarballs spreading to rainbow sheen over approximately 1.5 miles.

Summary of Trajectory Analysis

Early in the spill, the oil formed a slick that extended from the vessel to a few miles northeast of Punta Salinas. NOAA trajectory analysis predicted the behavior and movement of this oil on January 12, 1994. Figure 8 shows the trajectory analysis forecast, in which the key factors were nearshore waves and local wind patterns.

Trajectory analysis requires an accurate description of the wind field and surface currents. Often detailed weather forecasts for the area can be difficult due to sparse reporting stations and significant localized effects, such as the land-sea breeze. However, in this case, excellent weather forecast and real-time wind observation support were provided by the National Weather Service Forecast Office in San Juan, Puerto Rico. NOAA input these wind data into the On-Scene Spill Model (OSSM; Torgrimson 1984).

The surface currents in nearshore areas are driven by a variety of processes, each of which is difficult to predict. Thus, two hydrodynamic models, Streamline Analysis

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Oil Distribution Map
prepared by NOAA

USE ONLY AS A GENERAL REFERENCE

Graphic does not represent precise amounts or location of oil.

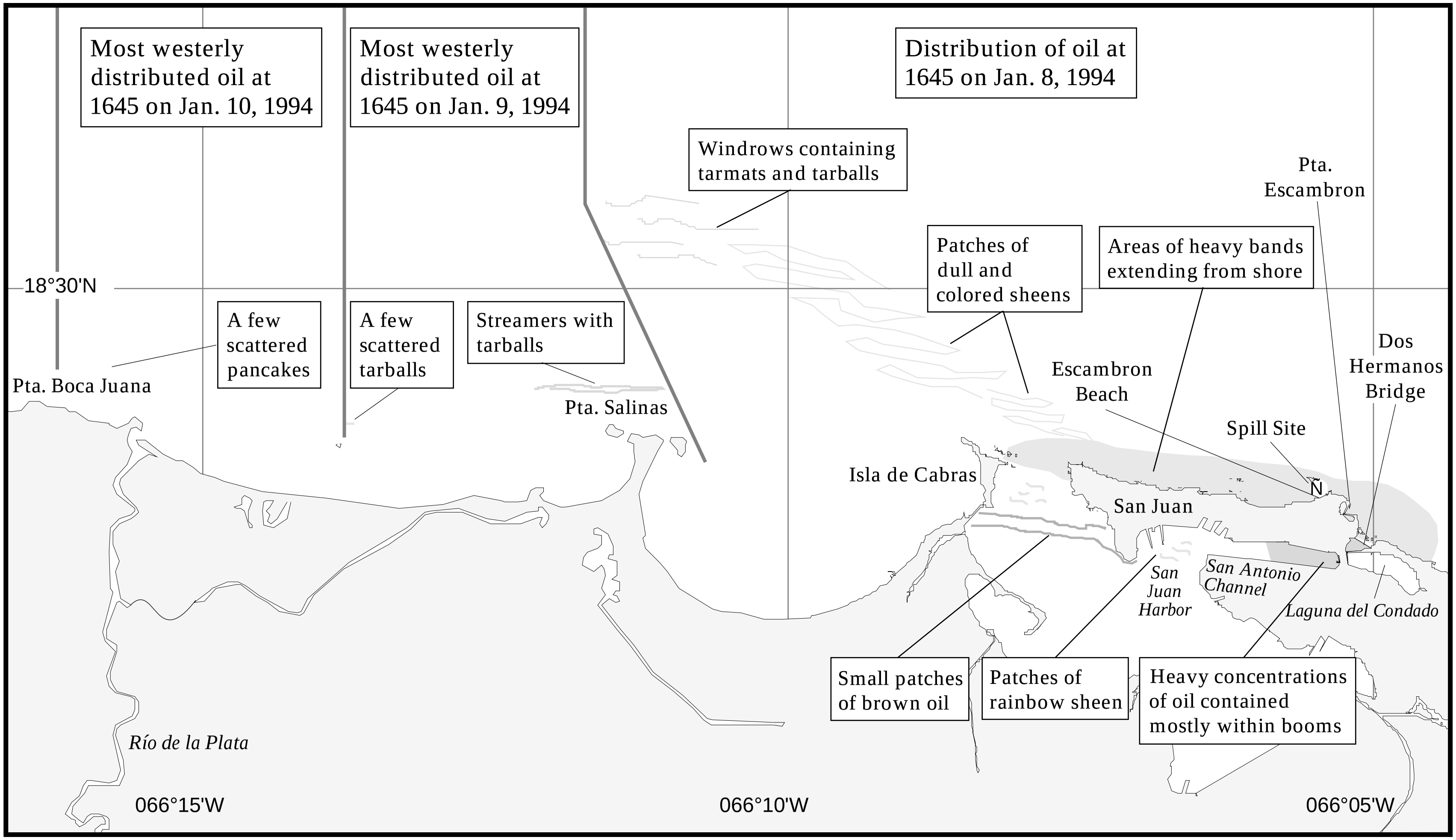


Figure 7. Oil distribution map.

Barge Morris J. Berman Spill

Trajectory Analysis
prepared by NOAA on 12 JAN 94

Based on estimated currents and winds.

Graphic does not represent precise amounts or locations of oil

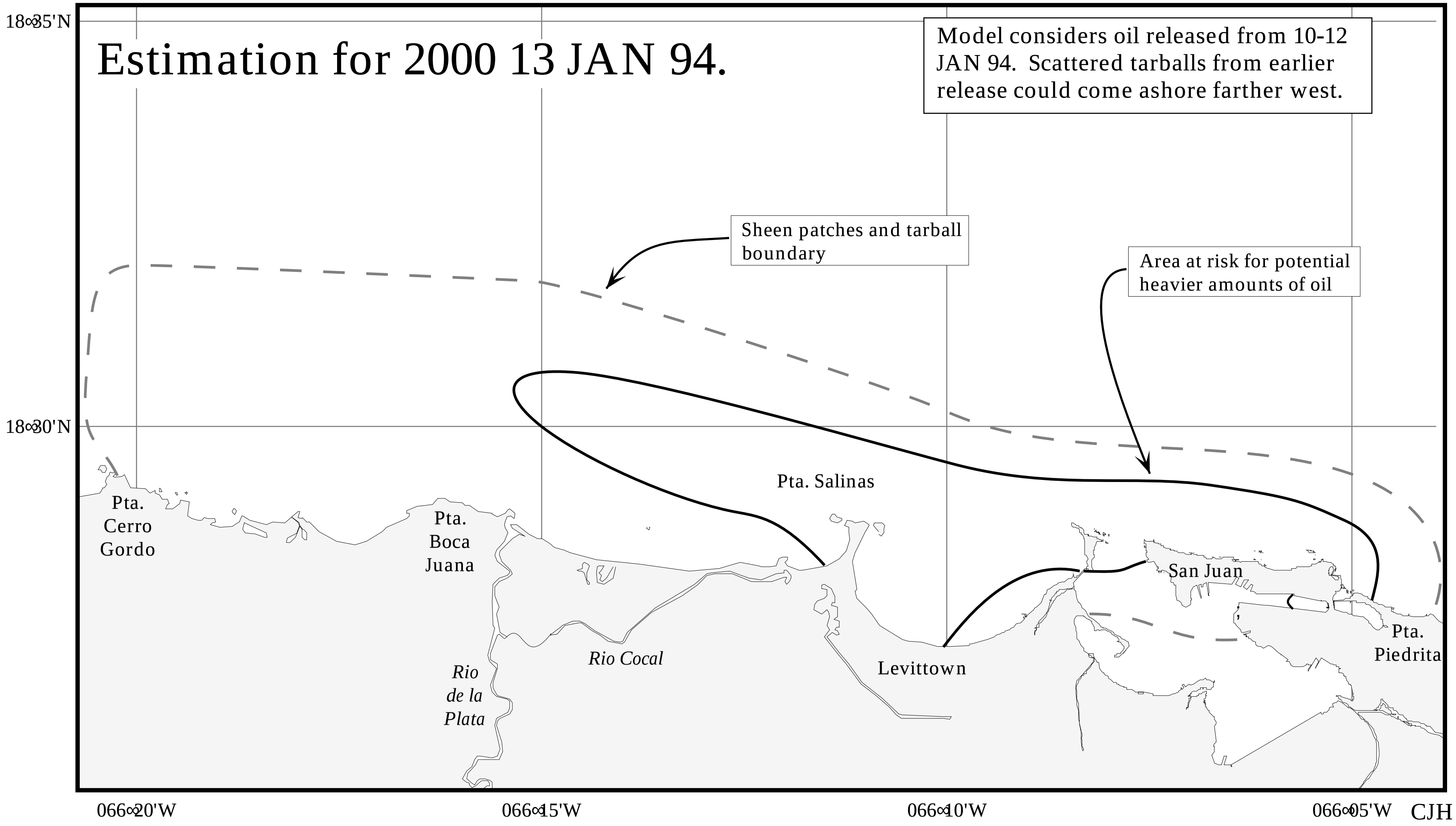


Figure 8. Trajectory analysis forecast; key factors are nearshore waves and local wind patterns.

of Currents (SAC) and Diagnostic Analysis of Currents (DAC), were used to simulate the complicated circulation patterns for the spill area.

SAC was used to define the tidal flow through San Juan Harbor. The model assumes barotropic conditions and no vertical transport with the flow field incompressible, irrotational, and steady state (Galt and Payton 1981). The model was calibrated using a tidal height station in the harbor. DAC was used to describe barotropic setup along the coastline due to Ekman transport. DAC simulates the flow by balancing pressure with Coriolis and bottom-friction forces. The model is based on a reduced form of the Navier-Stokes equation and assumes that currents are steady and relatively slow-moving with frictional forces confined to the surface and bottom (Galt 1975, 1980). Both SAC and DAC provide a simple method for extrapolating one current measurement over a large area based on bathymetry and fluid conservation laws.

Initially to calibrate the DAC circulation pattern, on-scene observers estimated the current speed and direction off Punta Salinas (approximately one-quarter to one-third knot) by deploying packets of fluorescein dye from a helicopter. (Eventually the model was calibrated daily using the actual observed movement of the oil.) The tidal currents for San Juan Harbor were simulated using SAC. Although a tidal current station was unavailable in the National Ocean Service *Tide Tables 1994,* there was a tidal height station for San Juan Harbor (18° 28'N, 66° 01'W; NOS 1994). The tidal current velocities were estimated based on the tidal height prism for this station. OSSM linearly superimposed the current patterns generated from DAC and SAC to describe the overall circulation in the nearshore areas off northern Puerto Rico.

The movement of the tarballs created from the release at the spill site required a longer-term analysis since tarballs can float for months at sea before coming to rest on distant coasts. NOAA estimated that scattered tarballs could come ashore on northwestern Puerto Rico around the end of January, and at Mona Island and the Dominican Republic one to three weeks later (NOAA 1994b). NOAA was also tasked with determining the trajectory implications for scuttling the barge offshore. Trajectory analysis suggested that oil released further offshore posed a relatively greater risk to neighboring islands and a more widely dispersed impact along the northern coast of Puerto Rico. Moreover, impacts would most likely be widely dispersed unless the tarballs concentrated in convergence lines. This analysis was consistent with the observed behavior of the released oil.

RESOURCE IMPACTS

The spill occurred in a relatively high-energy environment, impacting mostly sand beaches, rocky shore, and man-made structures. Very little of the spilled oil entered sheltered environments, such as mangrove forests. Under normal conditions, high natural removal rates and low effectiveness for recovery would be expected. However, many circumstances of this spill were unusual:

1. Oil rapidly came ashore into catchment areas, causing severe but localized impacts and allowing high rates of oil removal by shoreline recovery operations.
2. The spill occurred in the surf zone within a few hundred meters of shore, resulting in nine days of continual introduction of fresh oil into rich, subtidal habitat, killing subtidal organisms.
3. The oil was a very heavy fuel oil, some of which sank. Submerged oil in nearshore habitats was a serious problem. Removal of oil from the seafloor was difficult because of the high wave energy and difficult access. Final shoreline cleanup could not commence until the submerged oil was removed because of the remobilization of the submerged oil during recovery efforts.
4. The oil persisted as scattered tarball fields that continued to lightly contaminate beaches in high-use areas, posing risks to open-water resources such as sea turtles and seabirds.
5. Removal of the oil from hard substrates, such as rip rap and natural rock, proved to be very difficult. The natural resource agencies, in consultation with the Caribbean Regional Response Team (CRRT), tested and approved the use of shoreline cleaning agents in high-use areas only to speed natural recovery.

Protection Strategies

The Sensitive Areas Annex of the Coastal Area Plan for Puerto Rico and the U.S. Virgin Islands was used in the early stages of the spill to identify sensitive areas and set protection priorities. The priority protection areas in the Plan were then visited by a team of spill response personnel from the USCG Strike Team, the Puerto Rico Environmental Quality Board (PR EQB), U.S. Fish and Wildlife Service (USFWS), and NOAA to develop spill-specific protection strategies for the specific oceanographic conditions present during the spill. All of the priority areas outside San Juan Harbor were inlets leading to more sheltered estuarine habitats or power plant intakes.

Site visits are extremely important so that current conditions can be considered in refining the basic protection strategy. For example, several of the protection strategies in the Coastal Area Plan recommended booming the seaward site of the inlets. However, high wave conditions during the spill precluded following this protection strategy, so fall-back positions inside the inlet had to be devised. With representatives from both the Commonwealth of Puerto Rico and USFWS, it was possible to agree on optimal placement of deflection booms to minimize environmental impact yet optimize operational requirements for access and increased equipment efficiency. The revised protection strategies included detailed field sketches showing the current shape of the inlet, water circulation patterns, location of sensitive areas, access points, recommended oil catchment areas, placement of boom and recovery equipment, anchor points, and areas to avoid (Figure 9).

Shoreline Habitat Impacts

Shoreline impacts were immediate and particularly severe from the Dos Hermanos Bridge north and west to Escambron Beach. Eventually, the oil spread as far east as the Río Grande de Loiza and as far west as Punta Borinquen, 68 nautical miles from the spill site (Figures 10A,B). The oiled shorelines were composed primarily of fine- to coarse-grained sand beaches, exposed rocky shores, and rip rap along the outer coast, and seawalls and rip rap along the channels and harbor.

These shorelines included many manmade structures of historical significance. Light to heavy impacts occurred to the heritage resources of Fort San Geronimo; two historic walls near the Dos Hermanos Bridge; the Tajamar Ruins; the Escambron Battery; and a rubble wall at the Reserve Officers Club. There was also concern that other archaeological sites would be oiled.

A few tarballs were observed entering Laguna la Torrecilla but shoreline impacts in this sheltered mangrove forest were minimal. No shoreline oiling was found in the Laguna del Condado inside of the Dos Hermanos Bridge, nor was oil found on mangroves or mudflats in San Juan Harbor. The only sheltered shorelines where oil stranded were the seawalls along San Antonio Channel and the port facilities.

On the sand beaches within a few miles of the grounding site, the oil came ashore only as continuous bands. In some areas, the oil stranded as large mats of thick oil which would accumulate over time, forming patches of heavy oil. These mats usually stranded at the high water line, but would also adhere to the rock platform exposed on the low-tide terrace or be buried on the lower beachface. This pattern was observed mostly at Laguna del Condado, where a large amount of the oil that was released when the barge was refloated eventually stranded. This site was seven miles east of the grounding, and no oil had been reported in this area prior to the refloating. These large mats of oil on distant sand beaches were also found at Punta Jacinto, at the northwestern corner of Puerto Rico, 68 miles west of the grounding.

SKETCH MAP

Site Name RIO DE LA PLATA
Site No. B12
Date 8 JAN 94 1030
Names USCG-GST EWOLDT
NOAA – MICHEL/CHRISTOPHERSON
FWS – LOPEZ

Checklist

- — North Arrow
- — Scale
- — Oil Distribution
- — High Tide Line
- — Low Tide Line
- — Substrate Types
- — Trench Locations

Legend

1△
Trench Number,
No Subsurface Oil

2▲
Trench Number,
Subsurface Oil

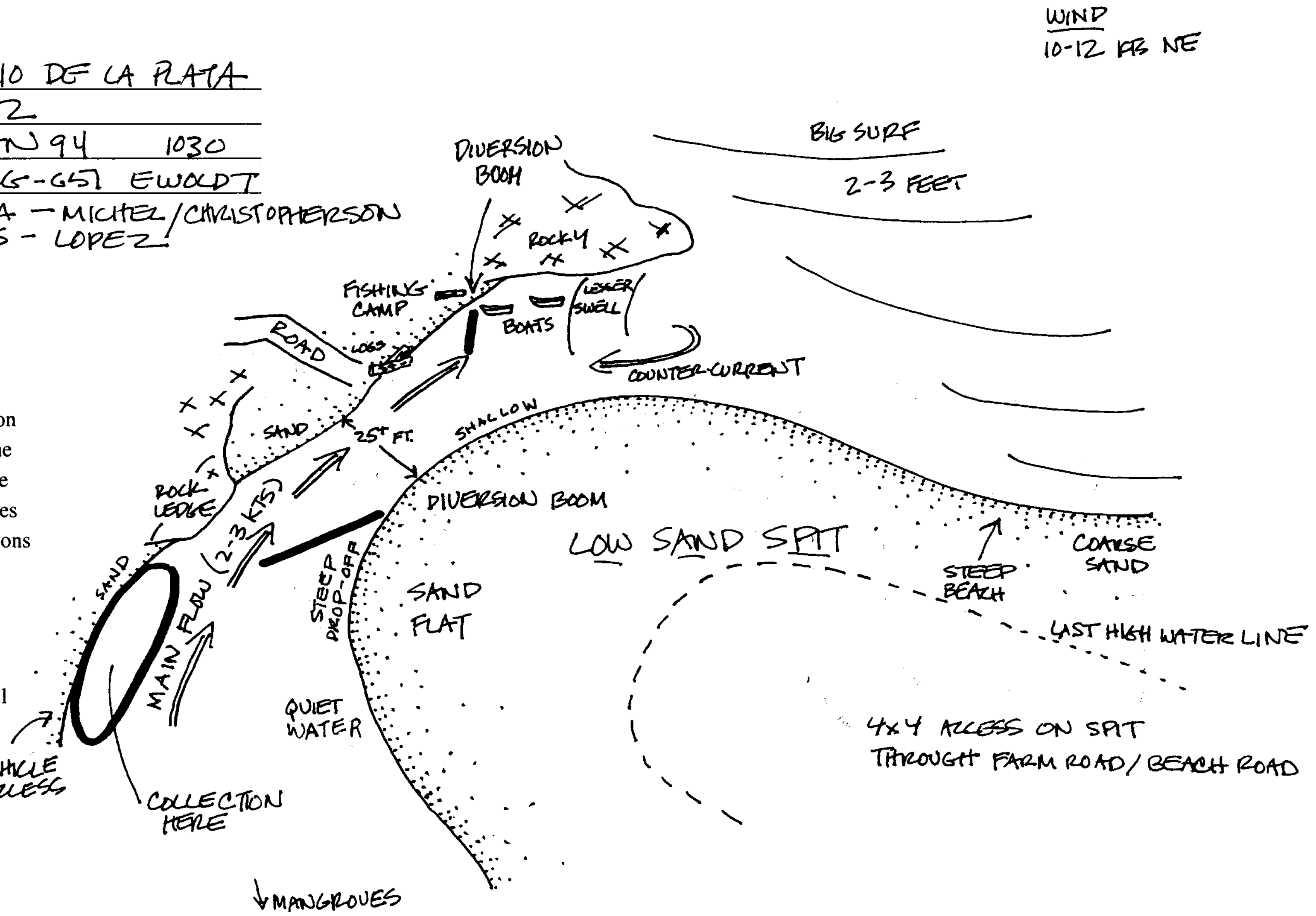


Figure 9. sample of detailed field sketches created for revised protection strategies.

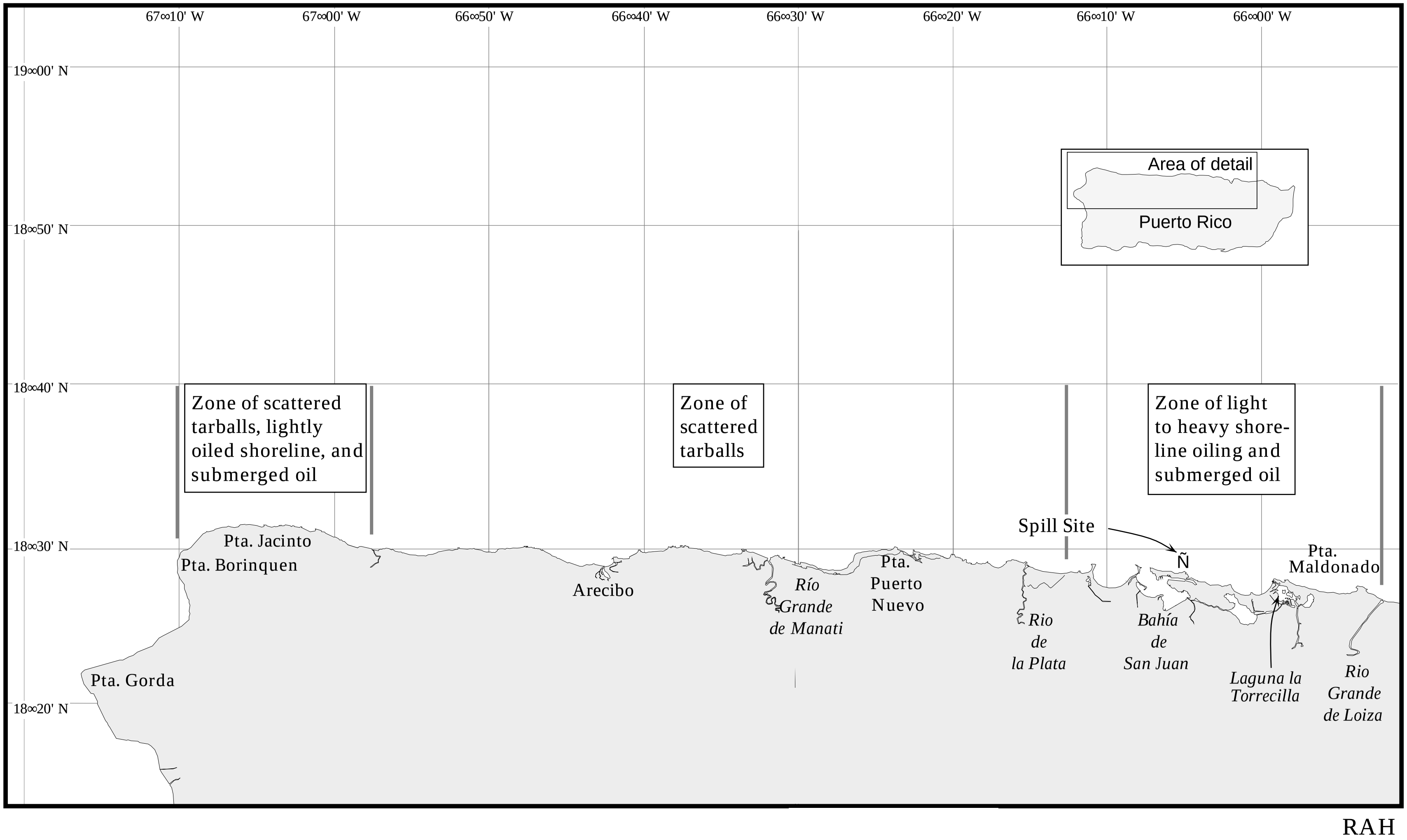


Figure 10A. Location map showing the grounding site and the extent of shoreline subsequently oiled.

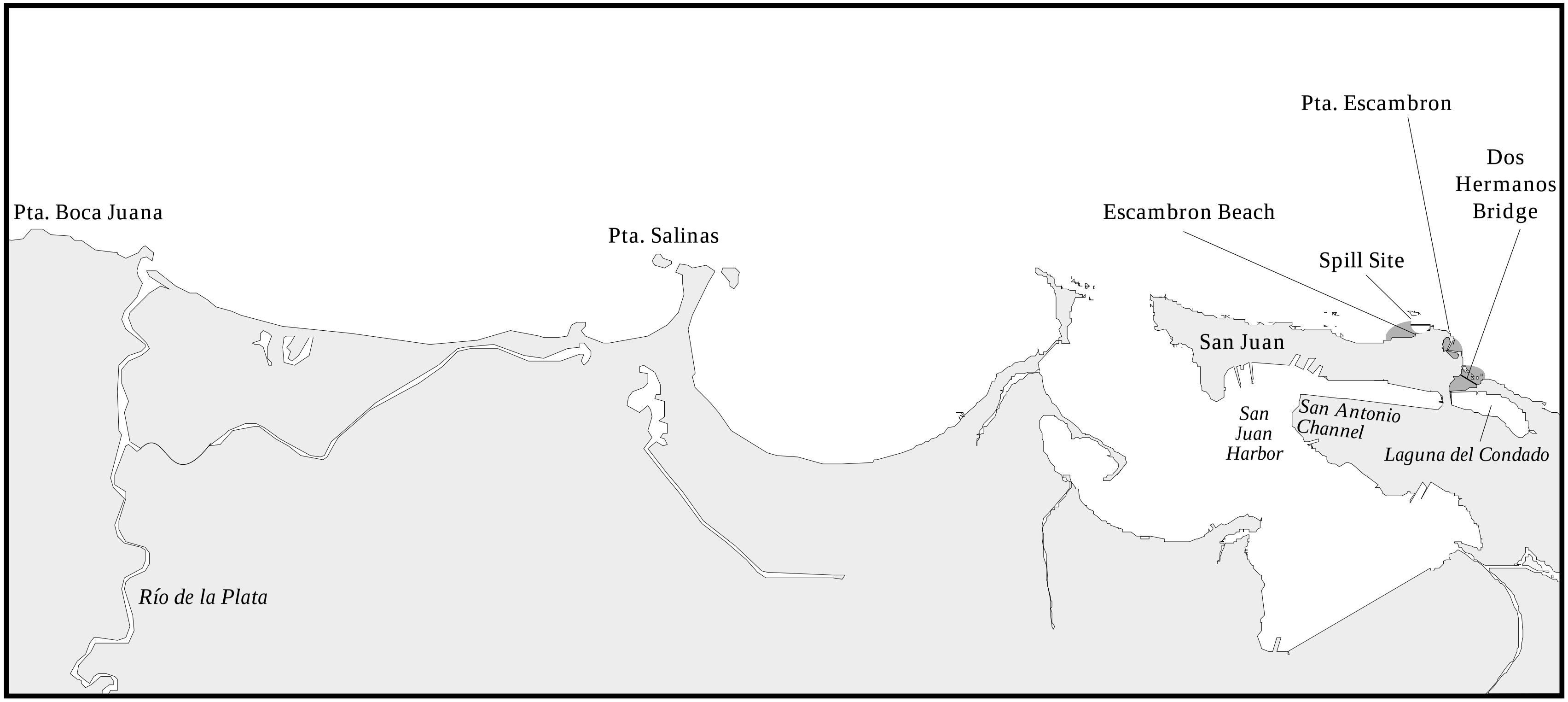


Figure 10B. Extent of oiling. Area of light to heavy shoreline oiling and submerged oil.

These large mats came from floating pancakes and tarball fields formed when the barge was refloated and towed offshore. The oil in the barge had cooled, weathered, and somewhat emulsified for seven days in the barge. Thus, the oil that was released after refloating was very viscous and tended to form large (greater than three feet in diameter) pancakes that maintained their integrity over large distances.

Frequent burial and erosion of the oil on sand beaches complicated cleanup. The northern beaches of Puerto Rico are very dynamic, with changing wave conditions that in turn cause rapid changes in sediment deposition patterns. The normal depositional cycles buried oil layers and tarballs four to eight inches deep.

Most of the rocky shores were composed of carbonate-cemented sand, or beachrock. The rock surface is highly irregular and rough, which increased oil adhesion. Oil pooled in depressions and crevices and heavily coated the rock surface in a band up to five yards wide along the upper intertidal and spray zones. The permeable rock surface allowed oil to penetrate up to several millimeters into the rock. The offshore rocks generated wave-refraction patterns that tended to concentrate oil or form a lee where wave activity could not remove the oil.

These areas of heavy oil accumulations were separated by large areas of sand beach and rocky shore where widely scattered tarballs were deposited, mostly on the eastern-facing portions in response to the easterly trade winds.

Subtidal Habitat Impacts

Floating oil slicks were recovered first. Within 24 hours of the spill, submerged oil accumulated in subtidal habitats. The submerged oil was identified in recoverable quantities in four distinct areas. Three were next to the grounding site. The fourth was 68 miles to the west of these areas. Each area is characterized below:

The first area was the site where the bulk of the floating oil was contained and recovered. It consisted of a very small embayment (the entrance to Laguna del Condado), approximately one nautical mile east of the grounding site, that was sheltered from direct waves but next to an area of very strong tidal currents. Submerged oil heavily coated seagrass blades and tarballs in the sediment of the seagrass beds. Tidal currents prevented larger deposits from accumulating.

The second area, immediately east of the grounding site, was a highly modified lagoon near Punta Escambron with a submerged breakwater on the seaward side that sheltered the lagoon from direct waves. The south side was more exposed than the north side. The lagoon was a natural catchment area where large amounts of floating oil accumulated, making it a major oil recovery site. Submerged oil was observed on the sandy lagoon floor within 24 hours after the spill: extensive mats of oil up to eight inches thick covered most of the bottom. The oil had to have entered the lagoon floating on the surface or suspended in the water column to bypass the shallow breakwater. Once inside the relatively quiet lagoon, the oil settled to the bottom. It was reworked by wave-generated currents into long troughs and ridges, similar to very large ripples. Sand tended to cover the oil in the troughs, so the oil appeared as long black ridges in some areas. This submerged oil tended to refloat and recontaminate the adjacent shoreline, a highly used recreational beach at the Caribe Hilton. In the more sheltered northern part of the lagoon, the oil formed large, continuous mats that were covered with sand.

The third area was located on the exposed outer shore, where offshore rock reefs formed a semi-protected lagoon and pocket beach (Escambron Beach) just a few hundred yards west (and downcurrent) of the grounding site. The submerged oil accumulated in the lee of the reefs, forming thick, cohesive mats on the sandy bottom and seagrass beds. Each afternoon, when the sea breezes and wave energy increased, pieces of the mats would break off and refloat or roll around on the bottom.

The fourth area was at Punta Jacinto, along the northwest end of Puerto Rico, where oil released after the barge was refloated came ashore. Heaviest shoreline oiling occurred on the more easterly facing beaches along a stretch of shoreline composed of pocket beaches and rocky headlands. Patches of submerged oil were observed along the same areas as the stranded oil. The submerged oil here was different from oil in the other areas in that it occurred as thick (up to eight inches), isolated patches of oil; the largest was on the order of 5 m long. The oil was less viscous and contained less sand compared to submerged oil in the other areas.

Floating tarballs and large pancakes were observed in widely scattered fields offshore after the barge was refloated. When this oil finally came close to shore, it picked up sand in the surf zone and became suspended in the water column or slightly negatively buoyant. Pieces stranded onshore or on the offshore rock reefs at low tide. Because of the exposed setting, the submerged oil was highly mobile; stable and recoverable concentrations occurred only in the lee of a large rock reef that protruded offshore for some distance. Waves refracted around the reef, and submerged oil accumulated on both sides of it. Large patches of oil also stranded on the exposed offshore rocks. In other locations, the submerged oil patches consistently moved to the west with the nearshore currents.

Biological Resource Impacts

Documented biological resource impacts consisted of injuries to or mortality of the intertidal and nearshore organisms that occupied rocky shoreline and subtidal, hard-bottom habitats. The majority of impacts were observed for benthic invertebrates (especially echinoderms and molluscs) and hard-bottom associated fishes. Several birds and sea turtles were also affected.

Three species of sea urchins were particularly impacted. Many urchins were not dead, but appeared to be injured, displaying drooping spines and tufts of algae growing on the testes and spines. In addition to the sea urchins, injured invertebrates included many molluscs (snail, chiton, limpet, mussel, and octopus) and several crabs (Sally Lightfoot crab and blue crab).

Impacted fish included species of parrotfish, squirrelfish, damselfish, surgeon fish, tang, needlefish, grunt, hogfish, yellowtail snapper, grouper, blennie, eel, mojarra, angelfish, chromi, scorpionfish, porgy, and puffer. Some of these species (particularly some of the damselfish) display territorial behavior, maintaining and defending small patches of hard-bottom habitat. These fish will not readily move away from their territory and thus were more susceptible to the effects of oil in the water column. Many of the fish are recreationally and commercially important, including several species of grunt, hogfish, snapper, and grouper. Several of the smaller, more colorful “tropical reef” species, such as angelfish, damselfish, and chromis, may also be important in the aquarium trade (Vicente 1994).

Many fish also displayed sublethal symptoms, including fin rot, lesions, skin ulcers, eye ulcers, missing eyes, apparent blindness, “gasping” or “suffocating” behavior, lethargy, color fading, and lack of buoyancy control and normal orientation in the water column. In addition, fish that usually display constant feeding behavior were not seen feeding in oil-impacted areas (Vicente 1994).

Wildlife rescue and rehabilitation requirements were minimal and were provided via the existing system. The Puerto Rico Department of Natural Resources (PR DNR) and the Caribbean Stranding Network provided the needed services at their facilities in San Juan. Two oiled green sea turtles, an endangered species, were recovered. One of the turtles had oil on its neck, flippers, and mouth. The other turtle displayed spotty or patchy oiling. Both were cleaned and released by the Stranding Network (Caribbean Stranding Network 1994).

Oiled birds included two sandwich terns, one sandpiper, one yellow-crowned night heron, six rock doves, one belted kingfisher, four brown pelicans, twelve brown boobies, and one Audubon’s shearwater. Sandwich terns and brown pelicans are threatened species, and Audubon’s shearwater is an endangered species. The sandwich terns were both released after cleaning, the sandpiper died on arrival at the cleaning center, the night heron died after cleaning, one rock dove died and five were released after cleaning, the kingfisher died after cleaning, one brown pelican died and three were released after cleaning, five brown boobies died and seven were released after cleaning, and the shearwater was dead on arrival at the cleaning facility. Of the twenty-eight oiled birds recorded, seventeen were released and eleven died (Caribbean Stranding Network 1994).

The injuries and mortalities noted are consistent with those documented at many other spills, and were restricted to areas where the spilled oil was observed. Petroleum products such as the heavy fuel oil that constituted the largest portion of the spilled oil are usually associated with low acute toxicity due to the reduced amounts of soluble, lighter distillates of oil. However, chemical analysis of the source oil in this incident indicated that the heavy oil was “cut” with a lighter material, possibly to facilitate loading and offloading. It is believed that the lighter fraction in the mix was responsible for much of the initial acute toxicity observed. Because the barge grounded in the nearshore surf zone, the spilled oil was vigorously mixed into the water column, probably increasing the exposure of fish and nearshore invertebrates to these lighter components.

Birds and turtles showed evidence of physical oiling, which was removed during the cleaning process. The bird mortalities may have resulted from a number of spill-related considerations, including direct toxicity from ingestion or inhalation, thermoregulatory stress caused by oiling of feathers, and handling stress.

RESOURCE COUNTERMEASURES AND MITIGATION

Protecting natural resources and rapid cleanup of impacted shoreline and habitat were response priorities. Natural resource protection and cleanup was addressed by a shoreline assessment team composed of representatives from PR EQB and PR DNR, USFWS, National Park Service, NOAA, and the USCG.

Protection countermeasures involved protective booming and equipment staging in areas at risk and eliminating the continuous source of fresh oil by removing the barge from the nearshore environment.

Degree of shoreline oiling was assessed early in the response to begin characterizing shoreline impacts and develop priorities and recommend strategies for cleanup activities. These assessments continued throughout the cleanup efforts in order to track progress and update recommendations for final cleanup actions.

Much of the impacted shoreline was subject to high-energy, natural cleaning from wave action. There was need, however, for a great deal of manual and mechanical cleanup as well as use of a chemical shoreline cleaner for some areas. Cleanup activities were always developed with overall protection of the environment in mind. Impacts to habitats, sand dunes, and other natural resources from the cleanup activities were effectively minimized throughout the cleanup by a systematic review process involving local and Federal trustees, NOAA, and the USCG. This review committee developed guidelines to addresse removal of sand, nighttime activities, cleanup operations that might impact turtles or their nesting habitats, and use of all-terrain vehicles and other equipment on the beach.

Special consideration was given to protecting and cleaning up threatened and impacted heritage resources. One of the first actions was to recommend measures to protect these resources from further oiling as well as from response activities. These included the extensive use of heavy plastic coverings, sandbagging, sorbent padding, and equipment restrictions to minimize or eliminate potential areas of secondary oil and physical impacts. Sites were classified as restricted and activities were carefully managed, monitored, and limited as necessary (Figure 11).

For many archaeological sites along the north coast of Puerto Rico there is a potential for artifacts to be found. These site locations were confidential and thus could not be made known to responders. NOAA handled this dilemma by carefully reviewing planned response activities and comparing them with a map of archaeological sites. Whenever response activities were to be carried out in a sensitive area, trustee representatives were consulted. Activities were then carefully monitored or limited at these sites.

Once these resources had been protected from further impact and the known impacts documented and evaluated, recommended cleaning techniques were developed. The goal was to use the least obtrusive cleaning technique that yielded acceptable results. Chemists, masonry, and heritage resource experts were consulted prior to recommending any cleanup techniques.

Barge Disposition

The FOSC decided to scuttle the barge as the optimum response countermeasure and mitigation action. Shoreline cleanup and recovery processes showed little progress while the barge continued to leak oil at the grounding site and re-oil cleaned areas. The sensitivity of these areas was heightened because this oiling affected one of Puerto Rico’s prime tourist locations. Once the source of oil was removed, progress could be made with shoreline cleanup and resource recovery.

The FOSC requested that NOAA evaluate two primary concerns related to the removal of the barge. First, NOAA was asked to prepare a trajectory analysis of the floating oil from continued leakage at the nearshore grounding site and compare it with predicted releases that might occur due to the refloating, towing, and sinking operations. Second, NOAA was asked to consider potential impact to resources from continued nearshore leakage compared with potential resource impacts from the scuttling operations. NOAA’s discussion of these comparisons with other resource trustees and CRRT members is presented below.

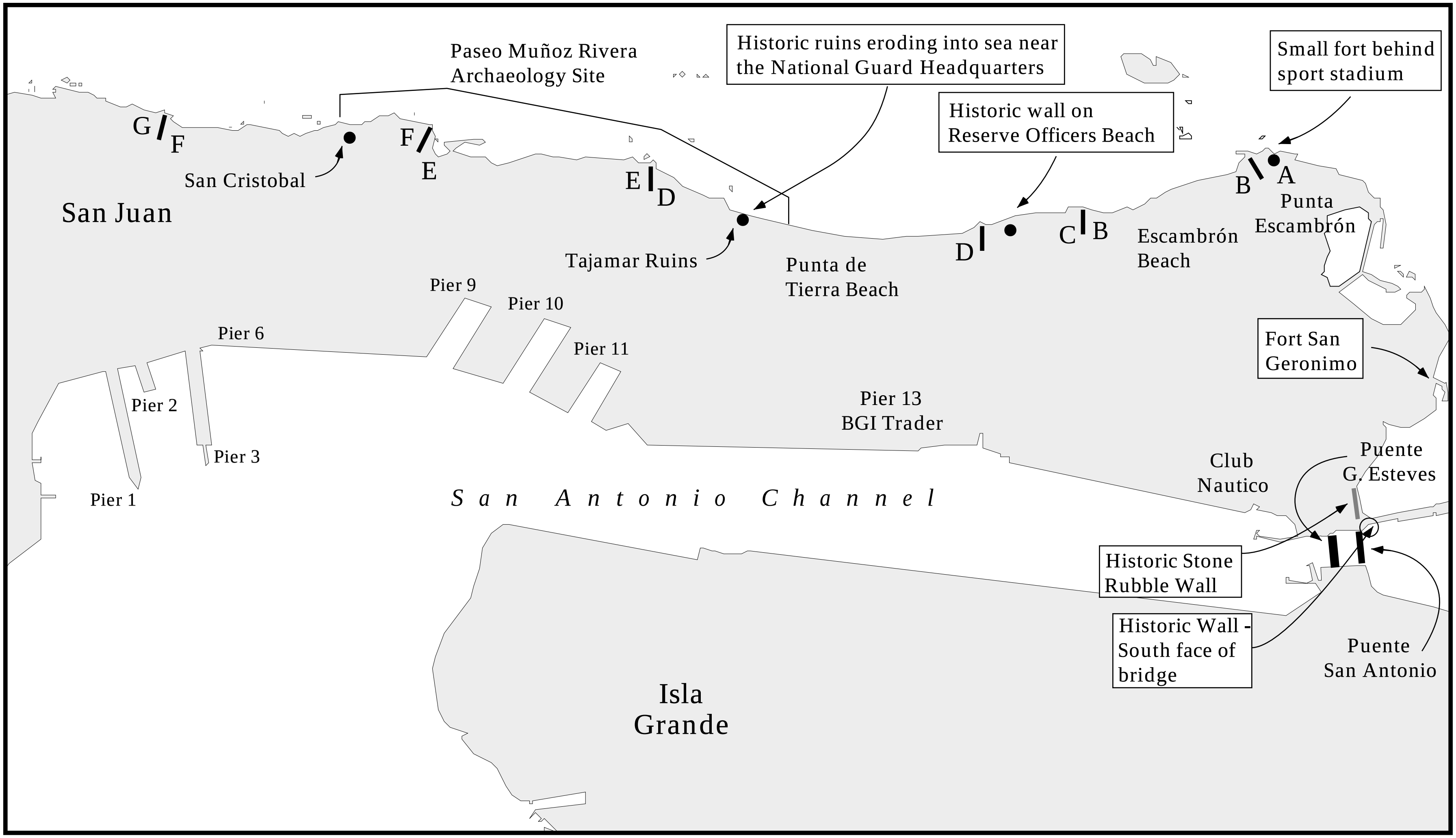


Figure 11. Zone 3, North shore spanish colonial historical structures.

Evaluation of Options

Trajectory models and analysis indicated that additional oil released at the grounding location would continue to affect the same areas of shoreline that had initially been oiled. Additional product released at the same location would impact shorelines west of the grounding site. Trajectory analysis indicated that offshore releases from scuttling would become more widely dispersed. Any potential shoreline impact to the west would involve less overall oil coming ashore as tarballs and pancakes. Options are summarized below.

Trajectory

Nearshore Offloading

- The same areas would continue to be heavily impacted until the barge was completely offloaded.
- The net movement of any oil washed off the beach would be to the west, eventually impacting, to some extent, the entire northern coast of Puerto Rico.
- There would be minimal threat to the Dominican Republic.
- No noticeable impact was expected on Cuba, the Bahamas, or Jamaica.
- An unusual wind could lead to additional heavy impacts to the east of the vessel.

Towing and Sinking Offshore

- A good deal of the oil could impact the northern shores of Puerto Rico, with lesser quantities spread over greater areas.
- There would be an increased chance of impact to the Dominican Republic.
- There would be an increased (though still not very likely) threat to Cuba, Jamaica, and the Bahamas.
- Oil would likely be more weathered and more naturally dispersed when it reaches the shoreline, resulting in overall less oil impact, with some probability of never impacting the shoreline.

Environmental Resources At Risk

Nearshore Offloading

- Impacts to the nearshore and intertidal habitats were severe around the barge and were expanding as the oil moved west.
- Because the oil was leaking into the surf zone, the oil readily mixed into the water column. Large numbers of intertidal and subtidal organisms near the barge had been killed just by coming in contact with the oil. These acute impacts to the rich, nearshore habitats were likely to worsen and affect larger areas as the leaking continued, including areas to the east and west.
- Shoreline cleanup could not be effectively conducted until all of the free-floating oil was removed from nearshore waters, delaying the recovery of affected intertidal communities.
- Leatherback turtle nesting activities would increase in February, so a delay in shoreline cleanup or repeated re-oiling could affect nesting turtles.

- The longer the oil remained in nearshore habitats, the more likely there would be impacts to manatees from Punta Salinas to San Juan.
- More sheltered, sensitive shorelines could be affected as the oil continued to leak and spread.

Towing and Sinking Offshore

- Depending on how much oil remained on board, oil could leak from the barge for an unknown period. The oil would not weather in the barge.
- Young and adult turtles concentrate in areas where oil from the sunken barge could accumulate as tarballs. Turtles try to eat tarballs, which fouls their mouths and flippers. In areas of heavy chronic oil discharges, up to 25 percent of the turtles were oil-fouled. More could be oiled.
- The potential effects of shoreline impacts in the Dominican Republic were unknown. However, they could be similar to what happened in Puerto Rico during the *Vesta Bella* spill: tarballs stranded on the entire eastern shore of Puerto Rico, and the eastern half of Culebra and Vieques islands, requiring a cleanup effort that took several weeks.
- Wherever the oil stranded, there could be scattered impacts to turtle-nesting beaches during periods of greater nesting activity (which starts in February and continues through the summer).

The threat of additional nearshore or shoreline impacts was the most important consideration for selecting the best disposition option. Adverse effects were predicted to be less from sinking the barge offshore with residual oil aboard than leaving the barge nearshore where it could break up on the reef.

Oil Treatment Options

Efforts were made to remove as much oil as possible before scuttling. Several additional options were considered, including pre-treating the residual oil with dispersants or solidifiers, igniting the residual oil, and exploding the barge before sinking it. These options were considered during the planning phase as potential ways of minimizing the additional spilling of oil.

However, each was dismissed in turn as ill-advised or not possible:

- Several preliminary laboratory tests were conducted on samples of the oil to determine the feasibility of using dispersants either as a pre-treatment or as needed if a large release occurred during the scuttle operations. LSU assessed the effectiveness of dispersants for possible use during the incident. While laboratory conditions did not adequately mimic actual sea conditions, they provided a perspective on the dispersibility of different oil/dispersant combinations. The effective dispersants under high-energy conditions were Corexit 9527, Enersperse 1037, and Enersperse 1583. However, aerial application of any dispersant on this heavy fuel oil would be unlikely to produce any effective dispersion. The process of premixing aboard the barge was thought to be difficult, if not impossible. Solidifying agents were dismissed as a treatment because there was no adequate mechanism for mixing them with the oil.

- Burning the residual oil was judged unfeasible. This very heavy, viscous oil would not ignite easily and maintaining combustion would have been very difficult. To provide enough atmospheric oxygen for a burn, large portions of the barge's decks would have had to be removed. This action would have made it impossible to maintain the pressurized air bubble that was keeping the barge afloat.

- Exploding the barge before sinking it would have resulted in a relatively large single release of product. This is in contrast to the potential for small, periodic releases expected if the barge was scuttled intact. After considering the tradeoffs, the FOSC concluded that there would be no environmental benefit from detonating the barge.

The FOSC further concluded that mechanical means could recover any leakage from the barge resulting from the refloating and scuttling operation. The MSRC vessel, *Caribbean Responder,* along with other skimmers and boom-towing vessels, could follow the barge offshore to collect floating oil.

Selection of Scuttle Site

The scuttle site was a naval munitions dump site, 6,600 feet deep and approximately 20 nautical miles northeast of San Juan. An option to tow the barge farther and into even deeper water was reviewed, but offered no additional benefit. Rather, it was felt that other islands west of Puerto Rico would be at greater risk for tarball impacts the farther away from Puerto Rico the barge was towed.

The USCG carefully considered the alternatives before deciding to scuttle the *Morris J. Berman*. The emergency action taken to refloat and sink the barge in deep water offshore involved the fewest adverse impacts to the environment, the public, and response personnel.

Decision Consequences

Although some new areas were oiled when the barge was scuttled, impacts in these areas were expected. Preparations were therefore in place to protect resources there and conduct cleanup operations quickly. A large initial release occurred at the grounding site as the barge was refloated. This discharge impacted the previously hit areas near the grounding site. As the barge was towed to the predetermined scuttle site, it left a sheen trail that impacted some new areas further east. This was because the vessel's track was in a northeast direction. Following the sinking of the barge, an estimated 200 barrels of oil was observed on the surface at the scuttling site. This oil moved westward and began to break up into tarballs and patches. Observers noted a near-constant, thin, silver sheen extending one-quarter to one-half mile to the west at the scuttle site over the next several months. It is thought that this sheen resulted from a small chronic leak of residual oil and clingage left in the barge.

Within two weeks following the scuttling, shoreline impacts were reported on the northwest end of Puerto Rico. This impact area had been pinpointed in a trajectory forecast made before the scuttle operation. Cleanup crews rapidly removed beached oil as it came ashore to prevent burial or impacts to sea turtles expected to begin nesting soon.

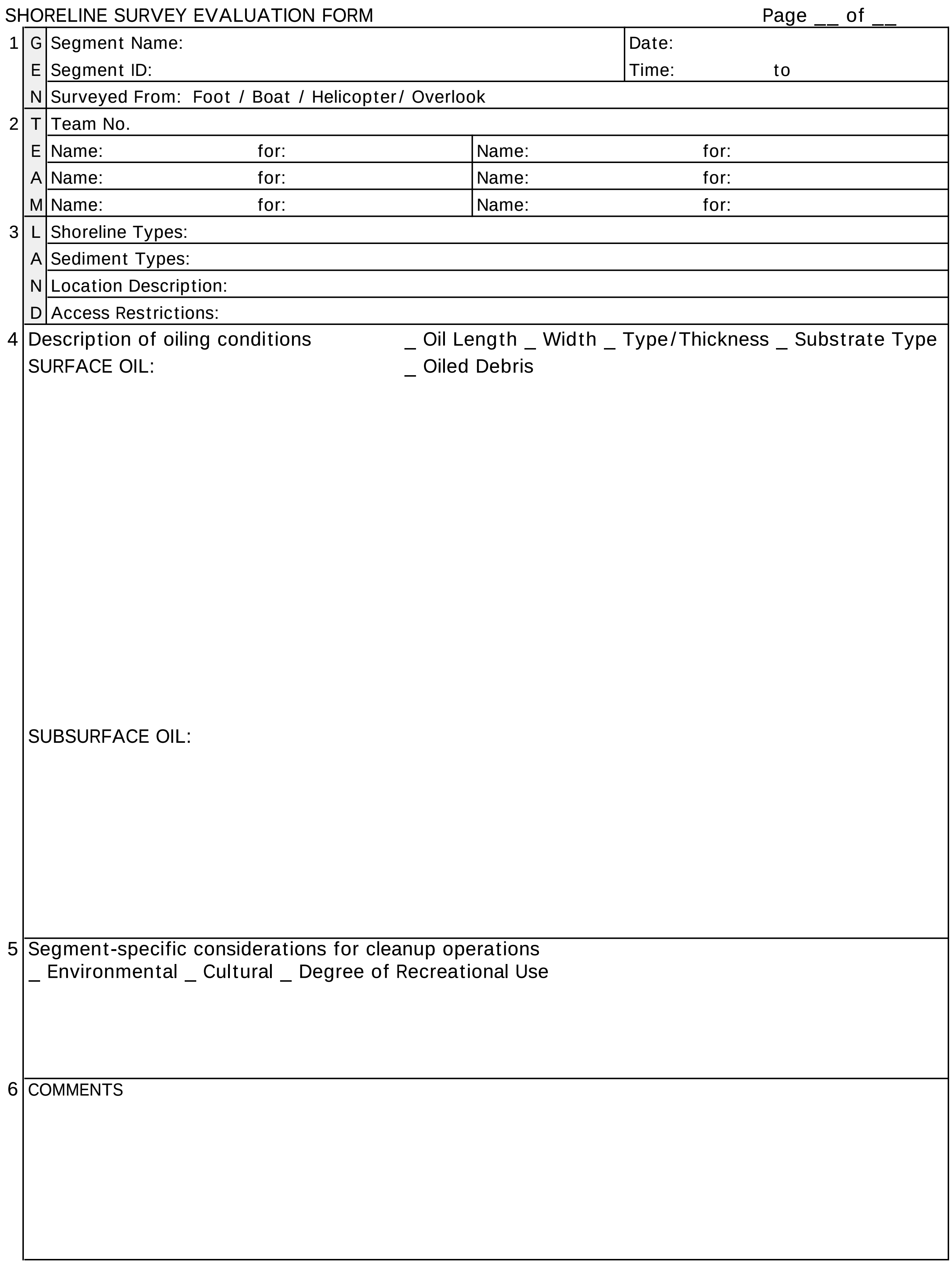
Submerged oil mats were discovered in several protected areas and crenulate bays along the northwest coast near Punta Jacinto. This oil was more emulsified than the submerged oil near San Juan. It is thought that this oil floated from the scuttle site, converged in these protected areas, and mixed with enough sand to sink the oil. Cleanup crews removed the majority of submerged oil using vacuum/suction devices and submersible dredges.

Shoreline Assessment and Cleanup Process

A Shoreline Assessment/Inspection Team (SAIT), consisting of representatives of PR EQB, PR DNR, NOAA, and the USCG, systematically collected information on the shoreline oiling conditions to provide recommendations for cleanup and to evaluate the effectiveness of the cleanup so that further cleanup requirements could be identified. Near the end of the cleanup, this same team was involved in the “how clean is clean” process.

Simplified shoreline assessment forms and codes for describing the oil were developed in both English (Figure 12) and Spanish. Teams were trained in the shoreline assessment methods. The focus was on standardized terminology and descriptors, so that sequential surveys could be used for comparison. There was very little turnover in the team membership, which ensured that experienced observers were available during the nearly two months of intensive shoreline cleanup.

Segmentation of the shoreline into cleanup zones was initiated by the cleanup contractors in order to effectively manage the oiling assessment and cleanup activities. These zones were formalized and subdivided into smaller areas as required during later stages of cleanup. Eventually 18 zones were delineated, varying in shoreline length from 300 yards, for the areas next to the grounding site where the oiling was heavy but highly variable, to tens of miles, where scattered



SHORELINE SURVEY EVALUATION FORM Page __ of __

1	G	Segment Name:	Date:
	E	Segment ID:	Time: to
	N	Surveyed From: Foot / Boat / Helicopter/ Overlook	
2	T	Team No.	
	E	Name: for:	Name: for:
	A	Name: for:	Name: for:
	M	Name: for:	Name: for:
3	L	Shoreline Types:	
	A	Sediment Types:	
	N	Location Description:	
	D	Access Restrictions:	

4 Description of oiling conditions _ Oil Length _ Width _ Type/Thickness _ Substrate Type

SURFACE OIL: _ Oiled Debris

SUBSURFACE OIL:

5 Segment-specific considerations for cleanup operations

_ Environmental _ Cultural _ Degree of Recreational Use

6 COMMENTS

Figure 12. Shoreline survey form used for systematic surveys of oiled shorelines.

tarballs occurred over long stretches of beach. Page-sized maps were made for each zone, so that oil locations could be specifically located. The USCG monitors used these maps to report daily cleanup progress and identify site-specific protection guidelines (Figures 13A,B).

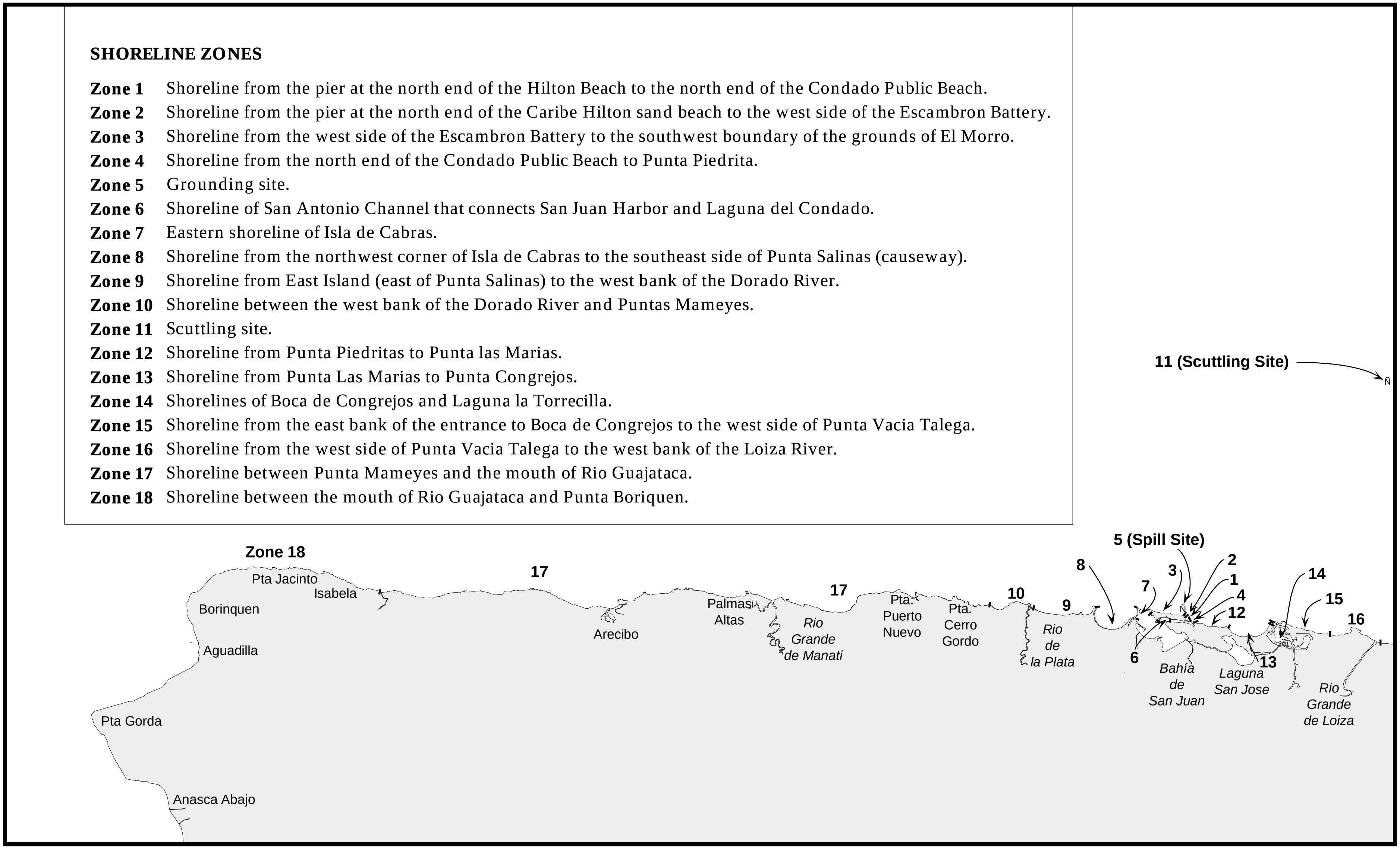
Cleanup methods and priorities were recommended based on the shoreline surveys. Recovery of free-floating oil was the highest priority. Skimmers were very effectively used in Zones 1 and 2 (Laguna del Condado entrance and the Punta Escambron/Hilton Beach lagoon) at natural collection sites sheltered from waves. Along the more exposed outer coast, vacuum trucks recovered thick accumulations, but oil snares were most effective where the oil tended to float in the surf zone. The oil snares were tied to a rope and strung out along the shoreline. They picked up so much oil that each snare had to be cut from the rope so that a worker could pick it up for bagging.

The SAIT recommended that sand beaches with continuous oil deposits be cleaned by manually removing the oiled sand, taking precautions to remove a minimal amount of clean sand. Before cleaning up a specific beach, a survey was conducted to determine the extent and degree of buried oil layers. Surf washing of buried oil layers was attempted, but the amount of buried oil was high enough to generate black oil slicks and the method was terminated. Large amounts of sand were removed from the Caribe Hilton beach, which was heavily oiled from the initial release and re-oiled from the largest accumulation of submerged oil.

Mechanical equipment was used later in the cleanup to remove large areas of heavily oiled sand and buried tar mats. At Zone 15B (Punta Maldonado), a tar mat roughly 220 yards long, four feet wide, and four inches thick, was present along the toe of the beachface in the western section of this segment. Portions of this tar mat were covered with up to 5 cm of clean sediment. An incipient pavement of heavily oiled sand was buried beneath this tar mat. The recommendation called for the removal of both layers of contamination (approximately 120 cubic meters of sediment) using a track hoe and a front-end loader. Machinery movement was closely monitored to prevent unnecessary traffic across the beach and sand dunes.

In all other cleanup activities, mechanical equipment was used only for hauling of oiled sediments collected by workers.

Widespread distribution of surface and buried tarballs was a particular problem on sand beaches. To minimize sediment removal and to speed cleanup, screens were built of wooden frames and chicken wire to sieve the tarballs out of the sand. This method was labor-intensive but effective at minimizing the amount of sediment removed. Initially, the workers shook the sieves so roughly that the tarballs broke up and passed through the screen. Tarball recoveries improved when the workers



SHORELINE ZONES

Zone 1	Shoreline from the pier at the north end of the Hilton Beach to the north end of the Condado Public Beach.
Zone 2	Shoreline from the pier at the north end of the Caribe Hilton sand beach to the west side of the Escambron Battery.
Zone 3	Shoreline from the west side of the Escambron Battery to the southwest boundary of the grounds of El Morro.
Zone 4	Shoreline from the north end of the Condado Public Beach to Punta Piedrita.
Zone 5	Grounding site.
Zone 6	Shoreline of San Antonio Channel that connects San Juan Harbor and Laguna del Condado.
Zone 7	Eastern shoreline of Isla de Cabras.
Zone 8	Shoreline from the northwest corner of Isla de Cabras to the southeast side of Punta Salinas (causeway).
Zone 9	Shoreline from East Island (east of Punta Salinas) to the west bank of the Dorado River.
Zone 10	Shoreline between the west bank of the Dorado River and Puntas Mameyes.
Zone 11	Scuttling site.
Zone 12	Shoreline from Punta Piedritas to Punta las Marias.
Zone 13	Shoreline from Punta Las Marias to Punta Congrejos.
Zone 14	Shorelines of Boca de Congrejos and Laguna la Torrecilla.
Zone 15	Shoreline from the east bank of the entrance to Boca de Congrejos to the west side of Punta Vacia Talega.
Zone 16	Shoreline from the west side of Punta Vacia Talega to the west bank of the Loiza River.
Zone 17	Shoreline between Punta Mameyes and the mouth of Rio Guajataca.
Zone 18	Shoreline between the mouth of Rio Guajataca and Punta Boriquen.

Figure 13a. shoreline zone map.

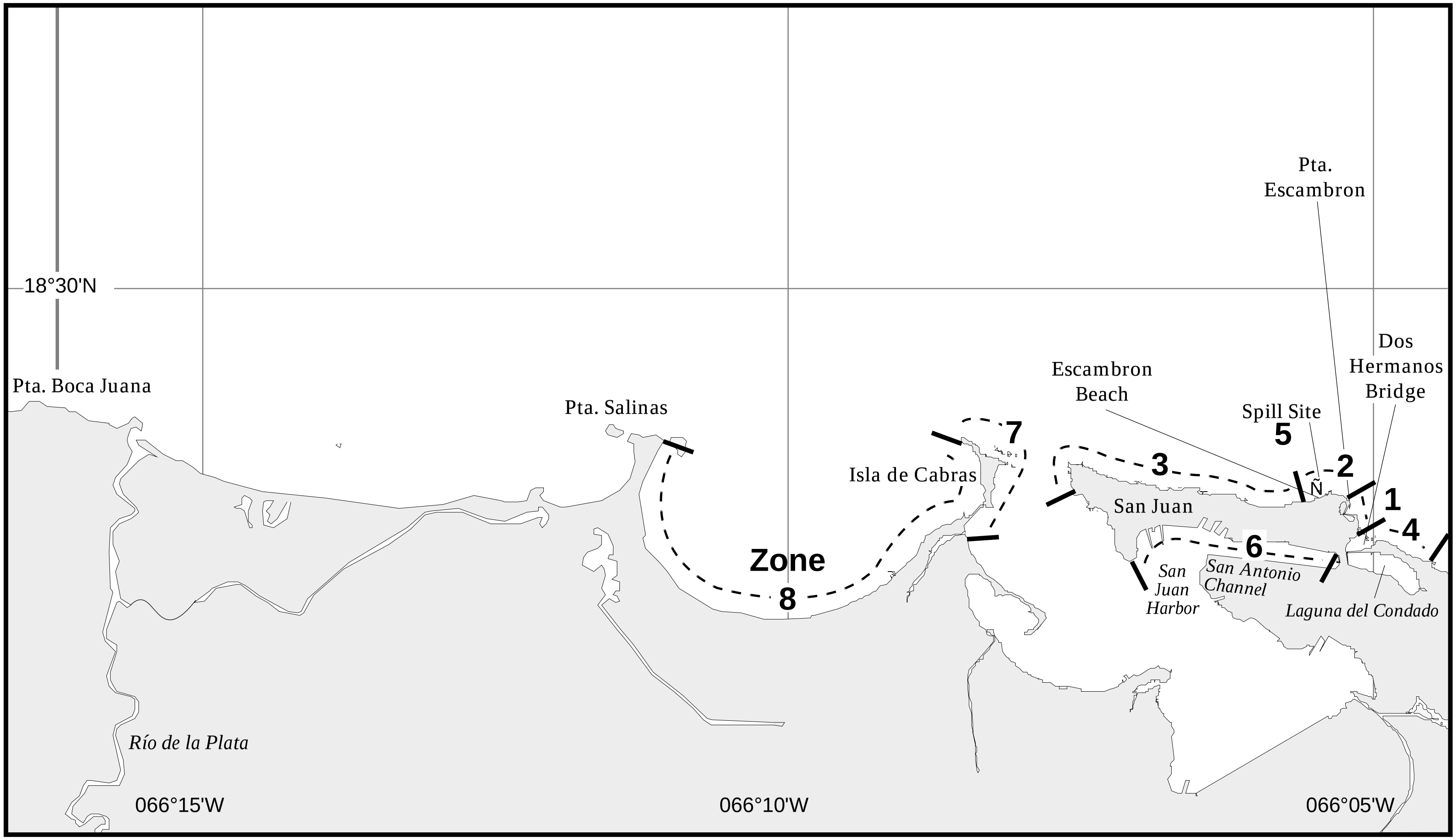


Figure 13b. inset zone map.

were instructed to sieve less sediment at a time and to shake the screens more gently.

On oiled rocky shores, the SAIT recommended that pooled oil be vacuumed or manually removed as soon as possible. Along areas of high recreational use, the team recommended testing of shoreline cleaning agents (see following section). No cleanup recommendations were made for where the shoreline was not accessible since natural removal was expected to be rapid.

High-pressure, hot-water washing was used extensively on heavily oiled rip rap. Sorbents were used to recover the released oil. Along high-recreational-use areas, the rip rap was cleaned to the point that oil would not rub off on contact. On heavily oiled seawalls, high-pressure, hot-water washing was conducted in high-recreational use areas, high-visibility areas, and in marinas to prevent oiling of boats. Specific areas to be cleaned were identified. Cleaning of oiled seawalls in the industrial area of San Antonio Channel was not recommended.

Guidelines For "How Clean is Clean"

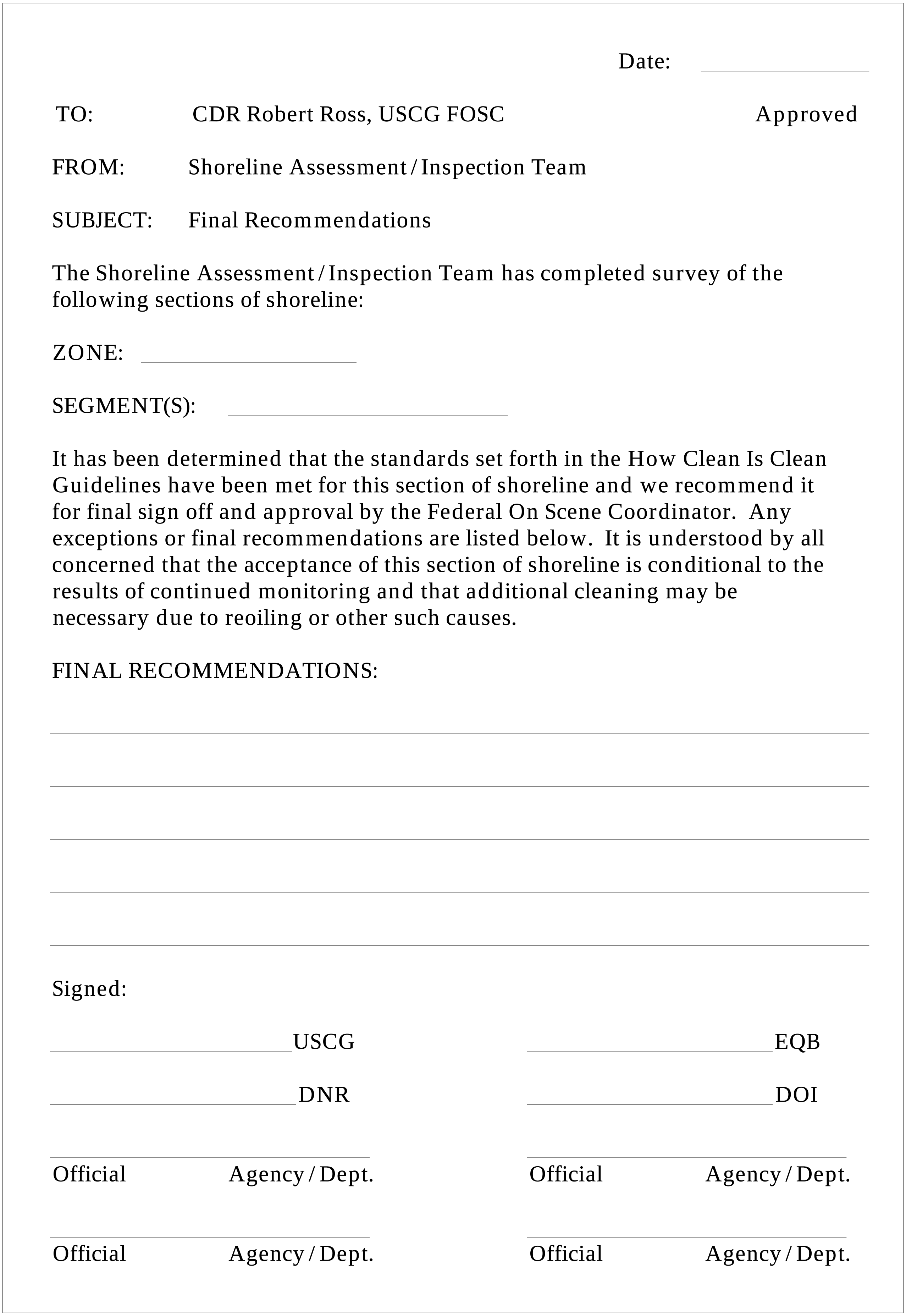
The SAIT developed a process for inspecting shoreline zones proposed for termination of cleanup efforts and final approval by the FOSC, as follows:

1. Beach supervisor conducted a preliminary inspection (check 1) and determined that the segment was ready for inspection by the SAIT.
2. The SAIT conducted an inspection (check 2) of the segment and recommended touch-up items to be addressed before scheduling the inspection for final recommendations.
3. A final walk-through was conducted with appropriate trustees and officials who had the authority to make final recommendations to the FOSC. The final recommendation would include a list of exceptions. Figure 14 includes the final recommendation form.

Guidelines used for determining what was "clean" for each shoreline type are listed in the following section. The figures illustrate both oiled and cleaned conditions.

Sand Beaches (Figures 15A,B)

<u>Surface Sediments</u> : The surfaces of sand beaches should free from visible oil except for some scattered tarballs or swash lines of minute tarballs that might occur as the sand is reworked by wave action. Beach sediments should be free from the smell of oil and should not feel oily. Tarballs will probably continue to wash ashore for a period of several weeks to months. High-recreational-use beaches should be monitored for tarballs and any accumulations should be removed. Sand replacement or sand washing should be implemented in heavily oiled, very high- use, recreational beaches.



Date: ____________

TO: CDR Robert Ross, USCG FOSC — Approved

FROM: Shoreline Assessment/Inspection Team

SUBJECT: Final Recommendations

The Shoreline Assessment/Inspection Team has completed survey of the following sections of shoreline:

ZONE: ____________

SEGMENT(S): ____________

It has been determined that the standards set forth in the How Clean Is Clean Guidelines have been met for this section of shoreline and we recommend it for final sign off and approval by the Federal On Scene Coordinator. Any exceptions or final recommendations are listed below. It is understood by all concerned that the acceptance of this section of shoreline is conditional to the results of continued monitoring and that additional cleaning may be necessary due to reoiling or other such causes.

FINAL RECOMMENDATIONS:

____

____

____

____

____

Signed:

____________ USCG	____________ EQB
____________ DNR	____________ DOI
____________ Official Agency/Dept.	____________ Official Agency/Dept.
____________ Official Agency/Dept.	____________ Official Agency/Dept.

Figure 14. Form used to make the final recommendations to the FOSC regarding signoff and approval for completion of cleanup activities.

Figure 15A. Seawall and mixed sand and gravel beach at Escambron, San Juan, taken on January 10, 1994, looking west. The barge had grounded just north and east of this point. Oil came ashore continuously for over a week, until the barge was moved. Cleanup methods included vacuuming of floating oil, deployment of snare, manual removal, and high-pressure, hot-water washing of the seawall. Note the high wave energy of this site, indicated by the breaking waves.

Figure 15B.Same site on May 10, 1994, after cleanup had been completed. No oil was visible either on the surface or with depth.

Buried oil : During the survey team inspection on segments where buried oil has been reported, the team dug a series of pits at regular intervals to determine whether any buried oil layers remained. Also, areas where buried oil is likely to persist will be inspected. Any buried oil layers will be manually removed. Sand that is only stained will not be removed. Buried oil in areas identified as important cultural or archaeological sites will be removed in accordance with trustee guidelines.

Beachrock (Figures 16A,B)

Areas of high recreational use : Heavily oiled, natural beachrock in areas of high recreational use will be cleaned using shoreline cleaning agents and high-pressure, hot-water flushing. Only one treatment with the cleaner and pressure-washing system will be conducted (as outlined in the operational guidelines) to minimize the potential for damage to the beachrock. Even after cleaning, there will be black oil on the undersides of the rock, in crevices, and some patches on the surface, and extensive oil stain. The objective is not to remove all of the oil, but to remove the gross oil to enhance natural removal.

Areas with limited recreational use or no access : Gross oil will be removed at accessible sites, with no further cleanup of these areas. All identified areas are located in high-energy settings where natural removal is expected.

Rip Rap (Figures 17A,B)

High recreational use areas : Heavily oiled rip rap in areas with high recreational use will be cleaned using shoreline cleaning agents and/or high-pressure, hot-water flushing. No cleanup will be conducted in areas with difficult access, high-energy settings that pose risks to workers, where oil recovery is not possible, or where natural recovery is expected to occur quickly. Only one treatment with the cleaner and pressure-washing system will be conducted (as outlined in the operational guidelines). Even after cleaning, there will be black oil in crevices between the rip rap boulders, some patches on the surface, and extensive oil stain. The objective is not to remove all of the oil, but remove the gross oil to enhance natural removal. Sorbents will be deployed along rip rap areas to recover sheens as needed.

Areas with limited recreational use or no access : Gross oil will be removed at accessible sites. No further cleanup of these areas will be conducted. All identified areas are located in high-energy settings where natural removal is expected.

Figure 16A. Rocky shore, seawall, and mixed sand and gravel beach at Escambron, San Juan, taken on January 19, 1994 looking east from the stairs shown in Figure 15A. The heavy oil had coated much of the intertidal zone.

Figure 16B. Same site on May 10, 1994, after cleanup had been completed. The only visible oil was staining on the sides of the rocky outcrops of beachrock, which was not cleaned with high-pressure washing because of the friable nature of the beachrock.

Figure 17A. Mixed sand and gravel beach just north of Fort San Geronimo, San Juan, taken on January 10, 1994. This site was a natural accumulation area formed by the bridge to the fort. Large amounts of heavy oil had penetrated the beach sediments.

Figure 17B. Same site on May 10, 1994, after cleanup had been completed. The surface sediments were clean, but a layer of lightly oiled sediments remained at 15-20 cm below the surface.

Seawalls (Figures 18A,B)

High-recreational-use/high-visibility areas: Seawalls in high-recreational use/high-visibility areas will be cleaned using hot-water pressure washers. They should be cleaned so that they do not feel tacky when touched. Staining may remain on some seawall areas even after hot-water pressure washing.

Other seawalls: Gross oil should be removed from seawalls that continue to generate sheens. Seawalls that could contaminate boats and equipment should be cleaned with hot-water pressure-washers. Heavily oiled seawalls around staging areas will be cleaned with hot-water pressure washers. Some staining may remain.

Chemical Shoreline Cleaners

Evaluating Needs

Responders expected that efforts to clean the heavily oiled solid structures would have limited success because the oil was strongly adhered to the substrate. Therefore, the FOSC requested that testing be conducted to determine whether chemical shoreline cleaning agents would help remove the heavy oil coating to the degree needed for these shorelines in high-use areas. Shoreline cleaning agents would be used only after gross oil removal (by vacuum, sorbents, and manual removal) was completed. The NOAA SSC was asked to develop and implement product selection and field-testing protocols to identify potential products for use.

Product Review and Selection Criteria

The first step in evaluating potential chemical agents for use was to develop initial screening criteria. Shoreline cleaning agents were first used during the *Exxon Valdez* oil spill (Fiocco et al. 1991). Environment Canada, the U.S. Environmental Protection Agency, and French researchers at the Centre de Documentation de Recherche et D’Expérimentation (CEDRE) have developed laboratory screening tests for shoreline cleaning agents (Clayton 1993). Environment Canada had tested over 60 potential products (Fingas et al. 1992). Walker et al. (1994) outlined effectiveness, operational, and environmental considerations for chemical oil spill treating agents. Based on these data, the following criteria for initial selection were developed:

1. The agent must be listed on the National Contingency Plan Product Schedule.
2. The agent has been tested as having greater than 20 percent removal effectiveness in standard laboratory screening tests for effectiveness, using the Environment Canada effectiveness test protocols.

Figure 18A. Seawall and sand beach directly in front of Punta Escambron, San Juan, taken on January 18, 1994. The barge had grounded just offshore of this point. The beachrock ledge in the background was the site of the test of shoreline cleaning agents. Free-floating oil accumulated in the lee of the beachrock, and oil was recovered with vacuum and snares for several weeks. The seawall was cleaned with high-pressure, hot-water washing. The viscous oil did not penetrate or adhere well to the sandy beach sediments.

Figure 18B. Same site, taken on May 10, 1994, after cleanup had been completed. There was no visible oil on the seawall or sediments. Note the recreational use of the shoreline.

3. The agent has been demonstrated in field tests to be an effective shoreline cleaning agent.
4. The product must be immediately available.

The third criterion was included because it was believed that the emergency phase of an oil spill response is not the time for testing completely new products. Three products met these criteria, listed here with the results of the laboratory tests on removal effectiveness: the revised formula Corexit 9580 M-2 (53 percent); PES-51 (21 percent); and Corexit 7664 (27 percent). Corexit 9580 and PES-51 are sprayed neat directly onto the substrate. Both Corexit 9580 and PES-51 are designed to “lift, float, and recover” the oil. Corexit 7664 is applied as a one- to three-percent flushing solution. Corexit 7664, which tends to disperse the treated oil, was chosen for the field test because some of the potential application sites were located in high-energy settings where it would be difficult to recover the released oil. There was concern that the released oil would re-contaminate adjacent shorelines. Thus, dispersion of the treated oil in areas of very high surf conditions was to be considered as a possible solution to re-oiling problems. The strategy was to use Corexit 9580 as a soak, then flush with the three-percent Corexit 7664.

Product toxicity was also evaluated. There was a significant difference in the toxicity test results among the various products (Table 1). Standard toxicity test results are very difficult to compare for insoluble products because the tests are conducted using nominal concentrations, i.e., total toxicant per volume of water.

Table 1. Toxicity tests for shoreline cleaner candidates (units are expressed as parts per million).

Test	**PES-51**	**Corexit 9580**	**Corexit 7664**
96 hr. LC$_{50}$			
F. heteroclitus	1425	>10,000	
48 hr. LC$_{50}$			
Artemia	665	2,800	>10,000
48 hr. EC$_{50}$	18.7	38	
C. gigas			
96 hr. LC$_{50}$			
Rainbow trout	13.6	>5,600	850

The insoluble components float on the water surface and generally do not contribute to the test organisms’ actual exposure. The actual water-accommodated fraction can be orders of magnitude lower in concentration than the nominal concentration.

Corexit 9580 and PES-51 are relatively insoluble, whereas Corexit 7664 is water soluble. These differences should be noted when comparing the toxicity test results in Table 1.

Field-Testing of Candidate Products

The next step was to develop a field test in which the selected products could be evaluated to compare the effectiveness of the shoreline cleaning agents against high-pressure, hot-water flushing alone (Figure 19). Thus, the temperature and pressure were incrementally increased until the oil was removed, compared to hot water alone in seawall test plots delineated at each site. The beachrock test site conditions were similar. However, the high surf conditions prevented deployment of booms and snares to contain and recover the oil, and the Corexit 7664 flush was not used because of equipment problems.

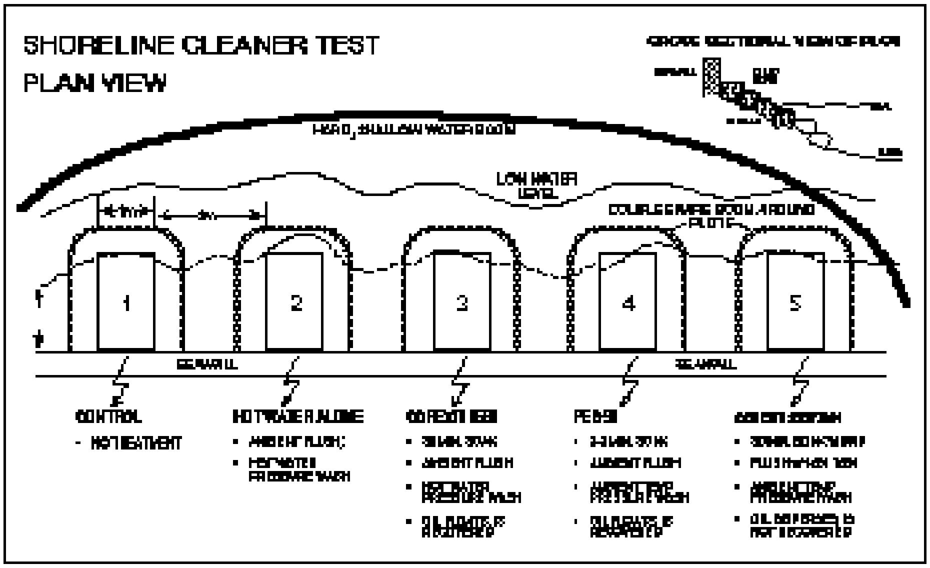


Figure 19. Schematic of the shoreline cleaning agent test site on rip rap substrates.

Test plot treatments included:

- Control (no treatment);
- High-pressure, hot-water flushing alone; and
- Application of each product at the recommended application rate (Corexit 9580 and PES-51 were applied at one to two gallons per ten square yards).

After a soaking period specified by the manufacturer, the two plots treated with Corexit 9580 and PES-51 and the water-only plot were flushed with ambient seawater at pressures of 100 pounds per square inch (psi). Water temperature and pressure were incrementally increased to removed as much oil as possible. The second Corexit 9580 plot was flushed with a three-percent Corexit 7664 solution at ambient temperature. Snare boom at the water level recovered released oil.

Field Test Results

Figures 20A-F are a series of photographs from the tests on natural beachrock. On the beachrock, high-pressure, hot-water flushing alone was only moderately effective in removing oil. Warm-water, low-pressure flushing (110°F and 250 psi) was totally ineffective. Using temperatures up to 175°F and 1,000 psi, a heavy oil stain still remained (Figures 20A and B). More importantly, the high pressure needed to remove the oil started to chip off the beachrock. The worker tended to hold the wand in one place to blast the oil off, causing the rock to chip, rather than sweep a small area with the spray. Use of Corexit 9580 significantly increased the amount of oil removed from the beachrock substrate, with the most oil removed at 175°F and 1,000 psi (Figure 20C), the highest temperature and pressure tested. It was important to note that because the chemical had softened the oil and it was being removed, the worker tended to use a sweeping motion with the pressure sprayer rather than pointing the water spray at one spot to blast the oil off. Thus, there was no chipping of the friable beachrock when Corexit 9580 was used as the chemical cleaning agent. After 24 hours, the treated plot had large areas with nearly 100 percent removal of the oil down to clean beachrock, although there were still areas of stain and thicker coating. Because of the high pressures used, some oil was dispersed as indicated by the brown color of the runoff water (Figure 20D). Some of the oil did remain black and float. In laboratory experiments with fresh oil and Corexit 9580 at ratios of 20:1 and 10:1, the mixture showed dispersion after 30 seconds of wrist shaking (to represent high-energy mixing), but after 45 minutes, most of the oil had returned to the surface (Henry 1994).

PES-51 was the second cleaning agent tested. This product is essentially d-limonene with some biosurfactants. Manufacturer guidelines call for flushing within two to three minutes after application, so it does not require a soak period. PES-51 also does not require hot-water flushing according to the manufacturer's recommendations for use, so ambient seawater at high pressure was used to flush the treated area. PES-51 improved the amount of oil removed from the beachrock compared to the water-alone treatment (Figure 20E), but not as much as Corexit 9580. Oil removal was very patchy, with some areas of clean beachrock while extensive areas still contained a heavy oil coating. There did not appear to be areas of partial oil removal down to a stain. Visually, it looked as if the area would need two applications to be most effective. Also, there were patches where the friable beachrock had been blasted off by the high-pressure spray. Most of the oil that was removed came off very quickly with the first pass of flushing. The worker then tended to hold the spray wand in one place trying to mobilize more oil from the

Figure 20A. Plot for high-pressure, hot-water washing alone. The concrete blocks define the corners of the test plot. On the left, washing was conducted with water up to 500 psi and 140°F. Note that very little oil was removed. On the right, washing was conducted with water up to 1,000 psi and 175°F. At this pressure, parts of the rock began to chip off.

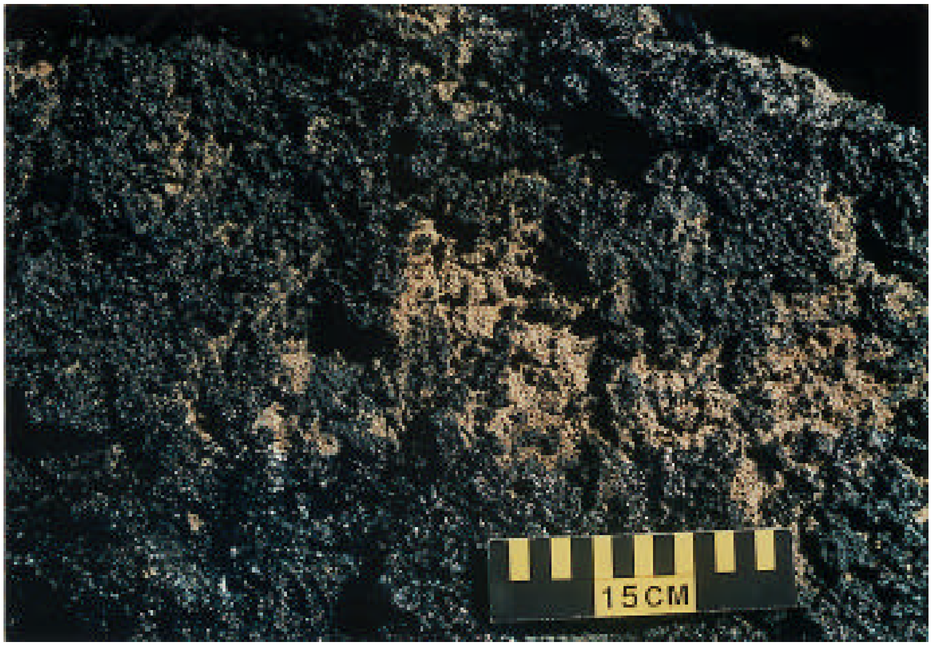


Figure 20B. Close-up of the high-pressure, hot-water washing-alone test plot, showing the area of chipped rock. The lighter area above the scale delineates the line between the area washed with 1,000 psi and 175°F; below the line the rock was washed with 500 psi and 140°F water. There was little chipping of the rock at 500 psi.

Figure 20C. Plot for the Corexit 9580 cleaner, which was flushed with high-pressure, hot water: the left side of the plot at 500 psi and 140°F; the right side at 1,000 psi and 175°F. The right side was significantly cleaner without any chipping of rock. The worker tended to sweep the entire area with the spray because oil was continually released during washing.

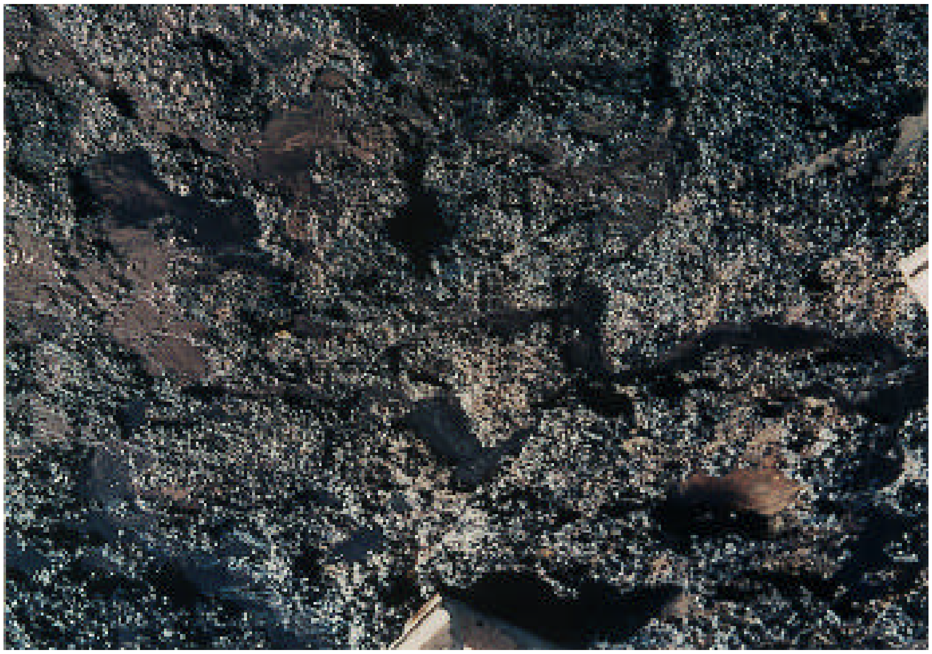


Figure 20D. Close-up of the Corexit 9580-treated beachrock surface during flushing operations. Note that some of the oil has dispersed, forming brown, muddy wash water in addition to black oil.

Figure 20E. The plot for the PES-51 cleaner was flushed with ambient water. The left side was washed with water pressures up to 500 psi; the right side was washed at 1,000 psi. AObservers noted that more oil was removed than with hot-water washing at similar pressures. After the initial release of oil, the worker tried to remove more oil by holding the wand in one place rather than sweep a small area with the spray. On the right side, rock chipped at 1,000 psi.

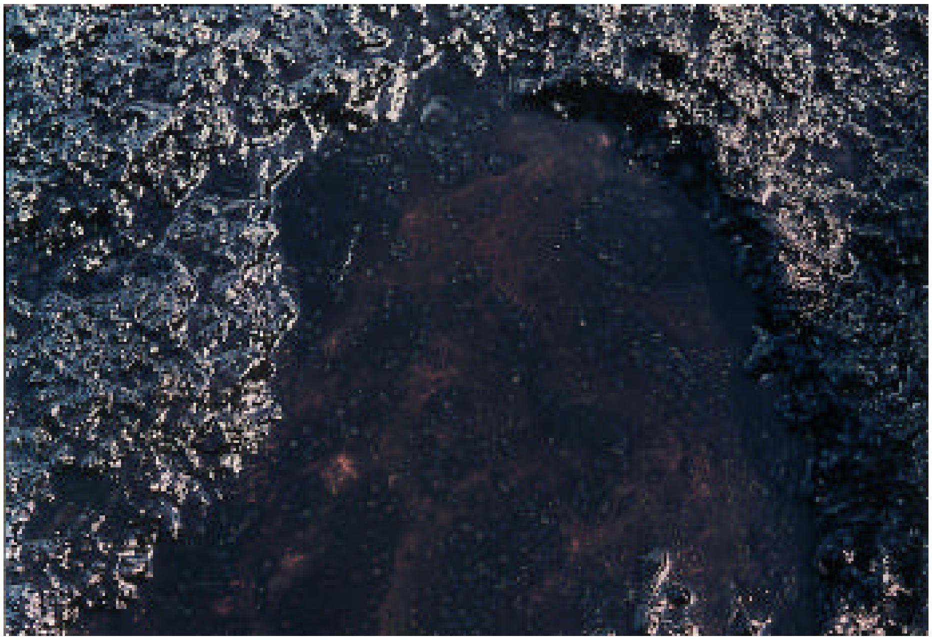


Figure 20F. Close-up of the PES-51-treated beachrock surface during flushing operations. None of the oil was dispersed, even at 1,000-psi water pressures. Treated and released oil was liquid and black, with small bubbles attached to floating slicks.

substrate, which removed some beachrock. There was no dispersion of the treated oil; the runoff water was clear and the released oil remained black and recoverable (Figure 20F).

On rip rap (Figures 21A-D), the results were similar in that the high-pressure, hot water flushing was less effective alone than when used with the cleaning agents. However, there was no chipping of the rip rap, even at pressures up to 1,200 psi because the rip rap was of a different rock type. Corexit 9580 appeared to be more effective than PES-51, but only moderately so. Applied as a surface spray, neither product was very effective at removing oil that had penetrated into the sediment between the crevices or on the undersides of the rip rap. The flush with Corexit 7664 did not appear to improve the amount of oil removed. Conditions were such that it was not possible to determine whether the released oil behaved differently when flushed with Corexit 7664. Neither was it possible to determine whether there was any effect on dispersion of the treated oil with the Corexit 7664 flush.

Caribbean Regional Response Team Involvement and Approval Process

CRRT members were involved in all aspects of field test development and evaluation. They reviewed proposed testing protocols and subsequently approved them. Members of the CRRT came on-scene to help evaluate the field tests.

Subsequently, the FOSC made a request to the CRRT to use either or both Corexit 9580 and PES-51 on beachrock and rip rap in selected areas. The use of the agents was subject to the following conditions:

- Areas to be considered for treatment would be limited to high-recreational use or high-visibility beachrock and rip rap, or heavily impacted, low-energy beaches prone to tar mat formation;
- An ecological effects monitoring plan would be developed in consultation with the CRRT and local resource experts;
- Sorbents would be used to recover the released oil;
- Shoreline cleaning agents would not be used where the product could affect nearshore living corals or in the intertidal zone below the oil; and
- Pooled and mobile oil would be removed to the extent possible before using the shoreline cleaning agent.

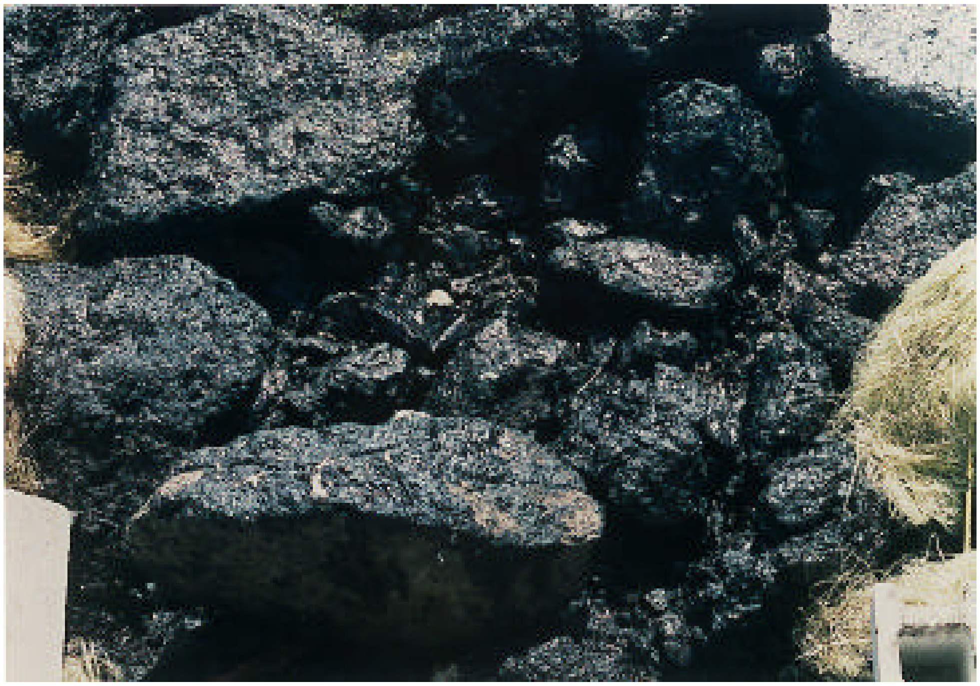


Figure 21A. The rip rap washing test reference plot. No pressure washing of any kind was conducted. All the plots had been cleaned to the extent possible by manual wiping.

Figure 21B. Plot for high-pressure, hot-water washing alone on rip rap. Pressure and temperature were incrementally increased to 1,200 psi and 175°F. Smooth rock surfaces were cleaned much better than the rough surfaces.

Figure 21C. Plot for the Corexit 9580 cleaner on rip rap; washing was conducted up to 1,200 psi and 175°F water.

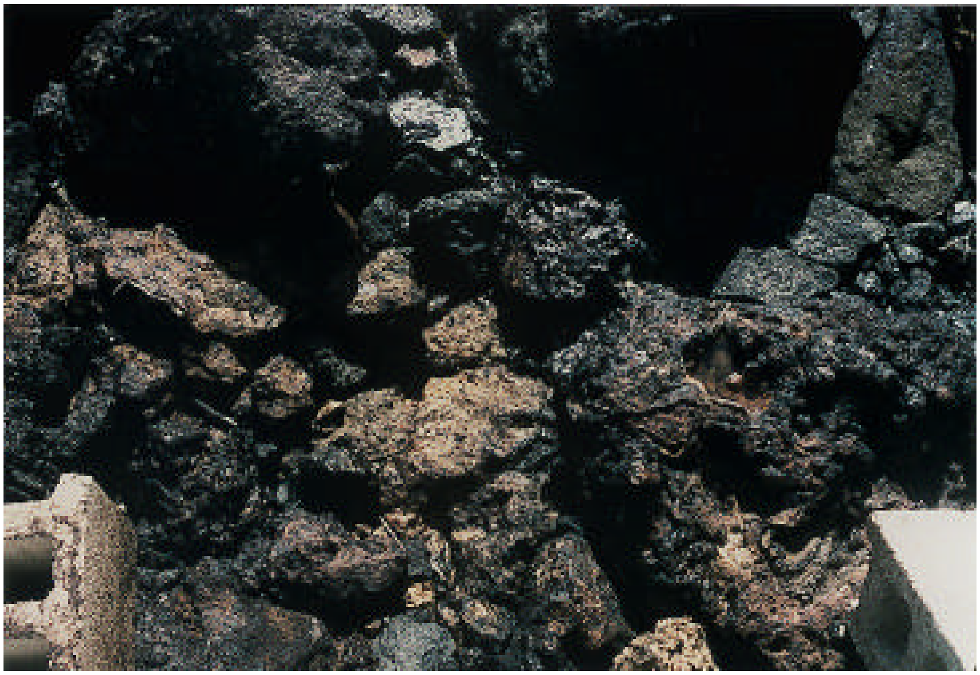


Figure 21D. Plot for the PES-51 cleaner on rip rap with ambient-water-flushing at 1,200 psi.

Based on the field-test results and the toxicity data, the CRRT approved Corexit 9580 for use on natural beachrock, rip rap, seawalls and other structures in selected areas, mainly because of its inherently lower toxicity. The guidance identified specific sites where the chemical could be used and the maximum number of gallons to be used on each site. The operational plan also incorporated health and safety considerations for workers applying the agents.

In practice, most of the hard substrates were cleaned with high-pressure, hot-water washing without chemical application because the water alone was effective. However, Corexit 9580 was used extensively with satisfactory results in Zone 2 from Punta Escambron to the Dos Hermanos Bridge on several hundred yards of beachrock in high-use areas.

Although approved for use on several archaeological sites, where it would allow the use of gentler pressures because of the concern that high pressures would destroy the historic seawalls, Corexit 9580 was used only for a few test applications on historic masonry structures.

OTHER SPECIAL INTEREST ISSUES

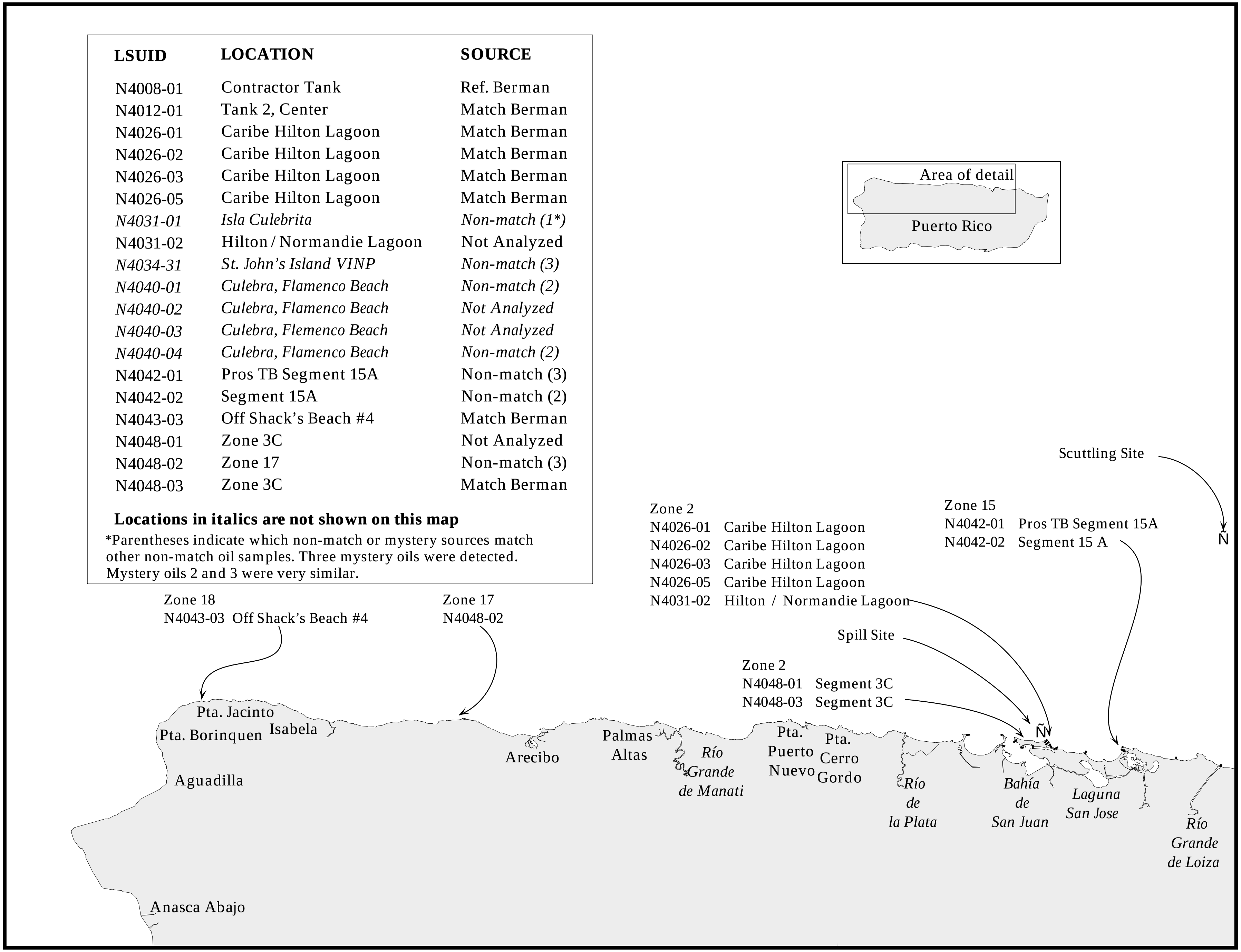
Mystery Spills

During the response, areas throughout the Caribbean east of the spill site were significantly oiled. Reports of oiling were received from all of the islands of the U.S. Virgin Islands, as well as Vieques, Culebra, and shorelines along Puerto Rico's northeastern and eastern coasts. There was initial concern that these incidents were somehow related to the *Berman* spill. This, however, did not correlate with known current and wind patterns in the area.

Eventually, source fingerprinting of samples from these other areas confirmed that oil found east of the Río Grande de Loiza along Puerto Rico's northern coast was from other sources. At least three separate sources of different oil were identified from these mystery spills. All of the impacts east of the Loiza were categorized as "mystery" spills and responded to under a separate Federal project number.

Seventeen oil samples were submitted for analysis during the *Berman* response in addition to two reference oils. Of the thirteen samples analyzed, seven were a positive match to the *Berman* oil. Figure 22 summarizes the results from the source-fingerprinting analyses.

Figure 23 shows a double-index plot of selected source-fingerprinting indexes (SFI) for the "unknown" samples analyzed. The circle represents the target range for the SFIs plotted and was determined from the analysis of two reference oils analyzed a



LSUID	LOCATION	SOURCE
N4008-01	Contractor Tank	Ref. Berman
N4012-01	Tank 2, Center	Match Berman
N4026-01	Caribe Hilton Lagoon	Match Berman
N4026-02	Caribe Hilton Lagoon	Match Berman
N4026-03	Caribe Hilton Lagoon	Match Berman
N4026-05	Caribe Hilton Lagoon	Match Berman
N4031-01	*Isla Culebrita*	*Non-match (1*)*
N4031-02	Hilton / Normandie Lagoon	Not Analyzed
N4034-31	*St. John's Island VINP*	*Non-match (3)*
N4040-01	*Culebra, Flamenco Beach*	*Non-match (2)*
N4040-02	*Culebra, Flamenco Beach*	*Not Analyzed*
N4040-03	*Culebra, Flemenco Beach*	*Not Analyzed*
N4040-04	*Culebra, Flamenco Beach*	*Non-match (2)*
N4042-01	Pros TB Segment 15A	Non-match (3)
N4042-02	Segment 15A	Non-match (2)
N4043-03	Off Shack's Beach #4	Match Berman
N4048-01	Zone 3C	Not Analyzed
N4048-02	Zone 17	Non-match (3)
N4048-03	Zone 3C	Match Berman

Locations in italics are not shown on this map

*Parentheses indicate which non-match or mystery sources match other non-match oil samples. Three mystery oils were detected. Mystery oils 2 and 3 were very similar.

Figure 22. source fingerprinting sample locations.

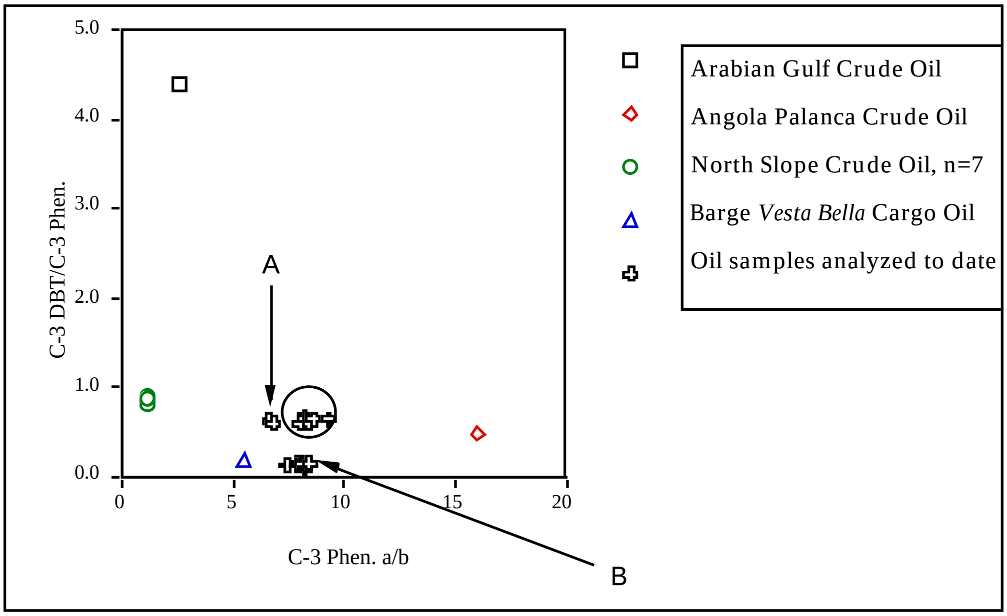


Figure 23. SFI plot of selected crude oils, the reference oil from the Barge *Vesta Bella* and samples analyzed from the *Berman* incident. The circle indicates the target range of SFI values for oils sourced from the *Berman*. Samples indicated by arrows A and B are non-matches to the *Berman* reference oils. The cluster of samples indicated by arrow B may actually represent two “mystery” sources.

total of 12 times. The results indicated by arrow A are for duplicate analyses of the sample submitted from Isla Culebrita. Initially, this sample was reported as a positive match. However, after reevaluation and analysis of a larger data set, this sample scored as a non-match (although there is a strong correlation between the oils, it is not the same oil loaded on the *Berman*). Samples indicated by arrow B represent the non-match samples submitted and identified as St. Johns Island; Culebra, Flamenco Beach; and Segment 15 and Zone 17 (Punta Cerro Gordo to Isabella). The cluster of samples identified by arrow B may actually represent two “mystery” sources.

Since these samples were not collected as part of a systematic survey design, little information could be provided as to the relative contribution of non-*Berman* oil except to say that some of the oil in the areas sampled came from other spills.

Submerged Oil Disposal

Submerged oil was a source of re-oiling along some beaches. It proved to be challenging from the standpoint of location, containment, and recovery and was a more costly effort than cleaning oil stranded on the shoreline. Disposal questions arose with recovery of submerged oil. This was especially true where submerged oil was dredged from the bottom of the two catchment lagoons near the grounding site.

This operation generated large amounts of sand and oily water. With the cooperation of the Commonwealth of Puerto Rico, a workable solution to this problem was implemented. A series of three swimming pools was used to separate the oil from the sand and oily water. Oil was removed from the first pool for reprocessing. The sand was likewise separated in the first pool and taken for biological treatment at a land farm. The oily water was pumped through the other two pools for filtering and decantation before being pumped to sea as clean water. This process allowed for rapid removal of large amounts of submerged oil with no additional adverse effects to the environment.

Vendor Proposal Review Process

During the response to the *Berman* spill, the command post was continuously visited by vendors proposing products or services to assist in the cleanup. At times their proposals were inappropriate to the given requirements of the response. An attempt was made to systematically review and document requests from companies that had products or services to offer for the response and cleanup effort. Vendors were given an opportunity to present their proposals to the FOSC via a review process. The vendor supplied information about his or her service or product, along with pertinent brochures, test results, etc. NOAA, PR DNR, PR EQB, and USCG Strike Team representatives then evaluated the material. If the team recommended the proposal, they forwarded it to the FOSC representative and the operations section chief for final disposition.

A number of bioremediation product representatives solicited review of their materials for potential use as shoreline treatments. Consultation with bioremediation experts in EPA and NOAA indicated little likelihood that attempts to augment natural processes would result in significant benefit. As a result, bioremediation was not considered as a viable technique during the initial response and cleanup stages.

Some products were evaluated in the context of their potential use as decontamination materials or for disposal for oily debris. After initial review, information packets and vendors were referred to appropriate USCG and contractor personnel.

To make the best use of the proposal-review process, the team organized chemical oil-spill treating agents into the following categories:

herding agents
emulsion-treating agents
solidifiers
elasticity modifiers
shoreline cleaning agents
shoreline pre-treatment agents
oxidation enhancing agents
burning agents

A key consideration with respect to product or services screening is that its use must be consistent with specific spill response or removal needs. These needs should be identified so that responders can focus on appropriate measures rather than waste time reviewing inappropriate ones. Many proposed products could not be considered because they were not listed on the National Contingency Plan Product Schedule.

As a result of problems encountered during the *Berman* and other spill responses related to vendor proposals, the following guidelines are presented to make the process more effective:

AVOID

- vendors dealing directly with response personnel
- vendors conducting ad-hoc tests on site
- giving vendors the “run-around”
- experimenting with totally new products

ENCOURAGE

- finding appropriate products to solve identified response needs
- access to information on viable products
- determining spill-specific effectiveness of viable products

LESSONS LEARNED

As a major spill of a Group V oil, the *Morris J. Berman* spill presented a wide range of new challenges to the responders. Many lessons were derived from having to deal with an oil spill that floated and sank. There were many difficulties in tracking, containing, and recovering the oil. However, this spill provided the opportunity to test different methods under difficult field conditions. The operational lessons learned during recovery of submerged oil have been reported in Burns et al. (1995) and Ploen (1995). In this section, lessons learned by the scientific support staff are summarized.

Group V oils can pose special problems related to the instability of the blend and the potential for separation when spilled.

It still is not clear whether the oil that spilled from the barge behaved as a mixture or separated into different fractions. Examination of separate samples of the raw residual oil and the cutterstock used for blending might have offered information on the compatibility of the mixture, its likelihood to separate into individual fractions as it cooled and entered the water, and its potential for sinking. Samples from the barge contents did not separate in laboratory tests, but these samples may not have been representative of the originally released oil.

Tracking spills of Group V oils is very difficult because the slicks break into widely scattered fields of tarballs and pancakes with little associated sheening.

The oil from the *Morris J. Berman* was tracked using three different methods: visual observations (including use of the Laplogger positioning system), remote sensing using the Coast Guard's AIREYE system, and helicopter-based, infrared (IR) imaging (for nighttime observations). All three methods had only limited success once the oil formed widely scattered tarballs moving to the west. The scattered tarball fields and pancakes did not provide a significant enough visual or IR signal to allow for optimum surveillance, making it difficult to spot and identify the oil from the air.

Drift buoys have special limitations.

Satellite-tracked surface drifting buoys were used to better predict the fate of oil that might be released at the barge scuttling site. The real-time data collected from the buoys provided an indication of the speed and direction of the surface current, including a quick indicator of local current reversals and gyres. For areas with simple oceanographic flow conditions, the drifters work well. However, for a spill in an area where surface currents rapidly change spatially and temporally, the transmission rate and subsequent position fix may be too infrequent to define the current pattern.

Use of modern remote sensing technology and equipment requires experience in oil spill surveillance and operationally oriented information management.

Oil spill response personnel must be trained to operate IR sensors and understand tactics for their use during oil spill operations, in addition to the techniques and skills required for aerial observations of oil. Since a reliable technique has not yet been developed to distinguish oil from water using passive IR systems, training must include interpretation of the IR imagery to identify oil slicks while rejecting false positives. Remote-sensing techniques need to be integrated with positioning systems so that the locations of observed oil can be better defined to support oil spill operations. Simple systems for annotating and summarizing the image products and converting the information into easily understood, more useful formats should also be developed. The hand-drawn overflight maps produced with computer software following visual surveillance, or the AIREYE SLAR “snapshot” serve as examples of an easily understood format for conveying this information to the incident command.

Area contingency planning should incorporate appropriate identification, protective strategies, and response methods for cultural and heritage resources.

Protecting and cleaning the heritage resources that were oiled by the spill had not been addressed in the Coastal Area Plan for Puerto Rico and the U.S. Virgin Islands. The FOSC quickly and effectively responded by establishing the Heritage Resources Team, comprised of representatives from the Coast Guard, NOAA, NPS, the State Historical Preservation Office, and local resource trustees. The team successfully worked together on-scene to address all concerns and decisions related to the issues pertaining to heritage resources. The process and many of the issues and concerns could have been addressed in area planning and subsequently dealt with more efficiently during the response.

Potential for public concern over the safety of eating locally caught seafood should be considered.

Six weeks after the spill, fishermen complained about public perception of seafood quality because people would not buy their catch. There was no evidence of tainting and the information provided to the appropriate authorities showed little risk of this happening. Early on in a spill, the possibility of tainting should be considered and, if appropriate, dealt with proactively. Indeed, if it is determined that there is a risk of tainting, the public should be forewarned.

Whenever chemical oil-spill treating agents are being considered, the response organization should establish a data management system to categorize and evaluate promising products.

A key consideration with respect to product or services screening is that its use must be consistent with specific spill response or removal needs. These needs should be identified so that responders can focus on appropriate measures rather than waste time reviewing inappropriate ones. Many products proposed were not eligible for consideration because they were not listed on the National Contingency Plan Product Schedule. Having specific selection criteria helped narrow the list of potential shoreline cleaning agents to the most promising products, which were then tested for site-specific testing. Responders should not deal with totally new, unevaluated products; they want access to information on viable products.

Field-testing of promising products is extremely difficult under emergency response conditions. Field test kits would simplify the process.

Before full-scale use of chemical agents, it is often necessary to evaluate site-specific effectiveness, with the actual weathered oil and substrate to be cleaned, and the toxicity of the products under the proposed application strategy. During this spill, methods of determining effectiveness and effects were very subjective and qualitative. Field test kits would have provided a more quantitative measure of both endpoints. MSRC now funds development of field kits for shoreline cleaning agents.

Using comprehensive information management and documentation during the spill response can enhance decision-making and ensure thorough, successful, post-spill reporting.

The daily activities were thoroughly recorded, both for the NOAA team and the response in general. The documents and record of the activities associated with the fate and effects of the oil; the natural and heritage resource impacts, countermeasures, and mitigation; the shoreline oiling assessments; and the mystery spills, vendor proposals, and submerged oil were carefully managed and documented in several published reports. The FOSC Heritage Resources Report and Natural Resources Report, the Submerged Oil Report, and the NOAA Information Management Report comprehensively document the processes, recommendations, and decision-making that occurred during the response.

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