Operational Science Advisory Team-2 (OSAT-2)

Net Environmental Benefits Analysis (NEBA)

Gary Shigenaka
National Oceanic and Atmospheric Administration (NOAA)

OPERATIONAL SCIENCE ADVISORY TEAM-2 (OSAT-2) SUMMARY REPORT FOR FATE AND EFFECTS OF REMNANT OIL REMAINING IN THE BEACH ENVIRONMENT

Annex M: NET ENVIRONMENTAL BENEFITS ANALYSIS

INTRODUCTION AND BACKGROUND

Net environmental benefits are the gains in services (the sum total of the resources and processes that are inherently supplied by natural ecosystems) or attained by remedial actions, minus the environmental injuries caused by those actions. Net environmental benefit analysis (NEBA) is a methodology for comparing and ranking the pros and cons of different management alternatives. NEBA can be thought of as the evaluation of tradeoffs associated with cleanup or remediation to determine if the remedial action is warranted and sufficient. NEBAs can be conducted for a variety of stressors and management options, including chemical contaminant, hydropower, and global climate change mitigation proposals.

Efroymson et al. (2003) formalized the NEBA approach into a structured framework and noted that NEBA was an extension or elaboration of ecological risk assessment. They identified the key difference between the two processes as the consideration of environmental benefits, which traditional risk assessment does not incorporate. Efroymson et al. summarized the major advantages of NEBA in supporting management decisions:

> NEBA has the potential to help land managers avoid the possibility that the selected remedial or ecological restoration alternative will provide no net benefit over natural attenuation of contaminants and ecological recovery. An alternative may provide no net environmental benefit because: (1) the remedial or ecological restoration action is ineffective (the action does not substantially change the risk) or (2) the remediation alternative causes environmental injuries greater than the damage associated with the contamination because (a) the need for remediation has been driven by human health risk, not ecological risk; (b) the ecological injury from contamination has been overestimated because of conservative assumptions; or (c) injuries associated with remediation were not properly addressed.

The first use of the NEBA process occurred in 1990—and in an oil spill setting—to evaluate whether a mechanized “rock-washing” technique would be used during the *Exxon Valdez* response. The apparatus envisioned was a large, barge-mounted processing plant that removed beach material from the shoreline, transported it to the barge via conveyor belt, cleaned it, and returned it to the beach. From the outset, the rock washer appeared to be a formidable engineering effort, as well as being environmentally intrusive (Tebeau, 1995).

The U.S. Coast Guard (USCG) Federal On-Scene Coordinator (FOSC) requested that the National Oceanic and Atmospheric Administration (NOAA) conduct a detailed

NEBA study to compare the benefits of excavation and rock washing with the benefits of natural cleanup. The NEBA study was completed, but its conclusions became the source of disagreement between Exxon and the State of Alaska. NOAA essentially cast the deciding vote, stating that there was "no net environmental benefit to be gained by shoreline excavation and washing" and that "this technology has the potential of aggravating the injury to the environment caused by the spill." Based on NOAA's recommendation, the FOSC opted to not authorize the project.

The *Exxon Valdez* NEBA approach was a comprehensive and well-documented process for reaching a decision on the appropriateness of a specific technology and on the level of effort required for implementation. However, the approach was time-consuming (it took several weeks), and required collection of substantial quantities of engineering and scientific data. In the *Exxon Valdez* spill, this time was available as the response had evolved into a protracted (multi-year) cleanup effort, and much of the required scientific knowledge had been acquired during the course of the response effort.

Advocating for the application of NEBA to oil spill response, Jenifer Baker (1999) distilled the process into a five-step procedure:

1. Collection of data, characterization of environmental services, and description of cleanup methods;
2. Case studies for cleanup methodology;
3. Forecast of environmental effects/outcomes;
4. Comparison of remediation to natural attenuation;
5. Tradeoff analysis for proposed alternatives and decision.

NOAA’s Shoreline Assessment Manual, frames and describes the approach for assessing oiling (i.e., Shoreline Cleanup Assessment Technique, SCAT) in any coastal habitat. This reference describes the overall philosophy for developing a shoreline cleanup plan:

> Bringing their agency’s expertise, Shoreline Assessment Teams collect the data needed to develop a shoreline cleanup plan that maximizes the recovery of oiled habitats and resources, while minimizing the risk of injury from cleanup efforts. Consideration should always be given to:
>
> - Potential for human exposure, by direct contact or by eating contaminated seafood;
> - Extent and duration of environmental impacts if the oil is not removed;
> - Natural removal rates;
> - Potential for remobilized oil to affect other sensitive resources; and
> - Likelihood of cleanup to cause greater harm than the oil alone.

For the *Deepwater Horizon* OSAT-2 activity, the NEBA evaluation is a multi-agency undertaking to systematically assess the environmental fate and effects of the oil remaining on sand shorelines after cleanup endpoints have been reached, as well as evaluate the tradeoffs associated with cleanup beyond those endpoints. As defined by the OSAT-2 charter, the three types of residual oil to be considered on sand beaches are:

1. Supratidal oil buried below 6-inch surface cleaning depth;
2. Small Surface Residue Balls (SSRBs) on mechanically-cleaned beaches; and
3. Surf zone submerged oil mats

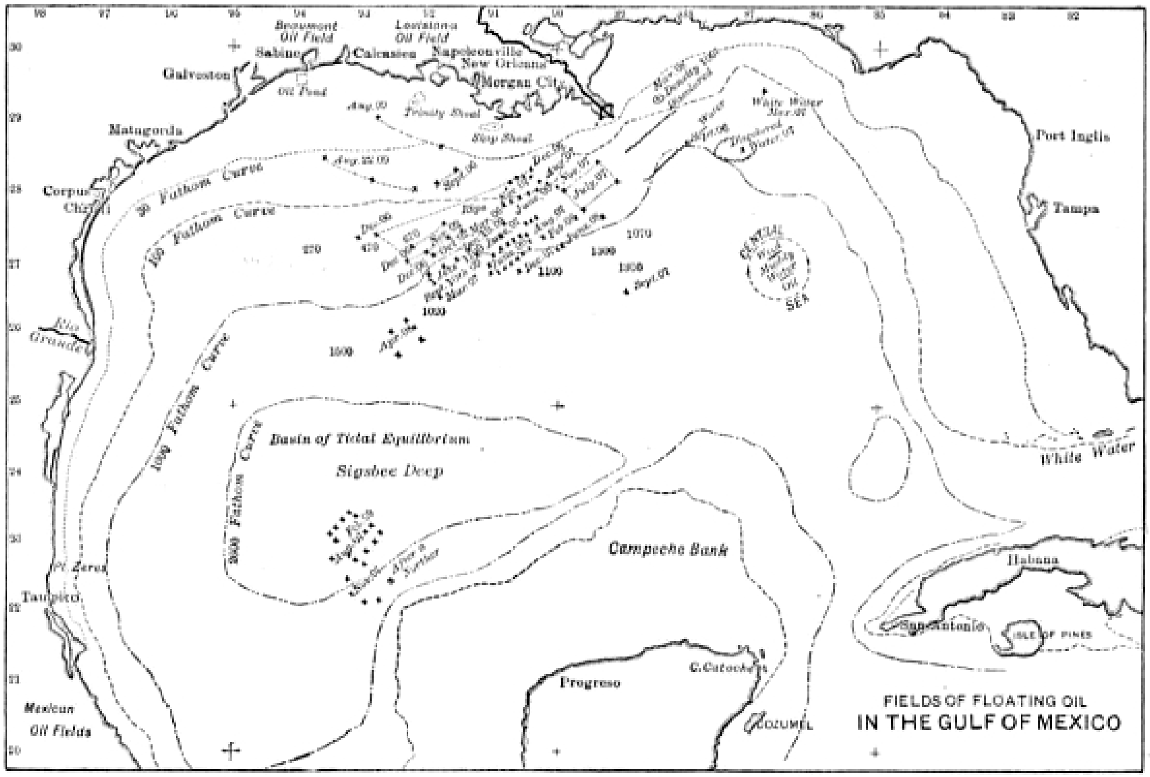
While the time constraints associated with the OSAT-2 review and the *Deepwater Horizon* response do not permit a formal ecological risk assessment or NEBA, we propose to use the approaches and frameworks for both to provide a more detailed tradeoff analysis for the cleanup endpoints. Some empirical information in the form of chemical analyses was generated for this review, but was limited in extent; therefore, much of the toxicity assessment and tradeoff analysis relied on information extrapolated from the literature. The uncertainties associated with the assessments and the constraints they impose on our conclusions are discussed as appropriate.

Ultimately, the question to be answered in the OSAT-2 review: *Does the evaluation of the available information support the defined cleanup guidelines?*

"NATURAL" SOURCES OF OIL IN THE GULF OF MEXICO AND BACKGROUND CONCENTRATIONS

It is well-known that oil is present both under and in the Gulf of Mexico. Figure 1 is a map printed in a 1910 edition of Scientific American (Soley, 1910) showing the "fields of floating oil" in the Gulf of Mexico. The earliest European explorers to the region observed different forms of "bitumen," apparently in substantial quantities on the waters of the Gulf:

> "(Bitumens) have been reported by navigators at different times, at different points and in different forms, but the fields of floating oil have attracted little attention though it is believed that they have always existed. In 1543 the companions of DeSoto, after his death, sailed down the Mississippi and along the coast to the westward and found numerous evidences of the presence of the bitumens. Taking refuge from a storm in a creek, they found a scum cast up by the sea like pitch, with which they payed the bottoms of their vessels. In 1598, a writer says, 'there is found in great quantities upon the coast, east and west of the Meschacebe, especially after high south winds, a sort of stone pitch called by the Spaniards copec; they mix it with grease to make it more liquid and use it as pitch for their vessels.' Acosta, the famous author of a history of the West Indies, affirms it to be generated of an oil which empties itself into the ocean in great quantities. The English sent to discover the Meschacebe found it in two places; the sea was covered with the oil or slime which had a strong smell…" (Soley, 1910).



FIELDS OF FLOATING OIL IN THE GULF OF MEXICO.

Figure 1. Map of floating oil in the Gulf of Mexico, circa 1910 (Soley, 1910).

Of course, what early writers termed "bitumen" would later be called petroleum oil, and became the basis for the subsequent ongoing exploration, production, refining, and transportation activities in the Gulf of Mexico. The so-called “natural” inputs of oil into the Gulf continue, despite the large-scale extraction of reserves; these inputs (Figure 2) are commonly referred to as oil ”seeps.” Collectively, these seeps represent a significant input of oil and gas into the Gulf of Mexico; Tunnell (2010) estimated that 1000 seeps discharge around 400,000 barrels (~17 million gallons) per year.

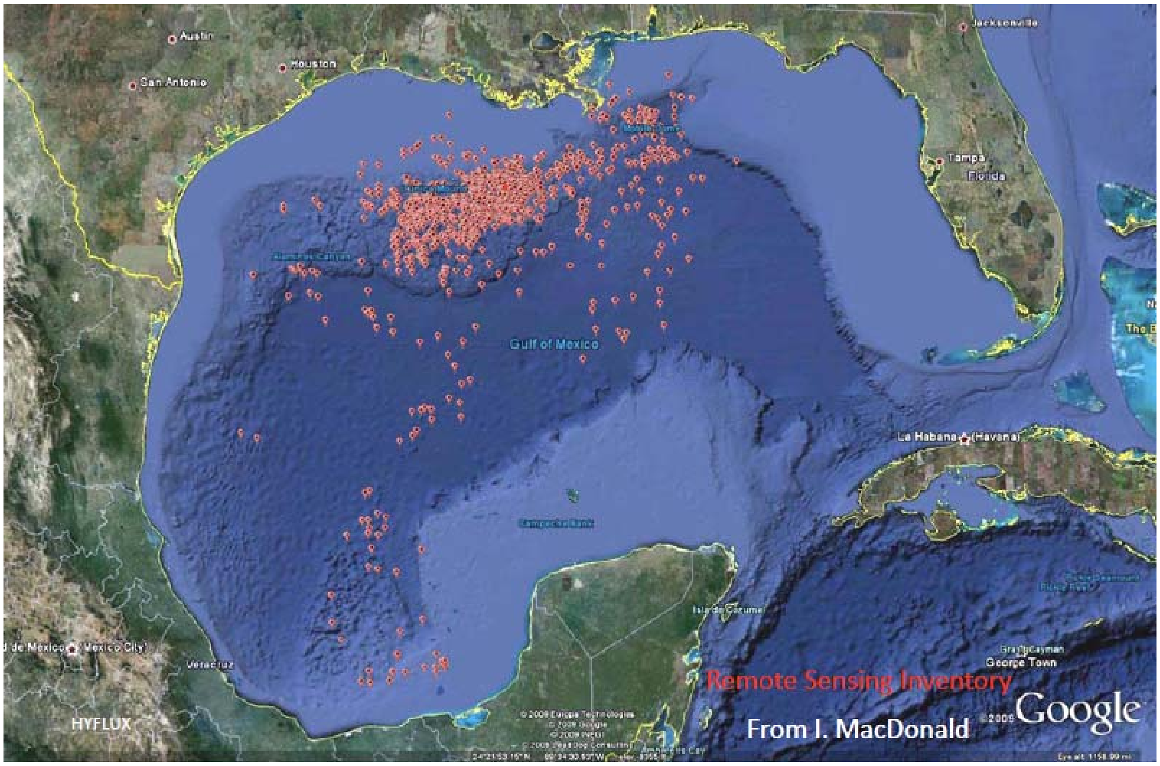


Figure 2. Map of oil seeps documented in the Gulf of Mexico. Information from I. MacDonald, in Tunnell (2010).

At least some of the seeps in the Gulf are sufficiently large to produce surface expressions of sheening on the surface of the water. Under appropriate conditions of sea state, lighting, and cloud cover, these sheens can be observed in satellite imagery (Figure 3).

Figure 3. Satellite imagery showing surface sheens from natural seeps (Tunnell, 2010).

In addition to these "natural" sources of oil discharge into the marine environment, non-spill-related human activities also are an important input. During the 1990 *Mega Borg* oil spill off the western coast of Texas, the occurrence and observation of tar balls and other forms of oil on beaches known to have not yet been impacted caused confusion and concern for both response and damage assessment activities. As a result, Henry et al. (1993) systematically surveyed the coast of Louisiana for tar balls that they subsequently analyzed to determine source. Their results reflect multiple sources, with transportation-related (i.e., tank washings and sludge discharges) accounting for more than 50% of the over 500 tar balls analyzed. Henry et al. also quantified a "background" density of tar balls on the Louisiana beaches they surveyed, ranging from 9.6 – 40 tar balls per 50 meter transect.

For the OSAT-2 analysis, the "take-home" lesson is that the background level of oil on Gulf coast beaches is *not* zero, due to non-spill-related natural and human inputs. As shown by the surveys of Henry et al., the background levels of oil can vary widely even within the shorelines of one state. While we do not have similar surveys for the other states of the Gulf, we could expect a comparable or greater range of variability. The challenge for response and for the OSAT-2 group was to interpret *Deepwater Horizon* oiling within the context of this unrelated background oiling.

OVERVIEW OF SAND BEACHES IN THE GULF OF MEXICO

Sand beaches in Louisiana, Mississippi, Alabama, and Florida are important shorelines that serve as human recreational resources and provide important ecological services. NOAA's response "job aid" for Characteristic Coastal Habitats (NOAA, 2010) describes the salient features of these beaches as follows:

- These beaches are flat to moderately sloping and relatively hard-packed.
- There can be heavy accumulations of wrack.
- They can be important areas for nesting by birds and turtles.
- Upper beach fauna include ghost crabs and amphipods; lower beach fauna can be moderate, but highly variable.

Sand Beach Dynamics: Accretion and Erosion

Sand beaches are highly dynamic environments that respond to and reflect the physical forces to which they are subjected. Or, as oceanographer Willard Bascom observed (1964):

> …beaches owe their existence to wave action…they have a dynamic quality. That is, beach materials are always in motion—as long as there are waves—although this mobility is not readily apparent to the casual observer.
>
> …The motion of the beach material may be parallel to the shoreline, in which case it is transported by alongshore currents, or it may be moved toward or away from the land by wave action. There are two major beach forms created by the waves: berms and bars. Berms are flat, above-water features that make up the familiar part of a beach. Bars are underwater ridges of sand that parallel the shoreline and are seldom seen except at unusually low tides. On most beaches there is a constant exchange of sand between these two features, the direction of transport depending on the character of the waves. When the waves are large and follow close upon each other as they do under storm conditions, the berm is eroded and the bar builds up. When calm conditions return, the small waves rebuild the berm at the expense of the bar.

The physical drivers affect the shape of the beach in three dimensions: its width, length, and orientation as viewed from above; and its profile, or cross-sectional anatomy/topography. As Bascom noted, the beach profile changes seasonally (due to the change in wave energy experienced during summer and winter months), but also over much shorter time frames (responding to tides, currents, storm events, and human actions such as beach "renourishment" or grooming). Bascom further observed:

> A beach responds with great sensitivity to the forces that act upon it—waves, currents, winds. It is a deposit of material in transit, either alongshore or off- and onshore. The important thought in the definition is that of motion, for beaches are ever-changing, restless armies of sand particles, always on the move. Most sand movement occurs under water, the result of waves and wave-caused currents that organize the particles into familiar forms. But the motion of a beach before the waves, even when huge quantities of sand shift in a single day, may not be noticed by a casual observer. The short-term changes are usually imperceptible.

The beach profile is higher during the summer due to lower wave energy during summer compared to other seasons. The lower energy waves deposit sediment onto the beach, adding to the beach profile. Conversely, the beach profile is lower in the winter due to the increased wave energy associated with storms and the associated mobilization of sediments. Higher energy waves erode sediment from the beach berm and dune, and deposit it offshore, forming bars. The removal of sediment from the beach berm and dune decreases the height of the beach profile relative to the water level.

The shape of a beach depends on whether or not the waves are constructive or destructive (i.e., accretive or erosional). Constructive waves move material up the beach while destructive waves move the material down the beach. On sand beaches, the backwash of the waves removes material forming a gently sloping beach. Cusps and horns form where incoming waves divide, depositing sand as horns and scouring out sand to form cusps. This action forms the uneven face on some sand shorelines.

The shorelines of the Gulf of Mexico are especially dynamic, and, many fear, at risk. In Louisiana alone, nearly 5,000 km^2 of coastal land is estimated to have been lost between 1932 and 2000, and more than 550 km^2 became submerged during Hurricanes Katrina and Rita alone in 2005 (U.S. Geological Survey [USGS] National Wetlands Research Center, 2006). While most of this loss was coastal wetlands, the barrier islands along the northern Gulf between Louisiana and Florida are also disappearing, with the principal causes of land loss identified by Morton (2008) as frequent intense storms, a relative rise in sea level, and a sediment-budget deficit. This net loss of shoreline, primarily in the form of sand beaches, becomes a factor in discussions about any remedial actions that might accelerate the rate of loss.

It is against this backdrop of ongoing disappearance of shorelines that short-term beach changes are observed in the spill-affected region. Even within time frames measured in days and weeks, shifts in vertical profiles driven by waves and currents can be documented on the beaches of the Gulf coast. Figures 4 and 5, which are based on data provided by the *Deepwater Horizon* Shoreline Cleanup Assessment Technique (SCAT) teams, show the changes in beach profiles between the summer and late fall months of 2010.

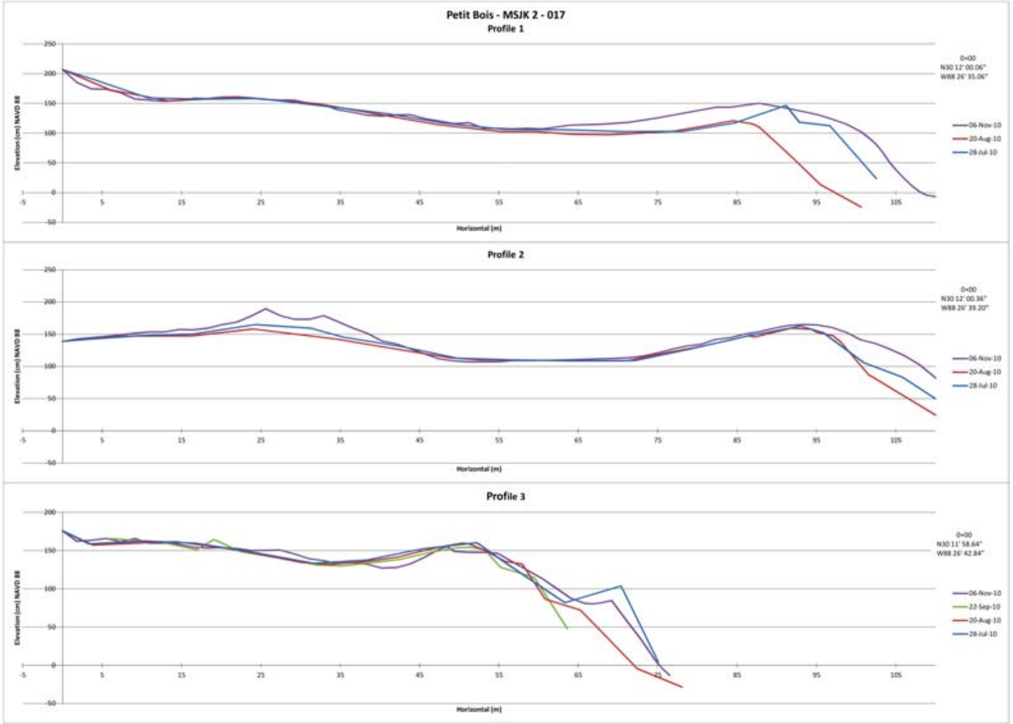
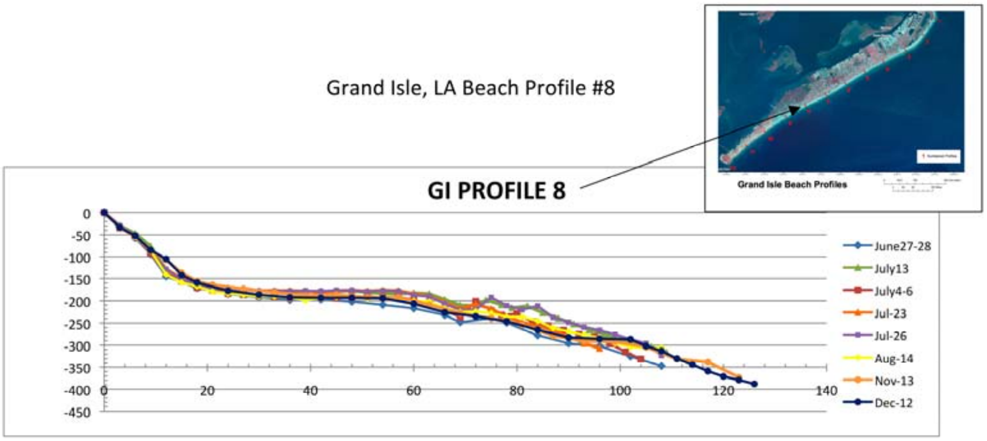


Figure 4. Beach profiles from Petit Bois, Mississippi, between July and November 2010.



Beach profile #8 from June 27 to Dec 12, 2010

Between June 27 and July 26, 2010 profile 8 shows horizontal variation of 20+m and a vertical elevation change of 50+cm

Figure 5. Examples of sand beach profiles compiled during the *Deepwater Horizon* response at a SCAT transect in Grand Isle, Louisiana.

Behavior of Oil on Sand Beaches

The fact that sand beaches constantly change, both horizontally and vertically, presents challenges for spill assessment and response. In particular, net accretion or erosion on a given beach can quickly mask or reveal oil that had previously stranded, adding an element of urgency to both survey and removal activities.

NOAA (2010) summarized the predicted oil behavior on sand beaches as follows:

- Light oil accumulations will be deposited as oily swashes or bands along the upper intertidal zone.
- Heavy oil accumulations will cover the entire beach surface; oil will be lifted off the lower beach with the rising tide.
- Maximum penetration of oil into fine- to medium-grained sand is about 10-15 cm, up to 25 cm in coarse-grained sand.
- Burial of oiled layers by clean sand can be rapid (within one day), and burial to depths as much as one meter is possible if the oil comes ashore at the beginning of a depositional period.
- Organisms living in the beach sediment may be killed by smothering or lethal oil concentrations in the interstitial water.
- Biological impacts include temporary declines in infauna (organisms living in the interstitial spaces of the beach), which can affect important shorebird foraging areas.

Oiling conditions resulting from the accretion or erosion of sand on Gulf coast beaches are readily illustrated by shoreline oil during the *Deepwater Horizon* response effort. Figures 6 and 7below show two forms of residual oil (buried by accretion and recently exposed by winds) found on the same beach in Bon Secour National Wildlife Refuge, Alabama in January 2011.

Figure 6. SCAT Team auger hole in the beach at Bon Secour National Wildlife Refuge, 8 January 2011. Buried oil layer circled in red.

Figure 7. Recently uncovered (by northerly winds) surface residue balls on the beach at Bon Secour National Wildlife Refuge, Alabama, 8 January 2011.

Cleanup of Oil on Sand Beaches

Viewed narrowly, cleanup of oil on sand beaches is relatively straightforward and logistically simple. In many (but not all) locations, sand beaches are accessible to cleanup crews and equipment. Most (but not all) beaches are capable of supporting crews and equipment. Oiled substrate is generally (but not always) conceptually and practically simple to remove. NOAA's response "job aid" (2010) summarizes response considerations as follows:

- Sand beaches are among the easiest shoreline types to clean.
- Cleanup should concentrate on removing oil and oily debris from the upper swash zone once most of the oil has come ashore.

- Manual cleanup, rather than road graders and front-end loaders, is advised to minimize volume of sand removed from the shore and requiring disposal.
- Efforts should focus on preventing vehicular and foot traffic from mixing oil deeper into the sediments.
- Mechanical reworking of lightly oiled sediments from the high-tide line to the middle intertidal zone can be effective along exposed beaches.

However—as indicated by the qualifiers in the paragraph above, the narrow view is not necessarily a true or realistic view. Constraints imposed by the varied nature of the beaches in the operational areas of the Gulf result in a much more complex matrix of cleanup options and approaches. It is useful, however, to begin the cleanup discussion at the broad guidance in the NOAA Shoreline Assessment Manual (2000). That document identifies generic cleanup issues and endpoints for sand beaches:

- High public use on beaches usually requires a quick cleanup and high degree of cleanliness.
- The sand beach cycle is short, so reworked and relocated sediments often can be rapidly returned to their normal distribution on exposed beaches. Wave action can be an effective final “polishing” process, removing stain from sediments.
- Oil on the surface of sand beaches is relatively easy to clean; however, difficulties arise when the oil is buried because of the amount of sediment that must be removed.
- If sand can be replaced by existing nourishment projects, more sediment removal is generally allowed where oil must be quickly removed from public beaches.

Cleanup endpoints for sand beaches are also suggested in the Shoreline Assessment Manual:

> Cleanup can be terminated when no visible oil remains on the surface, except for scattered tarballs or swash lines of minute tarballs that may occur as the sand is reworked by the waves. All tarballs or tar patties that can be removed by reasonable cleanup techniques, or that can be remobilized, should be removed. Remaining tarballs and tar patties should be at or below normal background frequency. Increases in tarball frequency above background will require further cleanup. Cleanup can be terminated when no oil layers are found in trenches dug into the beach. Buried tarballs should be at or below background frequency.

However, the old saying, “The devil is in the details,” is applicable here. What, exactly, do terms like “scattered tarballs,” minute tarballs,” “reasonable cleanup techniques,” and “normal background levels” mean when formulating guidance to field assessment teams and/or cleanup crews? For clarity and consistency in approaches and results, it is important to define/quantify these terms.

For *Deepwater Horizon*, “Stage III” is the phase of the response identified by SCAT for baseline re-surveys, new Shoreline Treatment Recommendations, post-treatment inspections, Monitoring and Maintenance, re-evaluation SCAT surveys, and transition out of the SCAT program to long-term Monitoring and Maintenance. The Stage III guidance produced in the Mobile operational area focuses on the particulars of sand beaches in the Mississippi-Alabama-Florida operational area, taking into account stakeholder concerns, land ownership, specific resources, and historical/archeological issues:

- Heavy accumulations of wrack (e.g., *Sargassum*, seagrass blades, *Spartina* stems), and other organic debris, which are collectively critical components of sand beach ecosystems, can be found on sand beaches.
- Areas that have been mechanically sifted are often light and fluffy and no longer considered hard-packed.
- They are used by birds and turtles for feeding and nesting throughout the affected area and by endangered small mammals in Alabama. Specific Best Management Practices for listed species and migratory shorebirds will be identified during the Section 7 review of site-specific STRs.
- Upper beach fauna include ghost crabs and amphipods; lower beach fauna may be highly variable, but can include coquina clams (*Donax*), mole crabs, amphipods, polychaetes, etc. on high-energy beaches, and a much wider variety of species on lower energy beaches.
- Occasionally historic shipwrecks, normally wood hulled with iron and/or brass spikes, are found on the beaches; some are covered quickly by sands and exposed as sands shift during storm events. Some are occasionally buried in dunes. In many cases, portions of wrecks are visible on the surface, but there are occasions where an entire vessel may be buried by sand.
- Other kinds of historic properties that may be present on sand shoreline include prehistoric and historic sites that may be located on nearby terraces that have eroded onto the beach surface below an exposed/eroding bank. While not in situ, these resources are indicative of the presence of nearby historic properties.
- Most of the barrier islands of Mississippi, Louisiana, and Florida have a high rate of retreat in a generally westward direction in association with long shore currents, therefore, the oil that is buried may be exposed within a few months. This could assist natural recovery in some cases, or it could reintroduce oil to the system in other cases.
- Mechanical activities relating to moving and scraping sand on barrier islands of Mississippi, Louisiana and Florida are of great concern as they could potentially affect sediment transport and retention.

On amenity beaches that are not subject to other environmental management constraints, a phased approach for cleanup of oiling conditions other than oil mats was devised and implemented for the Stage III guidelines, and often relied on specialized equipment (see Figures 8 and 9), as noted below (excerpted from the Grand Isle, Louisiana Shoreline Treatment Recommendations form):

1. Mechanical mobile cleaners first remove oiled debris and surface oiled sand. This mechanical removal may be conducted as night operations. The oiled sand is stored at designated sites within the "hot zone" for onsite treatment using either the Ml SWACO Sand Treatment System (MSSTS) in accordance with the Ml SWACO Equipment Operating Manual dated 9 July 2010 or sand sifting machines. (The MSSTS on Grand Isle was decommissioned as of 3 November).
2. Where SCAT teams locate thin layers of buried oil residue (0.5-1.0 inch thick), use tilling to the depth of oiling to expose the oiled sediment. Deep tilling plows will go down to 18 inches in designated areas (see attached map). Install sand fencing in tilling areas to reduce wind-transport of tilled sand.
3. Mobile beach cleaners remove the oiled sediments for onsite treatment at the MSSTS or sand sifters.
4. Manual clean up crews walk the previously cleaned area and manually remove any patties, oiled debris, or oiled sand that the mobile beach cleaners missed. This includes removal of all oiled non-natural or man-made debris. No foot traffic or equipment in marsh or dune areas; do not disturb any vegetation. Unoiled wrack should not be disturbed unless it is blocking access to contaminated sediments. In this occasion the wrack can be moved to the closest tidally influenced area. Manual cleanup crews should be comprised of no more than 4

small teams that work closely together (team members within 1/2mile of each other) to minimize potential disturbance to wildlife.

5. The sand removal strategy is to work from the east and west ends of the island towards the central area, where the MSSTS is located.
6. Oiled sand is processed by the MSSTS. Sand treated by the MSSTS must be cleaned to LDEQ RECAP standards. The treated sand is replaced on the beach at designated locations between zones 4 and 10 as directed by the SCAT Ops Field Liaison.

Figure 8. Example of mechanical equipment used on sand beaches: Sand Shark 3000.

Figure 9. M1 SWACO Sand Treatment System (MSSTS) deployed at Grand Isle, Louisiana. Photo: from Associated Press.

Variations on mechanical approaches to sand beach cleanup have been employed in different locations along the Gulf coast. Figures 10 and 11 show equipment deployed for "Operation Deep Clean" along the Alabama shoreline for heavily trafficked amenity shorelines. This approach excavates large volumes of sand, transports it to industrial sifters, then transports the screened material back to the source beach where it is graded by heavy equipment back into the general beach profile.

These large-scale mechanical methods can be contrasted to a manual pickup-only approach designated for a sand beach area in a National Wildlife Reserve (Figures 12 and 13). Although certain vehicles and mechanized equipment are permitted onto the upper portion of the beach, these are restricted to those supporting survey teams and the cleanup crews; all oil removal is performed with hand tools under the oversight of Federal landowner resource experts.

Figure 10. “Operation Deep Clean” excavation activity near Gulf Shores, Alabama, 8 January 2011.

Figure 11. PowerScreen bulk sieving operation in Gulf Shores, Alabama, 8 January 2011.

Figure 12. Manual cleanup of buried oil at Bon Secour National Wildlife Reserve, Alabama, 8 January 2011. Workers are unearthing a buried lens of oil for removal by hand-sieving.

Figure 13. Manual cleanup of buried oil at Bon Secour National Wildlife Reserve, Alabama, 8 January 2011, showing the hand-sieving of oiled sand to remove oiled material.

Integrated into shoreline cleanup is the delineation of "cleanup endpoints", the criteria for transitioning active cleanup to a post-response phase. As is the case for most oil spills, shoreline cleanup endpoints for the *Deepwater Horizon* spill vary widely and depend on the uses of the beaches, indigenous resources, presence or absence of cultural and historic resources, landowner and stakeholder concerns, ease of access, and a host of other considerations. Because of the threat of re-oiling, the term "cleanup endpoints" was replaced by the terminology of 2010 No Further Treatment (NFT) guidelines, to indicate when shoreline cleanup operations could be halted under the existing Shoreline Treatment Recommendations. For the sand beaches being evaluated for OSAT-2, the continuum of 2010 NFT guidelines is defined at one end by high recreational use sand beaches located in popular tourist destinations, where aesthetically clean white sand is a high priority; and at the other end, by National Parks/National Seashores where minimizing disturbance and maximizing conservation are critically important.

Operationally, the desire in so-called amenity beach areas to have aesthetically pleasing white sand beaches available for the enjoyment of residents and tourists suggests a need for rapid, high-volume oil removal techniques probably relying on mechanical equipment. For sensitive areas with ecological or cultural importance, low-impact methods dependent on manual labor to remove gross oiling are likely to be relied upon. Between these two ends of the continuum, exists a gradient of cleanup endpoints and—as shown in the figures above—acceptable cleanup methods.

This continuum itself, and the noticeable differences between cleanup approaches in adjacent regions on the Gulf coast, reflect the incorporation of the equivalent of site-specific NEBA-type tradeoff analyses—in that the important societal values for a given beach were identified (e.g., aesthetic, bathing and swimming value, cultural/archeological sensitivity, ecological importance, presence of endangered species, etc.); paths to minimizing oil impacts, and potential for cleanup damage, were weighed; and decisions concerning acceptable cleanup methods and "how clean is clean?" were translated into endpoints.

The incorporation and institutionalizing of NEBA-like concerns into spill response procedures has with time, become more explicit. For example, the October 2010 Mobile Area Stage III guidance (Yender, 2010) opens with words that sound very much like a description of NEBA, and in fact allude to the inclusion of the process:

> "…This document has been written with a single objective in mind:
> *Stage III Shoreline Treatment is to ensure shorelines are treated to the degree required to address stakeholder concerns over natural and cultural resources as well as recreational and economic uses…*
>
> …The following issues were considered to meet the objective:
> - Treatment should not cause more damage than the oil itself
> - Site Specific Oiling conditions

- Stakeholders/constituents issues of concern relative to oiling conditions and potential treatment options
- Treatment techniques and options readily available (or under close development), including operating parameters and limitations
- Clarity, recognition and acceptance of what can be achieved before treatment actions become unsafe, impractical, give no significant benefit or could start to cause further damage to a shoreline habitat/resource (the ***Net Environmental Benefit Analysis - NEBA - balance***)" (emphasis added)

Applying the evaluative framework described above, the decision-makers formulated guidelines for treatment of surface and subsurface oil and suggested endpoints for No Further Treatment (NFT). Although references to oiling above background levels remain for residential and amenity beaches, these shorelines are regularly and routinely subjected to mechanical cleaning and grooming for aesthetic reasons (NFT guidelines for both the Louisiana, and the eastern states [Mississippi, Alabama, and Florida] operational areas are presented in the discussion to follow on effects of shoreline cleanup).

The general philosophy for shoreline cleanup, as articulated in Michel and Benggio (1999), is:

> The goal of shoreline cleanup is to take actions that will reduce to minimum the time needed for an impacted segment to recover. Recovery is a difficult term to define, but can be generally thought of as the ecological and physical state of the shoreline had the spill not occurred. This is not the same as the pre-spill condition.
> Shorelines are in a constant state of change, so that even areas unaffected by a spill will change during the period of the response. Cleanup should be implemented when it will speed natural recovery of impacted resources; otherwise, natural recovery is generally preferred.

SAND BEACH OILING TYPES CONSIDERED BY OSAT-2

Supratidal oil buried below 6-inch surface cleaning depth

As discussed previously, the physical dynamics of sand beaches pose a constant risk of stranded oil being buried by subsequent beach accretion events driven by the forcing mechanisms of the nearshore environment. Figure 6 shows an oil layer at a depth of about 45 cm; results of the SCAT surveys in the four-State Gulf coast region show that oil layers can be found deeper than a meter below the surface of sand beaches.

Assessment of buried oil has its obvious challenges, compared to surveys of surface oil. The standard SCAT approach for sand beaches is to manually dig trenches or pits to determine if buried lenses of oil exist, and if they do, to then determine areal extent. Given the length of shoreline potentially impacted by the *Deepwater Horizon* spill, the SCAT teams working on sand beaches augmented their excavation capabilities by adding mechanical augering equipment. This permitted rapid and consistent assessment for buried oil across much more beach area than would have been possible with manual trenching only.

A cursory examination of aggregate SCAT data available at the time of this writing indicated that for a total of over 13,000 auger holes or trenches dug during the surveys, more than 4700, or 35%, revealed buried oil at trace amounts or heavier. While this is not a number that can be extrapolated beyond what it is—a gross indication of what field teams observed during the course of systematic shoreline surveys—it does indicate that the problem of buried oil was and is not trivial.

Small Surface Residue Balls (SSRBs) on mechanically cleaned beaches

Tarballs are weathered pieces of oil that represent the final stages in the weathering of oil that enters the sea from accidental spills, vessel operations, illicit discharges, or, in the Gulf of Mexico and other regions, natural oil seeps. In the *Deepwater Horizon* response, the weathered pieces of oil washing up onto Gulf coast beaches are termed “surface residue balls” (SRBs) to reflect the consistency of the oil (i.e., not tar-like). In the OSAT-2 analysis, small surface residue balls, SSRBs, are defined as SRBs less than the smallest mesh size employed in the mechanical beach sieving process for *Deepwater Horizon*-impacted sand beaches.

A series of physical and biological weathering processes begins to alter crude oil as soon as it is released to the water from a spill or natural seep. Typically, during its first few hours on the water surface, spilled oil spreads out to form a thin slick. During the *Deepwater Horizon* oil spill, some of the oil mixed with water to form a pudding-like, reddish emulsion (“mousse”). Winds and waves tore large slicks and patches of mousse into successively smaller patches that were distributed across the water by winds and currents.

Weathering of spilled oil and physical action of wind and waves result in the formation of tarballs/SRBs potentially encountered on a beach or floating in the water. SRBs typically range in size from tiny pellets up to a few inches across, but some are much larger and are described as patties and mats. In the *Deepwater Horizon* spill, large nearshore subtidal oil mats can be found in many operational areas and these are suspected to be supplying SRBs to the adjacent beaches.

The consistency of *Deepwater Horizon* SRBs varies with ambient temperatures, degree of weathering, and sand content, and qualitatively range from soft, sticky, and aromatic, to hard and relatively inert. Comparatively "fresher" SRBs (see Figure 14) are typically found in the intertidal or swash zone and are believed to have been recently detached from nearshore tidal oil mats; while the more weathered pieces (see Figure 7, above) are found higher on the beach, in the supratidal zone.

Density of SRBs can vary widely, depending on a host of factors including, among others, extent of original oiling, proximity to submerged oil mats, physical drivers influencing beach structure, and the effectiveness of cleanup. The SCAT teams routinely estimate SRB density, or surface cover, during surveys; for some beaches, less than 1% cover of tarballs or SRBs has been used as a cleanup endpoint. This threshold seems like an intuitively small amount of cover, but its appearance on the beach runs counter to intuition. That is, 1% cover appears, to the uncalibrated eye, to be much more. Figures 15 and 16 are two photographs of beach oiling (SRBs) on *Deepwater Horizon* sand beaches. Both of these photographs show surface oiling estimated by SCAT teams to be approximately 1%, and actual cover as determined by image analysis supports these estimates.

Figure 7, which appears earlier in this chapter in the Oil Behavior discussion, shows surface SRB cover on the sand beach of the Bon Secour National Wildlife Refuge in January 2011. This SRB surface cover was determined through image analysis to be 4.2%.

Figure 14. Relatively “fresh” SRB recovered from the intertidal zone of Bon Secour National Wildlife Reserve, Alabama, 8 January 2011.

Figure 15. SCAT team photo of SRB cover on beach, estimated by SCAT personnel to be approximately 1%; image analysis determination of actual cover was 1.5%.

Figure 16. SCAT team photo of SRB cover on beach, estimated by SCAT personnel to be approximately 1%; image analysis determination of actual cover was 0.6%.

Surf zone subtidal oil mats

Oil mats in the lower intertidal and shallow subtidal zones adjacent to sand beaches have been identified across the spill-impacted area. The mats were likely formed when floating surface slicks or shoreline accumulations of relatively fresh oil were remobilized in the surf zone and mixed with suspended sand to the point that they became denser than seawater and sank to the bottom. In some locations, deposition of sand may have resulted in the burial of these mats. Heavy accumulations of SRBs and patties may erode off these mats periodically and become deposited higher on the beach. These higher concentrations of SRBs and patties can be used to help identify the general locations of mats in the lower intertidal and shallow subtidal zones. With nearshore turbulence dislodging smaller pieces that are subsequently tossed onto the beach, the mats potentially represent a long-term source for shoreline oiling unless removed. Figures 17 and 18 shows a large (1 m X 3 m) subtidal mat in the shallow nearshore zone.

Figure 17. Subtidal oil mat off Orange Beach, Alabama, 20 June 2010.

Figure 18. Subtidal oil mat off Orange Beach, Alabama, 20 June 2010. Object in photo is boat oar.

The location of many of these mats—in very shallow water, in the surf zone—and the fact that they can be quickly coated or covered with sand and become difficult to discern, even in clear water, makes the assessment of their occurrence difficult. Therefore, determination of where the mats are located is a major challenge in dealing with them. Off the coast of Louisiana, nearshore water visibility is so poor that visual reconnaissance either from the air or through "snorkel SCAT" surveys (Figure 19) are virtually useless; other potential remote sensing techniques such as sonar are not possible in the rough and shallow water of the surf zone. The *Deepwater Horizon* response is investigating other assessment methods relying on the appearance of beach SRBs as indicators of nearby offshore mats, and Vibracore surveys to pinpoint locations.

Figure 19. "Snorkel SCAT" team member working along the coast of Alabama.

In those areas where mats can be located through good visibility or low water conditions, recovery can be relatively straightforward through manual or mechanical means. Teams can work in the lower intertidal and shallow subtidal zones (subject to safety constraints) to pick up the oil by hand or by using hand tools. When beach access permits the use of heavy equipment, an excavator with a modified bucket or a "marsh buggy" platform (Figure 20) can be used to remove oil mats. However, not all equipment is appropriate or permitted to be used on all shorelines; beaches under the jurisdiction of the U.S. Department of the Interior (National Parks, National Seashores, National Wildlife Refuges), state parks, areas determined to be critical habitat or essential fish habitat, and locations restricted by Section 7 or Section 106 constraints, may not allow the use of mechanized gear.

Figure 20. "Marsh buggy" amphibious vehicle removing oil mat, Bayou Chaland, Louisiana, 27 January 2011.

With this potential as a long-term reservoir for surface oiling, the cleanup goal for oil mats identified in the lower intertidal and shallow subtidal zones is their removal as a source that generates surface oil residue balls on the adjacent beach at concentrations in excess of background oiling conditions.

Manual and mechanical methods for oil mat removal have been approved for use during *Deepwater Horizon*. Mechanical means, relying on heavy equipment, are used for removal of large accessible mats. Manual methods (rakes, shovels, hands) are employed where the concentrations are too thin or too laterally restricted to be effectively recovered using mechanical means. Whether manual or mechanical methods of removal are used, explicit and detailed guidelines are prepared for each site to accommodate site-specific characteristics and constraints.

An example of a No Further Treatment (NFT) endpoint is that for Grand Isle, Louisiana: no visible oil and oiled debris above background levels. As noted earlier, the term "no oil above background" can be subject to multiple interpretations, but in this case, background for SRBs was defined as fewer than 50 5-cm diameter SRBs per 100 meters of shoreline (which is equivalent to fewer than 50 2-inch diameter SRBs per 110 yards). The NFT endpoint will be subject to further review as background oiling levels are more thoroughly evaluated by SCAT teams and the State/Federal trustees. This specific NFT definition applies to SRBs only and not to the oil-stained sands that can and do co-occur on the same beaches.

FATE OF RESIDUAL OIL REPRESENTED BY *DEEPWATER HORIZON* SAND BEACH CLEANUP GUIDELINES

A considerable amount of discussion has focused on the definition and derivation of the No Further Treatment (NFT) endpoints for sand beaches, both for the existing 2010 NFT guidelines and the development of 2011 NFT guidelines. As indicated, development of these guidelines have been tantamount to NEBA-like evaluations among response and stakeholder agencies until consensus is reached about the endpoints to be applied. The adoption of Stage III 2010 NFT endpoints has already occurred in both Louisiana and the eastern States; discussion on 2011 NFT guidelines began in January 2011. Consensus is formalized by the signoff by appointed representatives of the involved parties and basically constitutes the end product of tradeoff analysis between the surmised effects of the residual oil portrayed as the given endpoint, and the assumed impacts of cleanup to a higher standard. That is, the signatory parties have agreed that the environmental benefits of continued cleanup are not justified by the anticipated effect of the presence of the oil and potential adverse effects of the cleanup itself—in other words, prolonging or increasing cleanup will do more harm than good.

The concept of leaving any residual oil in the environment following an oil spill can be difficult to recommend, especially to a spill-weary and wary public; but two important points need to be communicated.

1. The pre-spill environmental background concentration of oil, especially in the Gulf of Mexico, is not zero. Tarballs and even oil mats have been a part of the beach habitat for at least hundreds, and likely, thousands of years, as illustrated by the early accounts of "natural" oiling conditions in the Gulf discussed earlier in this chapter.
2. Cleanup actions have their own environmental consequences beyond the primary objectives of removing spilled oil from the environment. As discussed in the following section, cleanup activity is not completely benign and, like the military actions with which the term is most often associated, can cause "collateral damage" or result in unanticipated consequences.

Recalling that an estimated 17 million gallons of "natural," or seep-derived oil, enter the Gulf of Mexico each year (Tunnell, 2010), some capacity of the regional physical and biological system must exist to accommodate the influence of this input. The chemical fate section of the OSAT-2 analysis discusses the suite of physical and biological influences that change the morphology and the chemistry of oil released into the environment, ultimately transforming it from an acutely toxic mixture to a less harmful and more inert material. A major part of this weathering equation appears to be biological — a well-adapted and well-evolved community of oil-degrading bacteria that have been credited with consuming/changing a substantial volume of the oil discharged from the MC252 wellhead between April and July of 2010 (Hazen et al., 2010). While the pelagic interaction of bacteria and oil obviously represents a different sort of situation than shoreline oiling, the deep-water evidence affirms the presence of vigorous oil-degrading communities in the Gulf of Mexico and establishes the potential for those or similar degraders to be a factor on the beaches as well.

Preliminary information from biodegradation researchers studying the influence of microbial communities on sand beaches suggests that while the presence of oil-degraders is confirmed, conditions are variably favorable for robust biodegradation (M. Boufadel, Temple University; J. Pardue, Louisiana State University; M. Huettel, Florida State University; oral communication with G. Eckert of National Park Service, January 2011). Moisture may be one of the more limiting factors for biodegradation of surface residues of oil; the physical structure of SRBs, with a weathered and sand-covered coating isolating fresher oil on the interior (see Figure 21) from physical and biological degradation, may be another.

Figure 21. SRB found on Bon Secour National Wildlife Reserve beach, Alabama, 8 January 2011. SRB has been broken open to expose its interior.

Based on other longer-term studies of oil fate in the environment, we expect residual (i.e., post-gross oil removal) concentrations of spilled oil to weather toward less toxic and more inert forms. A general rule-of-thumb for oil spill cleanup is that reducing the net concentration of oil and increasing its exposed surface area help to promote weathering processes that ultimately reduce the adverse effects of the spilled oil. In general, remedial response methods employed for spills represent some mix of these two considerations, removing residual oil from the environment and/or promoting weathering by increasing exposure and surface area. Ultimately, the end products of environmental weathering can be anticipated to be carbon dioxide and water (for aromatic hydrocarbon constituents), or relatively inert mineralized materials comprised of asphaltenes and beach material (Shigenaka et al., 1998).

The forms of oil represented by NFT endpoints are intermediate to the anticipated final products of weathering and degradation. The environmental risk associated with these weathered, but incompletely degraded, forms of oil is discussed in the risk assessment section of the OSAT-2 analysis.

POTENTIAL IMPACTS OF CLEANUP BEYOND EXISTING NFT GUIDELINES

The objective of the OSAT-2 Net Environmental Benefits Analysis is to compare the environmental consequences of the defined cleanup endpoints for the oil and beach types considered, and the consequences of cleanup beyond those endpoints. It is at this juncture that the concept of continued remedial efforts doing "more harm than good" becomes a concern.

Etkin (1999) summarized the concerns about oil spill cleanup beyond rational endpoints:

> In some cases, public and government pressure for the responsible party to undertake radical—and expensive—cleanup procedures may not always be in the best interest of environmental protection, even if it is well-intentioned. In these cases, public pressure for the spiller to "do something" to quickly restore the environment may be motivated more by aesthetics than by true environmental concerns. While a beach might look clean after aggressive cleanup efforts, the procedures employed may actually result in more environmental damage than the spilled oil itself.

It is this balance, and this tension, that underlie determination and implementation of cleanup endpoints. How this balance is achieved and the tension is managed is the art involved with the science.

The real and potential impacts of aggressive cleanup activity have been noted since the early days of oil spill response. For example, during the 1967 *Torrey Canyon* spill on the English coast, the use of highly toxic petroleum-based shoreline cleaning agents caused widespread acute toxicity to intertidal invertebrates on the rocky shore and impeded recovery of algal communities (Southward and Southward, 1978). Seneca and Broome (1982) described long-term damage to marsh habitat impacted by both oil and cleanup during the *Amoco Cadiz* spill in France. Baker (1999) used the *Amoco Cadiz* example to illustrate both the quandary as well as the potential operational compromise presented by heavy oiling and cleanup in a highly sensitive habitat:

> Analyses of case histories show that in extreme cases natural recovery times may be 20 years or more on heavily oiled, sheltered shores. On the other hand, aggressive clean-up of Brittany marshes after the *Amoco Cadiz* spill resulted in a prolonged recovery time of 20 + years. What would happen if it were necessary to deal with a new case of very thick oil deposits on a salt marsh? Because neither natural cleanup nor aggressive treatment provides the best environmental benefit, it seems that the greatest benefit would result from a moderate level of clean-up—sufficient to remove most of the bulk oil, but gentle enough to leave the surface of the shore intact and to avoid churning oil into underlying sediments. This can be achieved by using small crews and avoiding the use of heavy machinery as far as possible. The appearance of the shore after such treatment is likely to be somewhat oily and therefore not optimal from an aesthetic viewpoint, but there are numerous examples of biological recovery taking place in the presence of weathered oil remnants.

NOAA misgivings about the use of high-pressure hot-water washing of shorelines in Prince William Sound following the *Exxon Valdez* spill in 1989 led to a 10-year long-term monitoring program to assess cleanup impacts. The study determined that relative to oil alone, greater short-term biological damage was incurred through the use of the technique and sites treated in this way took 2 years longer than oiled-only sites to attain recovery endpoints (Skalski et al., 2001).

A review by Pezeshki et al. (2000) focused on the effects of oil versus the impacts of cleanup on U.S. Gulf coast marsh macrophytes. Their comparison showed that oil, including South Louisiana crude oils that could be expected to resemble the oil from the *Deepwater Horizon* spill, conferred a range of impacts on the dominant marsh plants of the Gulf coast. The reported effects ranged from little to none, to acute mortality. Similarly, the benefits of cleanup activities were recognized, particularly for large spills and spill volumes; but that also:

> …activities associated with physical clean-up (such as marsh buggy traffic and human foot traffic) may actually drive oil into the sediment or destroy the plant root and below-ground network, thereby causing plant mortality and delayed (if not permanently failed) recovery.

In addition to the physical effects of cleanup (e.g., habitat disruption), the very fact that cleanup is taking place and that there is a greater than normal human presence in sensitive habitats can impact use of those habitats by animals. Hill et al. (1997), Rodgers and Smith (1995), and others, discuss the negative implications of human disturbance on bird populations, with impacts including egg and nestling mortality, nest evacuation, reduced nestling body mass and slower growth, premature fledging, and behavioral effects. Beale and Monaghan (2004) even suggested that human disturbance is tantamount to “predation-free predation” on disturbed wildlife.

Quantitative assessment of oil spill cleanup worker impacts, from the perspective of disturbance to sensitive resources, is rare in the literature; most accounts are anecdotal. However, Burger (1997) studied the disruption of normal shorebird foraging activities by oil spill cleanup personnel and vehicles, compared to that caused by casual walkers and joggers, and determined a significantly higher level of disturbance (50% versus 5%). Burger inferred potentially severe implications from disrupted foraging for time-constrained migratory birds, ranging from mortality to reduced reproductive fitness once arctic breeding areas were reached.

As mentioned earlier in this chapter, the process for defining shoreline cleanup endpoints considers the potential impacts of observed oiling versus the estimated potential impacts from cleanup activities. The endpoint determination process is a consensus-based negotiation among participating agencies and stakeholders, and in effect is a net environmental benefits analysis nested in the operational response framework.

The habitat-specific endpoints for the Gulf coast are derived from the following general guidelines:

- No oiled accessible debris
- No surface oil on hard substrates (e.g., seawalls, pilings, riprap) greater than Stain (visible oil but cannot be scraped off with a fingernail) or Coat (less than 1/16 inch) at > 20% distribution in the oiled band; in high public use or visibility areas, the endpoint is no greater than Coat at 10% distribution in the oiled band
- Does not rub off on contact
- In areas with data on background rates of tar ball deposition, no tar balls greater than background for two survey periods;
- In areas without data on background rates of tar ball deposition, no tar balls > 1cm in size and at a frequency less than 1 to 5 per 100 meters depending on degree of use or sensitivity
- No oil sheens (excludes biological sheens) that affect sensitive resources

The final 2010 NFT sand beach endpoints for the Louisiana coast operational area are summarized in Table 1, and for the eastern (Mississippi, Alabama, Florida) operational area in Table 2.

Table 1. 2010 NFT Guidelines for Louisiana Sand Shorelines

Oiling Group	Cleanup Methods Recommended	Surface Oil	Subsurface Oil
Heavily Oiled Residential Beaches (e.g. Grand Isle and 100 yards on either side of the public access point on Elmers Island)	Mechanical removal Manual removal Grooming Sediment tilling/mixing Sediment relocation Sand treatment (M-I SWACO)	No visible oil above background levels	No visible oil above background levels
Heavily Oiled Non-Residential Beaches (e.g., Fourchon Beach, Elmers Island, Grand Terre, East Grand Terre)	Mechanical (fine-scale) [With approval by the State] Manual removal Grooming Sediment tilling/mixing Sand treatment (M-I SWACO) Natural recovery	< 1% visible surface oil and oiled debris	No subsurface oil exceeding 1-3 cm in thickness and patchy (10-50% distribution) that is greater than Oil Residue
Other Oiled Non-Residential Beaches (Mix of Heavy, Moderate, Light Oiling) (e.g., West Timbalier, East Timbalier)	Manual removal Natural recovery	< 1% distribution of oil and oiled debris	No subsurface oil exceeding 5 cm and patchy (10-50% distribution) of oiling that is greater than Oil Residue
Other Oiled Beaches in Special Management Areas (State and Federal wildlife refuges, parks, wilderness areas, with a mix of oiling conditions)	Manual removal Natural recovery	< 1% surface oil and oiled debris	No attempt to remove subsurface oil

Table 2. 2010 NFT Guidelines for Mississippi, Alabama, and Florida Sand Shorelines

Oiling Group	Cleanup Methods Recommended	Surface Oil	Subsurface Oil
Oiled Residential/Amenity Beaches (e.g. Dauphin Island, Gulf Shores, Orange Beach, Pensacola)	Mechanical (sifting) Manual removal Tilling or Sediment relocation	No visible oil above background levels	No visible oil above background levels
Oiled Non-Residential Beaches (e.g., West Dauphin, Eglin Air Force Base)	Mechanical (grooming - sifting) Manual removal Sediment tilling/mixing Natural recovery	< 1% visible surface oil and oiled debris; and no SRBs>5cm (2 inches)	No subsurface oil exceeding 1-3 cm in thickness and patchy (10-50%) distribution that is greater than Oil Residue
Other Oiled Beaches in Special Management Areas (State and Federal wildlife refuges, parks, wilderness areas, which may also have a mix of oiling conditions)	Mechanical (grooming - sifting) Manual removal Sediment relocation Natural recovery	< 1% surface oil and oiled debris; no SRBs>2.5cm (1 inch)	Subject to direction of Special Area Managers: No subsurface oil exceeding 3 cm in thickness and more than patchy (10-50%) distribution that is greater than Oil Residue

For both operational areas, the 2010 NFT guidelines for intertidal oil mats is:

> Removal of the thick surface oil to a thin layer that no longer generates soil/sediment balls in excess of <1% distribution on the adjacent beach over a consecutive 3-day period.

The challenges and the difficulties of the cleanup of residual environmental contamination, particularly the final trace amounts, are recognized and have been incorporated into the determination of "how clean is clean?" Crauder et al. (2010) compared the decreasing cleanup yield and increasing cost and effort with decreasing concentration to an exponential decay function:

> It may be relatively inexpensive to dispose properly of large amounts of materials at a waste cleanup site, but further cleanup may be much more expensive. That is, as we begin the cleanup process, the amount of objectionable material remaining to be dealt with may be a decreasing exponential function. Since certain toxic substances are dangerous even in minute quantities, it can be very expensive to reduce them to safe levels. Once again, it is the nature of exponential decay, not the exact formula, that contributes to the astronomical expense of environmental cleanup.

The process to determine 2010 No Further Treatment (NFT) guidelines has already occurred for the spill-affected Gulf. However, resource agencies now must determine 2011 NFT guidelines. There is little controversy for NFT guidelines for coastal marshes and mangroves, and for man-made structures; therefore, the more difficult decisions are those for sand beach 2011 NFT guidelines. In comparing the risk from residual oiling represented by NFT guidelines against the potential for additional environmental harm from a continued level of shoreline cleanup, it is necessary to forecast—or speculate—about what that continued, further level of cleanup might involve. For example, the Stage III guidelines for the eastern Gulf States identify an NFT endpoint of less than 1% oil and debris cover on some sand beaches. What if a more stringent guideline, perhaps 0.5 or 0.25%, were imposed? How would this be achieved operationally? Ultimately, what additional impact, if any, would result from implementation of a stricter definition of "background?"

Table 3 summarizes some of the critical dates that factor into cleanup decisions for sand beaches in 2011 and general descriptions of potential cleanup impacts. Informal discussions with SCAT personnel suggest that adoption of a lower background definition would not necessarily invoke new cleanup approaches or technologies, but much more likely, would involve a more rigorous and continued application of existing approaches. In other words, the same methods would be used, but applied more frequently or for longer periods of time; or in the case of mechanical sieving methods on sand beaches, perhaps made more selective by decreasing mesh size to capture more SRBs.

The tradeoffs to presumably successfully attain the lower surface cover NFT guideline endpoint would be a longer presence, and greater commensurate impact, of both equipment and personnel on the beaches. Reducing the mesh sieve size for sieving operations would certainly reduce the throughput of oiled sand being processed. It would be possible with some relatively simple empirical tests on shorelines undergoing treatment to quantify these impacts, by providing rough estimates of additional time/effort necessary to clean to a higher standard, and the environmental consequences of that continued treatment inferred for at least some resources (e.g., the sanderlings and semi-palmated plovers studied by Burger, 1997).

Over the longer term, the cumulative effects of more operational time spent on each beach would translate into an unquantified increase in impact from continued habitat disruption. The increased time spent per unit oiled area would also mean a decreased ability to meet deadlines for removal of oil and equipment from beaches imposed by human uses (e.g., tourist seasons) and by resource considerations such as decreased foraging and nesting use.

It is theoretically possible to quantify cleanup impacts by designing a study to monitor parameters of interest or concern on beaches receiving different levels of treatment, and comparing these to reference (untreated) beaches. Lessons learned from long-term monitoring efforts such as those sponsored by NOAA in the shoreline habitats impacted by *Exxon Valdez* suggest that rigorous study design is necessary to adequately characterize and account for natural variability in biological communities and the physical habitat. One practical consideration for implementing a study of this type to support spill response decision-making is that monitoring to quantify potentially subtle site differences can be both expensive as well as long-term; timely guidance for real-time spill response is not realistic, at least when using more traditional monitoring measurements and endpoints.

Table 3. Matrix of sand beach types with designated cleanup methods and potential cleanup impacts.

Table 3. Sand Shoreline Cleanup Impacts			
Oiling Group	Cleanup Methods Recommended	Critical Dates	Cleanup Impacts
Oiled Residential/Amenity Beaches	Mechanical (sifting) Manual removal Tilling or Sediment relocation	High traffic holidays and tourist seasons (March 1)	Presence of equipment and crews on beach Habitat disruption Fuel use Waste generation
Oiled Non-Residential Beaches	Mechanical (grooming-sifting) Manual removal Sediment tilling/mixing Natural recovery	High traffic holidays and tourist seasons (March 1) Bird nesting (March 1) Turtle nesting (May 1)	Presence of equipment and crews on beach Habitat disruption Fuel use Waste generation
Other Oiled Beaches in Special Management Areas (State and Federal wildlife refuges, parks, wilderness areas)	Mechanical (grooming -sifting) Manual removal Sediment relocation Natural recovery	Bird nesting (March 1) Turtle nesting (May 1)	Sensitive resource disturbance Habitat disruption Physical disturbance of surface layers

As noted previously, biodegradation may play a role in the longer-term fate of oil remaining on the shoreline after the major oil deposits have been reduced in size and effect. In areas where continued but restricted intervention to enhance oil degradation may be desirable or required and actual pickup of remaining oil SRBs or buried oil is not recommended (e.g., National Park Service-administered National Seashores or USFWS-managed wildlife refuges), it may be possible to supply moisture through pumps and/or sprinklers and add nutrients as necessary to speed biodegradation by indigenous biological communities. While this would present logistical challenges for minimizing environmental impacts of delivery systems and personnel, it may also provide a relatively lower impact way to accelerate residual oil reduction over natural rates. Consideration of this and any further remediation beyond NFT would require a focused tradeoff analysis—a further round of NEBA—to articulate environmental costs and benefits involved with increasing degradation rates by presumably a marginal amount over background.

Comparisons between the *Exxon Valdez* and *Deepwater Horizon* oil spills have been inevitable, and while it is notable that pockets of relatively less-weathered oil remain in the beaches of Prince William Sound (Figure 23) nearly 22 years after it was released, the determinants and drivers of oil behavior and persistence are strikingly different between these two situations. Specifically:

- The spilled oils themselves were different, the *Exxon Valdez* being a heavy North

Slope crude and the *Deepwater Horizon* a light sweet Louisiana crude;

- Ambient temperatures on the shorelines are substantially different, which affects rates of physical and biological degradation;
- The nature of the beaches is different, with Prince William Sound beaches composed of either cobble-pebble or boulder-cobble that is quite porous and penetrable by liquid oil, whereas the Gulf sand beaches generally consist of well-packed fine-grained sand.

Figure 23. Photo of liquid oil from *Exxon Valdez* remaining in beaches of Smith Island, Prince William Sound, Alaska, 26 August 2010, 21.5 years post-spill. Photo by David Janka, R/V *Auklet*.

With the possible exception of marshes in Louisiana, none of the oiled shorelines in the Gulf of Mexico approach the character or degree of oiling currently found in Prince William Sound, and it is an objective of the SCAT-STR process established for the *Deepwater Horizon* to ensure that such situations do not occur.

TRADEOFF ANALYSIS/NEBA

Results of the risk assessment for OSAT-2 indicate that overall environmental risks of the NFT endpoints for the three forms of residual oil (oil mats, SSRBs, buried oil layers) are, with a few exceptions, low. This is not unexpected, since the NFT guidelines were originally determined through a NEBA-like consensus process among stakeholders and responders.

A key consideration in the overall assessment of contaminant risk is route of exposure. That is, for a given chemical of concern, how are resources of concern exposed—if they can be exposed at all? Exposure models can be relatively complex. The CalTOX human health effects model for multimedia hazardous waste sites (McKone, 1993) includes 23 separate routes of exposure, but these can be grouped more broadly under the three categories of dermal contact, ingestion, and inhalation. Similarly, general routes of exposure for oil spill resources at risk include surface contact, ingestion, and inhalation/respiration. The nature of oil behavior in the environment and the behavior of the resources of concern determine the routes of exposure in a given spill scenario. For example, the fact that oil usually floats and that many seabirds spend large amounts of time at the surface of the seawater means that dermal (feather) contact of birds with oil is a major concern and a high probability of occurrence.

Based on the physical forms of the three oil types being considered, potential routes of exposure to resources of concern on Gulf coast sand beaches include the following:

- Lower intertidal and subtidal oil mats—dissolved or water-accommodated oil constituents “bleeding” into nearshore waters; surface contact with motile vertebrates and invertebrates.
- SSRBs—dissolved or water-accommodated oil constituents “bleeding” into nearshore waters from remobilized SSRBs; potential ingestion by mammals and birds; surface contact with motile vertebrates and invertebrates; surface contact with eggs and young of nesting birds.
- Subsurface buried oil layers—surface contact with motile vertebrates and invertebrates; surface contact with eggs and young of nesting sea turtles.

The NFT guidelines have defined a level of residual oiling that represents a balance between the projected impact of oil in the environment and the potential impact of continued cleanup activities. A basic assumption of this tradeoff analysis is that both—residual oil and continued cleanup—are not without risks and impact. That is, the *environmental risks from both oil and cleanup are never zero*. Moreover, the Gulf coast beaches being considered for OSAT-2 have a historical background level of oiling from both “natural” (seep) and human (transportation and other spills) sources. In other words: *the pre-Deepwater Horizon background level of beach oiling was not zero*.

A great deal of effort has been invested into the OSAT-2 analysis, and much of this has focused on evaluating the toxicity of the three forms of residual oil to resources of concern. For the purposes of portraying the components and summarizing the overall risk of NFT guideline oiling in the NEBA, a matrix (Table 4) has been created to provide four descriptive assessments (inherent oil toxicity, oil spatial distribution, exposure likelihood, and summed effects assessment) for different resource classes of concern. Incorporated separately in the same matrix is a descriptive assessment of further cleanup impact from remedial action necessary to reach a higher standard. Comparison of the scores for anticipated effect of residual oil and the score for anticipated effects of continued cleanup constitutes the heart of the Net Environmental Benefits Analysis and the formalization of tradeoff analysis for the sand beach oiling situations.

The NEBA process incorporates a significant element of "best professional judgment" to help extrapolate available data and information to the specifics of a given spill scenario. For OSAT-2, a diverse and experienced group of scientists, risk assessment practitioners, and responders were brought together to focus a diverse, relevant, and highly capable set of skills to perform the tradeoff analysis. These experts were asked to evaluate what is known about occurrence, exposure, and toxicity of the *Deepwater Horizon* oil on sand beaches and then to assign one of four "grades" (possible, POSS; low, LOW; medium, MED; and high, HIGH) to each of the cells of the NEBA matrix. Although these qualitative grades are simple in concept, they belie the underlying complex synthesis of a large amount of technical information to arrive at each entry or score.

The NEBA necessarily compares two different types of environmental impacts, toxicological and physical/disturbance, and so presents some conceptual hurdles of comparing "apples and oranges." However, the characteristics of impacts are related back to a common environment—the sand beach communities—and this provides a common denominator for the analysis. Ultimately, we are comparing impact and recovery to the habitat of and resources using sand beaches, which is a common metric and endpoint for the qualitatively different analyses.

The reader is referred to the specific resource annexes to understand how the matrix scores were derived. As the NEBA matrix (Table 4), illustrates, the OSAT-2 group of experts judged the relative environmental risk associated with the NFT residual oiling guidelines to be low; although some higher risk grades were assigned to specific resource exposure scenarios (discussed below).

The matrix breaks out components of resource risk into three categories and provides a fourth that is an overall sum or product of the other three. "Inherent Oil Toxicity" is a description of what we know about the direct toxicity of the particular form of oil to the organism of concern. "Oil Spatial Distribution" is a more global geographic analysis of the occurrence of oil in the habitat used by the organism; in other words, how widespread is the problem represented by particular form of oil on sand beaches? "Exposure Likelihood" is an assessment of the probability that an organism of concern can be exposed to a particular form of oil. “Summed Effects Assessment” is the estimated total risk to the organism, taking into account the other three considerations.

Potential impacts associated with additional cleanup activity on sand beaches to reach a more rigorous cleanup standard are graded as being generally higher impact relative to the residual oiling effects. Two assumptions drive this result:

- With the gross oiling removal mostly completed for the beaches being considered for OSAT-2, we are entering the period of diminishing returns per unit of cleanup effort—or the “tail” of the exponential decay function describing beach cleanup. An increasing amount of effort would be required to remove a decreasing amount of oil.
- With the turn of the seasons from winter to spring, we are approaching the periods of highest human and resource beach use. Warmer weather, vacation seasons, and feeding and nesting seasons represent potential conflicts with continued large-scale beach cleanup.

The summary columns of information in the NEBA matrix are color-coded to facilitate comparison. The NEBA risk categories range from green (POSS, or very low risk), to red (HIGH, high risk). Situations where exposure was judged to be not possible are shown as gray (N/A, not applicable). Even a cursory examination of the matrix shows that for most groups of organisms, the risk of residual oil at the NFT guidelines, is judged to be possible or low. The only combinations graded at a higher level of risk (LOW-MED or MED) are the possible exposure to sea turtle eggs and hatchlings, and the potential ingestion exposure of probing shorebirds to SSRBs.

Comparison of these results to the adjacent column summarizing risk from continued or augmented cleanup work on the beaches of concern in most cases reflects a higher risk level from the remedial activities. This is especially evident for birds, for which published literature has shown significant adverse impacts from shoreline cleanup activity, with substantial implications for the health of affected shorebirds. Sea turtles are portrayed as having a large range of cleanup risk, from low to high. This varied range is attributable to their seasonal (May-November) use of Gulf coast sand beaches for nesting. “Warmer” colors (yellow and red) shown in the cleanup impact column for beach mice reflect their endangered status, limited habitat range, and potential direct and indirect effects of cleanup activity on the integrity of the habitat.

As previously mentioned in this chapter, Burger (1997) demonstrated how the presence of spill cleanup workers and equipment adversely affected behavior of resident shorebirds relative to low-volume human activities. However, even those “normal” human beach activities used by Burger as a baseline may disturb important species. For example, Lafferty (2001) found that unrestricted typical beach uses caused 16 x greater disturbance to western snowy plovers than levels determined on protected beaches. This would suggest that nearly any reduction in human traffic on beaches constituting habitat for sensitive species would reduce external stress for those organisms. The challenge for NEBA in a case like this is to determine at what point the adverse impacts of the cleanup activities themselves and the indirect effects of the presence of the cleanup activities are more severe than the remnant oiling on the beaches. For shorebirds, the tradeoffs are clearer because more information exists for the effects of human disturbance, and oil cleanup in particular; less information is available for other resources.

The NEBA matrix, therefore, engenders a variable amount of uncertainty into its entries that is dependent on the amount and direct applicability of the information that was available. The OSAT-2 risk assessments and NEBA analysis reviewed previous research, interpreted new data generated for this effort, and where necessary, extrapolated results to the extent determined to be reasonable and relevant by the scientists assigned to the team.

There are a few resource examples in the NEBA matrix where overall risk from remnant oil was judged to be about equivalent to that for potential continued cleanup activities (e.g., submerged oil mat contact risk to aquatic invertebrates, fish, and adult sea turtles). Considered in isolation, it might be argued that this “tie” justified (or did not rule out) continued cleanup. However—this would ignore the reality that it is not feasible to isolate components of a habitat, an ecosystem, and of shoreline cleanup. Specifically: while the primary means for submerged oil mat removal might be vehicles or vessels operating from the water-side of the shoreline (Figure 20 illustrates one strategy), there will always be a beachside support aspect that could contribute to the higher levels of cleanup impact anticipated in the matrix for other resources like birds.

The general question to be answered in the OSAT-2 review is: Does the evaluation of the available information support the existing and proposed cleanup guidelines for sand beaches? The OSAT-2 technical analysis indicates that *the defined NFT guidelines are supported and that in most cases, treatment beyond those guidelines is likely to cause more environmental harm than the continued presence of the three oil types on the sand beaches*. Moreover, provisions for longer term monitoring of conditions should provide assurance to affected communities that exceedances beyond cleanup endpoints caused by storm events, seasonal shifts, or other changes will be appropriately addressed in the future. These provisions, called Monitoring and Maintenance, are briefly described in the following section.

Table 4. OSAT-2 NEBA matrix, summarizing results of resource risk assessments and evaluation of cleanup impacts beyond NFT guidelines.

NEBA MATRIX

ROUTE OF EXPOSURE	RESOURCE AT RISK				
	Aquatic Invertebrates & Fish				
	Inherent Oil Toxicity	**Oil Spatial Distribution**	**Exposure Likelihood**	**Summed Effects Assessment**	**Further Cleanup Impact**
Supratidal Buried Oil contact (adult)	LOW	LOW	N/A	N/A	LOW
Submerged Oil Mat aquatic contact	MED	LOW	LOW	LOW	LOW
SSRB ingestion (adult)	MED	MED	N/A	N/A	LOW
SSRB contact (young)	MED	MED	LOW	LOW	LOW
Supratidal Buried Oil contact (eggs/young)	MED	LOW	N/A	N/A	LOW
	Sea Turtles				
	Inherent Oil Toxicity	**Oil Spatial Distribution**	**Exposure Likelihood**	**Summed Effects Assessment**	**Further Cleanup Impact**
Supratidal Buried Oil contact (adult)	MED	LOW	LOW	LOW	LOW - HIGH
Submerged Oil Mat aquatic contact	MED	LOW	LOW	LOW	LOW
SSRB ingestion (adult)	HIGH	MED	N/A	N/A	LOW - HIGH
SSRB contact (young)	LOW	MED	LOW	LOW	LOW - HIGH
Supratidal Buried Oil contact (eggs/young)	MED	LOW	LOW	LOW - MED	LOW - HIGH
	Birds				
	Inherent Oil Toxicity	**Oil Spatial Distribution**	**Exposure Likelihood**	**Summed Effects Assessment**	**Further Cleanup Impact**
Supratidal Buried Oil contact (adult)	MED	LOW	POSS	POSS	HIGH
Submerged Oil Mat aquatic contact	MED	LOW	POSS	POSS	HIGH
SSRB ingestion (adult, surface foraging)	MED	MED	LOW	LOW	HIGH
SSRB ingestion (adult, subsurface probing)	MED	MED	MED	MED	HIGH
SSRB contact (young)	MED	LOW	POSS	POSS	HIGH
Supratidal Buried Oil contact (eggs/young)	MED	LOW	POSS	POSS	HIGH
	Mammals (Beach Mouse)				
	Inherent Oil Toxicity	**Oil Spatial Distribution**	**Exposure Likelihood**	**Summed Effects Assessment**	**Further Cleanup Impact**
Supratidal Buried Oil contact (adult)	MED	LOW	LOW	POSS	HIGH
Submerged Oil Mat aquatic contact	MED	LOW	LOW	POSS	LOW
SSRB ingestion (adult)	MED	MED	LOW	POSS	MED
SSRB contact (young)	MED	MED	LOW	POSS	MED
Supratidal Buried Oil contact (eggs/young)	MED	LOW	LOW	POSS	HIGH

MONITORING AND MAINTENANCE

“Monitoring and Maintenance” represents the *Deepwater Horizon* response strategy to transition from detailed active cleanup to a proactive approach to detect and respond to any new or episodic re-oiling that may occur. This is an important component of the long-term commitment of the response to address shoreline oiling; that is, the end of formal cleanup is not equivalent to inaction when oiling beyond NFT endpoints is encountered in the future. The objectives of Monitoring and Maintenance are to:

1. Routinely monitor shorelines for oiling conditions to document whether the No Oil Observed (NOO) above background threshold (pre-incident conditions) has been met; or if episodic oiling continues and Gulf Coast Oil Recovery Team (GCRT) deployment for oil cleanup maintenance is required.
2. Continue to conduct regularly scheduled monitoring and oil cleanup maintenance in areas of recurrent oiling per their Shoreline Treatment Recommendation-Maintenance (STR-M) or Shoreline Treatment Recommendation-Maintenance (Special Conditions) (STR-M (SC)).
3. Systematically document shoreline conditions that represent a range of substrate types and oiling conditions and represent a range of geographic areas to track the rates of natural recovery and to identify any changes in oiling conditions that may require deployment of GCRT for oil cleanup maintenance.

Key elements of monitoring include:

1. SCAT trained personnel will monitor selected shoreline sites to systematically document natural processes through visual / photo-monitoring and shoreline profile site surveys.
2. Operational monitoring…in conjunction with level of effort as described or outlined in an STR-M or STR-M (SC).
3. Government Landowner/Land Manager based monitoring utilizing routine shoreline monitoring programs already established at local levels.

REFERENCES

Baker, J.M.. 1999. Ecological effectiveness of oil spill countermeasures: How clean is clean? *Pure Appl. Chem.* 71(1):135-151.

Bascom, W.. 1964. Waves and Beaches: The Dynamics of the Ocean Surface. Garden City, NY: Anchor Books, Doubleday & Company, Inc., 267 pp..

Beale, C.M. and P. Monaghan. 2004. Human disturbance: people as predation-free predators? Journal of Applied Ecology 41:335-343.

Burger, J.. 1997. Effects of oiling on feeding behavior of sanderlings and semipalmated plovers in New Jersey. The Condor 99:290-298.

Crauder , B., B. Evans, and A. Noell. 2010. Chapter 4, Exponential Functions. In Modeling and Change: A Modeling Approach to College Algebra. Boston: Houghton Mifflin Co., 309-396.

Efroymson, R.A., J.P. Nicolette, and G.W. Suter. 2003. A framework for Net Environmental Benefit Analysis for remediation or restoration of petroleum-contaminated sites. Report ORNL/TM-2003/17 prepared for U.S. Department of Energy, National Petroleum Technology Office. 37 pp..

Etkin, D.S.. 1999. Estimating cleanup costs for oil spills. In Proceedings of the 1999 International Oil Spill Conference, Seattle, WA, 10 pp..

Hazen, T.C., E.A. Dubinsky, T.Z. DeSantis, G.L. Andersen, Y.M. Piceno, N. Singh, J.K. Jansson, A. Probst, S.E. Borglin, J.L. Fortney, W.T. Stringfellow, M. Bill, M.E. Conrad, L.M. Tom, K.L. Chavarria, T.R. Alusi, R. Lamendella, D.C. Joyner, C. Spier, J. Baelum, M. Auer, M.L. Zemla, R. Chakraborty, E.L. Sonnenthal, P. D'haeseleer, H-Y. N. Holman, S. Osman, Z. Lu, J.D. Van Nostrand, Y. Deng, J. Zhou, and O.U. Mason. 2010. Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science 330(6001):204-208.

Henry, C.B. Jr., P.O. Roberts, and E.B. Overton. 1993. Characterization of chronic sources and impacts of tar along the Louisiana coast. USDOI, MMS, OCS Study MMS 93-0046. 64 pp.

Hill D., D. Hockin, D. Price, G. Tucker, R. Morris, and J. Treweek. 1997. Bird disturbance: Improving the quality and utility of disturbance research. Journal of Applied Ecology 34(2):275-288.

Lafferty, K.D.. 2001. Disturbance to wintering western snowy plovers. Biological Conservation 101:315-325.

McKone, T.E.. 1993. CalTOX, a multimedia total-exposure model for hazardous-wastes sites. Part 1: executive summary. Report UCRL-CR111456PtI prepared by Lawrence Livermore National Laboratory for California Environmental Protection Agency. 31 pp..

Michel, J. and B. Benggio. 1999. Guidelines for selecting appropriate cleanup endpoints at oil spills. In Proceedings of the 1999 International Oil Spill Conference, Seattle, WA, 591-595.

Morton, R.A.. 2008. Historical changes in the Mississippi-Alabama barrier-island chain and the roles of extreme storms, sea level, and human activities. Journal of Coastal Research 24(6):1587-1600.

NOAA. 2000. Shoreline assessment manual. HAZMAT Report No. 2000-1.August, 2000. 114 pp.

NOAA. 2010. Characteristic coastal habitats: Choosing spill response alternatives. 86 pp.

Pezeshki, S.R., M.W. Hester, Q. Lin, and J.A. Nyman. 2000. The effects of oil spill and clean-up on dominant US Gulf coast marsh macrophytes: A review. Environmental Pollution 108(2):129-139.

Rodger, J.A. and H.T. Smith. 1995. Set-back distances to protect nesting bird colonies from human disturbance in Florida. Conservation Biology 9(1):89-99.

Seneca, E.D. and S.W. Broome. 1982. Restoration of marsh vegetation impacted by the AMOCO Cadiz oil spill and subsequent cleanup operations at Ile Grande, France. In Ecological Study of the AMOCO Cadiz Oil Spill October 1982, pp. 363-419.

Shigenaka, G., C.B. Henry, Jr., and P.O. Roberts. 1998. Pavement in Patagonia, asphalt in Alaska: case studies in oil spill pavement formation, fate, and effects. NOAA Technical Memorandum NOS ORCA 135. 28 pp.

Skalski, J.R., D.A. Coats, and A.K. Fukuyama. 2001. Criteria for oil spill recovery: A case study of the intertidal community of Prince William Sound, Alaska, following the *Exxon Valdez* oil spill. Environmental Management 28(1):9–18.

Soley, J.C.. 1910. The oil fields of the Gulf of Mexico: Their geologic place. Scientific American Supplement No. 1788, April 9, 1910, pp. 229-230.

Southward, A.J., and E.C. Southward. 1978. Recolonization of rocky shores in Cornwall after use of toxic dispersants to clean up the Torrey Canyon spill. Journal of the Fisheries Research Board of Canada 35:682-706.

Tebeau, P.A.. 1995. Effectively Managing Level of Effort in Oil Spill Cleanup: Resolving the 'How Clean is Clean' Issue, In *Proceedings International Oil Spill Conference*, AmericanPetroleum Institute, Publication Number 4620, Washington,DC, 663-666.

Tunnell, W. 2010. Gulf of Mexico oil spills: A historical and spatial perspective. PowerPoint presentation dated December, 2010.

USGS National Wetlands Research Center. 2006. USGS reports latest land change estimates for Louisiana coast. Press release, dated 3 October 2006, http://www.nwrc.usgs.gov/releases/pr06_002.htm.

Yender, R.A.. 2010. Stage III SCAT shoreline treatment implementation framework (AL, FL, MS). Prepared for Gulf Coast IMT, dated 9 October 2010. 12 pp. + appendices.