Improvements for the Mechanized Cleanup of Oiled Sand Beaches

Phase 1—Final Report

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Executive Summary

Historically, cleanup of oiled sand beaches has focused on strategies involving manual, mechanical, and flushing tactics. Often, these strategies are used concurrently. This study addresses potential improvements to strategies involving mechanical tactics.

There exists an extensive body of oiled sand beach cleanup and treatment experience gained from over 40 years of shoreline response operations and trials. This knowledge provides a solid basis for the development of new or improved tactics that could be adapted to the cleanup of oiled sand beaches.

Traditional mechanical sand beach tactics rely on use of equipment designed for earth-moving and construction, recreational beach litter removal, sand and gravel processing, and agricultural applications. Associated equipment is generally large and capable of moving or processing large volumes of material. As a result, use of these tactics must be carefully planned and executed to prevent undesirable environmental effects. Over the past decades, a number of new purpose-specific sand beach machines have been proposed to improve the state-of-the-art. Unfortunately, very few of have proven to be commercially viable and fewer are currently available. Application of these existing machines should be considered in future planning and response. Although the development of new purpose-specific mechanized beach cleaning equipment is always possible, no promising new candidates were identified during this study.

Improvements in mechanized sand beach cleaning, however, can be advanced through expanded (new) application of existing technologies designed for other purposes. Example industries which can potentially provide new equipment and tactics include pipeline construction, sand and gravel processing, mining, agriculture, industrial vacuum systems and hazardous material remediation.

In the short term, advancements can be made through streamlining the decision-making process. Decisions regarding oiled sand beach cleanup appear to be intrinsically straightforward; however, beaches are dynamic, are important environmentally, and frequently are major recreational or amenity resources. Response decisions and the selection of appropriate tactics should be science-based, in a manner similar to decisions regarding oiled marsh/wetland or bedrock intertidal habitats.

Phase 2 of this study is planned to identify and catalogue additional applicable tactics and equipment from related industry. Phase 2 will also include development of guidance documents to assist in the improved selection and implementation of new and/or mechanical oiled sand beach cleanup tactics and equipment.

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Acronyms and Abbreviations

API	American Petroleum Institute
AMOP	Arctic Marine Oilspill Program
AMSA	Australian Maritime Safety Authority
ASTM	American Society for Testing of Materials
CEDRE	Centre of Documentation, Research and Experimentation on Accidental Water Pollution
CONCAWE	Conservation of Clean Air and Water in Europe (European Oil Company Organization for Environment, Health and Safety)
DWH	Deep Water Horizon (oil spill)
EPA	Environmental Protection Agency
ESA	Federal Endangered Species Act
FEL	Front-End Loader
FAC	Florida Administrative Code
FLA DEP	Florida Department of Environmental Protection
GOM	Gulf of Mexico
HTTD	High temperature Thermal Desorption
IPIECA	International Petroleum Industry Environmental Conservation Association (Global Oil and Gas Industry Association for Environmental and Social Issues)
ITOPF	International Tanker Owner's Pollution Federation
IOSC	International Oil Spill Conference
LTTD	Low Temperature Thermal Desorption
MC252	2010 Deep Water Horizon oil spill
MOP	Manual of Practice
NHPA	National Historical Preservation Act
NOAA	National Oceanographic and Atmospheric Administration
ODC	Operation Deep Clean
SCAT	Shoreline Cleanup Assessment Technique
USCG	United States Coast Guard

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Phase 1—Final Report

1.0 Introduction

This report summarizes the results of Phase 1 of a study to improve the state-of-the-art in the Mechanized Cleanup of Oiled Sand Beaches. The Phase 1 effort includes identification of current practice based on a review of historical experience and applicable case histories, including recent events such as the Deepwater Horizon oil spill. Phase 1 also recommends improvements in operational practices and equipment.

For purposes of this study, sand beaches are defined as extending from the intertidal zone to the backshore (the landward limit of marine processes and therefore the general limit of potential oiling). Sand is defined as granular material that may include clastic rock and mineral fragments, shell, coral and carbonate fragments. Sand has a grain size in the range from 0.0625 to 2.0 mm (0.0025 to 0.079 in) in diameter, but in generic usage may include small amounts (less than 10 %) of granules, silts, or clay sediments.

The term "mechanized" refers to the utilization of machinery, including motorized devices, other than hand tools to facilitate oil spill control and treatment or cleanup, and includes purpose-designed equipment and equipment designed for other applications. Non-mechanical sand beach cleanup tactics include manual cleanup, water flushing, chemical treatment, bioremediation, and burning. Non-mechanical tactics are not addressed in this study.

2.0 Objectives

2.1 Phase 1

Phase 1 (this report) summarizes current practice for Mechanized Cleanup of Oiled Sand Beaches and provides the basis for development of operational tools and recommendations for improvement of future mechanized sand beach cleanup operations, including application of new technologies and equipment.

2.2 Phase 2

Phase 2 of this program will include a review and Catalogue of Response Guidelines for Mechanical Cleanup of Oiled Sand Beaches based on the review of historical and current practices. The Phase 2 document will include information on tactics, equipment specifications, operating parameters and standard operating practice. The catalogue will contain an introduction and description of each tactic in addition to summary information matrices or other data presentations. Note: The Catalogue may be used as a stand-alone document or attached to the Manual of Practice (described below) as a supporting appendix. Phase 2 is expected to encompass:

- Preparation of a **Manual of Practice for the Mechanical Cleanup of Sand Beaches**. This Manual of Practice (MOP) will be designed for Emergency Response use and will focus on selection and implementation of candidate physical procedures for mechanized cleanup of sand beaches. Although the selection process will be based primarily on physical/mechanical factors, guidance will be included for the identification and evaluation of potential environmental consequences of candidate actions as part of the selection process ("response guidelines").

- Preparation of a report presenting **Recommendations for Projects or Studies on Modifications, Engineering, and Demonstration Testing** to improve existing mechanical sand beach cleanup technologies.

- Preparation of a **Review of Potentially Applicable Existing and Developing Equipment and Tactics from Other Industries.** Target industries may include, but not be limited to earth moving, pipeline construction, mining, agricultural, and hazardous waste management. Identify promising technologies and equipment for development studies and/or demonstration testing as appropriate.

2.3 Phase 3

Phase 3 of the program is under consideration and the scope, funding mechanisms and timing for further work (if any) have not been formalized at this time.

3.0 Background Information on Mechanical Cleanup of Oiled Sand Beaches

3.1 Mechanisms for Oil Burial on Sand Beaches

Spilled oiled can be incorporated in shoreline sediments by a variety of mechanisms including:

- Fluid oil deposited on the shoreline surface may soak directly into underlying sediments. This is typical of oils having low viscosity, such as distillate fuels and some fresh lighter crude oils. Penetration into the sediments is dependent on factors including viscosity of the oil, sediment grain size and water content, degree of sediment compaction, and factors such as presence of biogenic pathways (animal burrows). Normally vertical penetration of oil will stop at the beach ground water surface. If there is enough oil, the entire overlying zone may be oiled and there may be a floating layer on the groundwater surface. A similar effect may occur when solid or viscous oil deposited on the surface is heated by the sun and decreases in viscosity sufficiently to migrate downward; the latter effect is most common when oil is deposited or stockpiled in the supratidal zone;

- Floating oil may also be deposited on the shoreline in discontinuous irregular patterns in the swash zone or as scattered tar balls or residue accumulations;

- Oil deposited on the surface can be covered (buried) by wind-blown clean sand or clean sand that is deposited by natural onshore or along-shore processes (accretion). Layering with depth is possible;

- Surface deposits of oil can be covered by sand when dunes collapse during storms;

- Oil deposited on shoreline surfaces can be mixed with clean underlying or adjacent sediments by wave action and longshore transport and be re-deposited at depth and/or in adjacent locations. Downward mixing of oil may be deeper than the groundwater water level. Development of multiple oil layers is also possible;

- Burial depths on open shorelines are generally less than several meters;

- Surface and subsurface oiling can co-exist; and

- Oil may flow or fall into animal burrows.

3.2 Oil Properties, Distribution and Weathering

3.2.1 Oil Properties

Surface and subsurface cleanup tactics are controlled primarily by the physical characteristics of the oil “on the beach”. Once exposed to weathering, these properties can be expected to differ from MSDS and standard product specifications, and must be assessed on a case-by-case basis. The following properties/characteristics are important to the selection of cleanup tactics:

- Density: The density of crude oil and products is dependent on their composition and temperature. Oil density is measured as specific gravity. Specific gravity is a comparison between the weight of the substance and that of freshwater at 15.6°C (60°F), which is assigned a value of 1.0000. Therefore, oil that floats has a specific gravity less than the water it is in, and oil sinks if its specific gravity is greater (keeping in mind that the specific gravity of sea water ranges from approximately 1.02 to 1.07).

  The oil industry commonly uses API gravity (°) for density measurement. API Gravity (°) can be calculated from specific gravity using the following formula:

  API Gravity (º) = [141.5/specific gravity (@60F)] –131.5

  Oil with a specific gravity of 1.0 has an API gravity of 10.0°. A high API value represents a light oil whereas a low value represents a denser oil.

  Oil density typically increases as evaporation and other weathering processes occur, and ultimately some oils may sink. Crude oils may also emulsify when spilled on water and exposed to mixing energy. Emulsification and incorporation of sediment also influence the effective density of the overall mixture. Density is an important consideration in the selection a cleanup tactic and must be monitored continually for changes that could affect the use of that tactic.

- Pour Point: Pour point is the temperature below which oil does not flow.

  - Many crude oils have pour points that are near or at ambient temperature, with the effect that they can change from liquid to solid and back depending on the ambient temperature range. Pour point can be expected to change as the oil weathers. High pour point oils tend to be solid at ambient temperatures and have good potential to be screenable;

- Viscosity: Viscosity is a measure of the resistance of a fluid which is being deformed by either shear or tensile stress, and may be thought of as a measure of fluid friction. Simply stated, the less viscous the fluid, the greater its ease of movement (fluidity). Oils having high viscosity are less likely to penetrate into sediments, may require special handling procedures, and may be screenable;

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- Emulsification: Crude oil tends to form emulsions which consist of small drops of water incorporated in the oil when subject to mixing energy such as wave action or turbulence associated with a well blowout or pipeline release. Formation of emulsions (mousse) tends to increase the volume and persistence of the spilled oil and can impact behavior and cleanup requirements. Emulsions typically do not flow, although they may exhibit measurable viscosity. As a result, they do not tend to penetrate into sediments when grounded on shorelines, although some emulsions have limited stability and may separate into oil and water phases over time or when heated (as by the sun) at which point oil may then penetrate into sediments. Stable emulsions and emulsions with incorporated sand may also be recoverable through mechanical means;

- Asphalt/Paraffin Content: Crude oils, and residual fuels associated with their refining, contain varying percentages of asphaltic and paraffinitic (waxy) components which can impact their behavior, persistence, and cleanup tactics. Crudes containing significant amounts of asphaltic compounds tend to be viscous, sticky, and persistent. Conversely, paraffinic oils tend to be less viscous, slippery and less persistent; and

- Friability: Friability refers to the cohesiveness of accumulations of oil/emulsions and sediment. In some cases, oil and sand forms aggregates or sand adheres to the outside of residue accumulations forming armored oil clasts. Friability describes the ease with which such accumulations of oil crumble, and is an important factor in the selection and use of many mechanical tactics. For example, cohesive accumulations can be recovered using techniques such as screening, whereas friable material can break into smaller particles that may be difficult to screen and thus require other treatment tactics.

3.2.2 Oil Distribution

Oil on and buried within sediment shorelines is unlikely to be uniformly distributed. In most cases, oil is deposited on the mid to upper tidal zone in irregular patterns by wave action, storm surges, and other marine processes. Resulting concentrations of oil may range from heavy to very light, both vertically and horizontally. Understanding this typical irregular distribution pattern is important in selecting mechanical beach cleanup tactics and in optimizing their performance.

Surface Oil Distribution: Shoreline oil characteristics are described in the Shoreline Cleanup Assessment Technique (SCAT) Manual (Owens and Sergy, 2000). SCAT descriptions for surface oil distribution include:

Trace (TR)	<1 %
Sporadic (SP)	1–10 %
Patchy (PT)	11–50 %
Broken (BR)	51–90 %
Continuous (CN)	91–100 %

Surface Oil Thickness: Surface oil thickness refers to the average or dominant oil thickness within the segment or zone. Using SCAT nomenclature, thickness is defined as follows:

- **Thick Oil** (TO): accumulations of fresh oil (including pools) or mousse >1 cm (0.39 in) thick
- **Cover** (CV): >0.1 cm (0.039 in) to <1 cm (0.39 in) thick
- **Coat** (CT): >0.01 cm (0.004 in) to <0.1 cm (0.039 in) thick; can be scratched off with fingernail on coarse sediments or bedrock
- **Stain** (ST): <0.01 cm (0.004 in) thick; cannot be scratched off easily on coarse sediments or bedrock
- **Film** (FL): transparent or translucent film or sheen

Surface Oil Character: Surface oil character provides a qualitative description of the form of the oil, and using SCAT nomenclature is defined as follows:

- **Fresh** (FR): un-weathered, low viscosity oil
- **Mousse** (MS): emulsified oil (oil and water mixture) existing as patches or accumulations, or within interstitial spaces

- **Tar Balls** (TB): discrete balls, lumps, or patches on a beach or adhered to the substrate. Tar ball diameters are generally <10 cm (3.94 in)
- **Tar Patties** (PT): discrete lumps or patches >10 cm (3.94 in) diameter that are on a beach or adhered to the substrate
- **Tar** (TC): weathered coat or cover of tarry, almost solid consistency
- **Surface Oil Residue** (SR): consists of non-cohesive, oiled, surface sediments, either as continuous patches or in coarse-sediment interstices. (Note: The terms SRB and SRP, surface residue balls and patties, respectively, were used throughout the Deepwater Horizon response to characterize agglomerated sand-oil mixtures held together by oil residue coating the sand particles)
- **Asphalt Pavement** (AP): cohesive mixture of oil and sediments
- **No Oil Observed** (NO)

Subsurface Oil Description The SCAT Manual defines the subsurface oiled zone as "the vertical width or thickness of the oiled sediment layer when viewed in profile by digging a pit or trench". SCAT terminology for describing subsurface oil distribution includes:

Saturated	(**Continuous**: 91–100 %)
Layers	(**Broken**: 51–90 %)
Patchy	(11–50 %)
Sporadic	(<10 %)
Multiple layers	
Depth of over burden	
Water level	

SCAT also defines specific characteristics of buried oil, including:

- **Subsurface Asphalt Pavement** (SAP): adhesive mixture of weathered oil and sediment situated completely below a surface sediment layer;
- **Oil-Filled Pores** (OP): pore spaces in the sediment matrix that are completely filled with oil; often characterized by oil flowing out of the pores when disturbed;
- **Partially Filled Pores** (PP): pore spaces filled with oil, which does not generally flow out when exposed or disturbed;
- **Oil Residue as a Cover (>0.1 cm: 0.039 in) or Coat (0.01–0.1 cm: 0.004–0.039 in)** (OP)" oil coating on sediment and/or some pore spaces partially filled with oil. Cover/Coat can be scratched off easily with fingernail;
- **Film or Stain (<0.01 cm: 0.004 in)** (OF): oil residue on sediment surfaces. Non-cohesive. Cannot be scratched off easily;
- **Trace** (TR): discontinuous film or spots of oil on sediments, or an odor or tackiness with no visible evidence of oil; and
- **No Oil** (NO): no visible or apparent evidence of oil.

3.2.3 Weathering

Changes in the physical characteristics of stranded oil can be critical, but often overlooked, factors in the design of an effective sand cleanup operation. A primary mechanism of change is known as weathering (although properties can also change in response to temperature, emulsion formation/collapse, and other factors). Significant property changes can decrease the effectiveness of some tactics or render them useless. Changes in oil properties should be expected and should be monitored so that tactics can be adjusted or changed as appropriate.

3.3 Effects of Mechanical Operations on Sand Beaches

3.3.1 General

Any mechanical cleanup operation results in some level of environmental impact. These impacts may range from immeasurable to significant, and as a result, potential impacts of proposed actions should **always** be considered before proceeding, and re-evaluated periodically as the response progresses. If necessary, a Net Environmental Benefit approach (Efroymson et al., 2003; Robberson, 2012; IPIECA, 2000) can be used to gauge the relative significance of a particular action versus an alternative action or doing nothing. The following discussion includes examples of potential factors that should be considered.

3.3.2 Sand Removal and Beach Stability

Beach stability and shoreline erosion are of significant concern in many regions. Mechanical removal can involve the removal of as much as $4.0 m^3/m$ ($5.23 yd^3/1.09 yd$) length of oiled sand shoreline and manual removal as much as $2.5 m^3/m$ ($3.27 yd^3/1.09 yd$) (Owens et al., 2009). During the 1993 *Bouchard B-155* Tampa Bay response (Owens, Davis, Michel, and Stritzke, 1995), 14.5 km (9.00 mi) of sand beach with surface and buried oil were cleaned by a combination of manual and mechanical tactics. The volume removed averaged to $1.9 m^3/m$ ($2.49 yd^3/1.09 yd$) by length or $1.4 m^3/m^2$ ($1.83 yd^3/1.19 yd^2$) by area.

Historically, indiscriminate use of mechanized tactics (such as use of bulldozers) on sand beaches have been reported to have removed unnecessarily large amounts of clean sand and/or mixed oil deeper into the beaches, resulting in the need to remove even more sand. Although there is minimal documentation in the literature to support many of these reports, it is probable that excess sand removal has in fact taken place and some level of undesirable impact has occurred during historical responses. Awareness of these issues can minimize uncontrolled use of tactics which indiscriminately remove or contaminate excess sand. Cleanup tactics which minimize sand loss are always preferred.

In all cases, sand beach operations should consider potential impacts resulting from sand disturbance and removal on the overall shoreline ecology and sedimentary balance. This balance may be sensitive to seasonal and event – related factors such as storms, and weather and seasonal projects should be included in tactics evaluation. Assistance in the determination of processes active during an event can be obtained from a number of knowledgeable sources including:

- U.S. Army Corps of Engineers;
- State and local governments;
- State and Federal Park and Wildlife Refuge agencies;
- local engineering companies;
- University experts; and
- National Weather Service.

3.3.3 Sand Compaction

Any foot traffic and mechanized equipment operation on a sand beach results in some degree of compaction and may injure organisms living in the sand. A measure of potential ground compaction by mechanical operations is ground pressure. Ground pressure can be calculated by dividing gross vehicle weight by its surface foot print (reported in bars or pounds per square inch: “psi”). It is important to recognize that the size and gross weight of a piece of equipment does **not** automatically equate to its ground pressure. Off road equipment, for example, is commonly configured to improve its ability to operate in soft (low trafficability) environments by increasing its footprint, thus lowering the ground pressure at points of contact. Table 3.1 presents approximate ground pressures for representative pieces of equipment used on the Deepwater Horizon oil spill. Also presented for comparison is the approximate range of ground pressure associated with responder foot traffic.

Table 3.1 Representative Ground Pressures for Beach Cleaning Equipment

Equipment	Gross Weight kg (lb)	Approximate Ground Pressure bars (psi)
Oil Responder (adult male oil spill responder)	80 (175)	0.17–0.2 (2.5–3.0)
Towed Wheel Screener (BT 3000)	6,200 (14,000)	0.75 (11.0)
Self-propelled Wheel Screener (C5000)	4,200 (9,200)	0.8 (11.5)
Tracked Force Feed Loader (Sand Shark)	13,000 (28,500)	0.4 (6.0)
Towed Multi-stage Wheeled Sifter (Sand Shark)	5,200 (11,500)	1.0 (15.0)

(Source: manufacturer’s data)

As suggested in this table, use of tracks can significantly reduce ground pressure. In many cases, ground pressure can be lowered simply by adding larger tires, installing tracks on wheeled vehicles (such as motor graders), or simply reducing tire pressure.

3.3.4 Ecological Effects

Human activity, including operation of mechanical equipment on beaches, has the potential to damage or disrupt organisms living there, or those which utilize the shoreline for nesting, resting, transit from the water to backshore areas, or other purposes. Sensitivities are often seasonal and may, or may not, be significant at the time of a response. In the U.S., activities and potential impacts to Threatened and Endangered Species must be consistent with the Federal Endangered Species Act (ESA). Regardless, ecological sensitivity must be considered in all cases.

3.3.5 Cultural Resources

Shorelines may contain artifacts of historic and/or cultural significance, locations of other cultural value, and even burial sites. As sand beaches are dynamic, they are not as sensitive in this regard as other shoreline types, but occurrences can occur, even at shallow depths. In the U.S., the protection of historic and cultural resources is mandated under the National Historic Preservation Act (NHPA) (1996), and all activities must be consistent with its provisions.

3.3.6 Amenity Uses

Sand beaches are typically accessible to, and used by, the public and have high amenity value. This value can escalate dramatically seasonally in many areas, and will often drive cleanup schedules and levels of effort.

3.4 Shoreline Properties and Selection of Tactics

Shoreline characteristics can control selection cleanup tactics. Relevant characteristics include:

3.4.1 Access and Trafficability

Equipment access to the beach and the ability to stage and operate equipment there can create important limitations on selection of tactics. Access can consist of pre-existing roads or landing craft access. If roads do not exist, the general topography of the area should be examined to determine its suitability for construction of temporary access roads and staging areas. In some cases, use of portable roadways such as used by the military, or use of landing craft may be necessary. It is important to remember that any disruption associated with access and staging likely involves restoration following the response.

Trafficability refers to the ability of the beach sediments (bearing strength) to support personnel and mechanized equipment. Beach compaction is the primary factor in determining trafficability. Beaches that are relatively flat and can be walked on normally will usually support most types of light vehicle traffic. Use of heavier equipment may require modification to the equipment (lower tire pressure, flotation tires, or tracks) or special equipment. In some cases, beaches may support vehicular traffic for only a limited number of passes. Procedures evaluating trafficability have been developed by the military (cone penetrometer measurements) to support amphibious landing on sand beaches are available and can be used for the assessment of heavy equipment feasibility, if necessary (Corps of Engineers, 1963; Willoughby, 1977).

3.4.2 Surface Morphology

Surface morphology can impact the performance of some mechanical tactics. Flat surfaces are necessary for efficient operation of some equipment, including motor graders and scrapers. Use of mechanized tactics on irregular surfaces may result in either removal of excess clean material or incomplete oil removal. Operations on such surfaces may require the use of smaller and more maneuverable equipment or manual tactics.

3.4.3 Sediment Stability

Excavation in beach sand can be difficult. The angle of repose of some beach materials is so low that excavations cannot be kept open long enough to complete observations. This commonly occurs with dryer sands. Slumping of material into pits and trenches dug below the water table is typical.

3.4.4 Environmental, Cultural and Political Sensitivity

Disruption to areas with particular sensitivities, such as those with as environmental, cultural, or political concerns, can influence selection of techniques, with intrusive and high activity techniques often being problematic.

3.5 Operational Variables

The success or failure of most tactics can be influenced by a number of controllable factors. These factors include:

3.5.1 Manufacturer's Specifications

Equipment manufacturers' specifications should be interpreted conservatively. This is particularly the case with utilization of equipment designed for other applications. Oil spill recovery operations involve many unpredictable conditions, some of which can be expected to change over the course of the response. Sand beach conditions often require specific equipment to be operated differently that would be normal for their intended use.

3.5.2 Operator Experience

Many standard cleanup tactics utilized equipment and operators that are intended for different operating objectives and environmental conditions. In most cases, operators are trained to maximize the pickup of materials. For oil spill cleanup, slower and more precise equipment operation may be required for efficient recovery of oil and oil sand (and minimization of clean sand removal). In such cases, retraining of equipment operators may be beneficial.

3.5.3 Controllable Parameters

Most types of equipment have a variety of operational parameters that can be controlled. These may include: depth of cut, forward speed, blade angles, belt speeds, vibratory shaker rates, flow rates, retention times, and many others. “Trimming” the operating variables for particular piece of equipment and situation is generally required. This process is conducted by operator “feel”, experimentation, and periodic performance testing. Adjustments can be particularly import in maintaining efficiency as the oil weathers. Performance indicators should be developed, periodically measured, and adjustments made as appropriate.

3.5.4 Accessories and Modifications

Most commercial equipment manufacturers offer a variety of accessories for their equipment. These can include different blades, buckets, rippers, screen sizes, tire sizes, flotation ties, tracks, attachable rubber squeegee blades, and many other equipment-specific options. In addition, experience has also shown that special modifications may also be necessary. These types of modifications include installation of flashings to prevent unnecessary loss on sand from part of some machines, lowering of tire pressure to improve trafficability, etc.

3.5.5 Availability

Even the most efficient piece of equipment is of little value if it is not available. Much of the equipment currently utilized for mechanical sand beach cleanup consists of conventional construction and agricultural machinery, which is readily available in most areas as are parts and services. Commercial beach cleaners have also become reasonably available in recent years, although parts, including non-standard size screens, may not be standard shelf items and may need to be specially manufactured. A number of oil spill-specific types of equipment have been proposed and manufactured. As a result of low demand, many of these devices never evolved beyond the prototype stage, and of those that have been manufactured, most were only offered for short periods and are no longer available. Availability is therefore a major consideration in the selection of any emergency response equipment.

3.5.6 Locational Control (Vertical and Horizontal)

Surface cleanup can be conducted visually. Subsurface cleanup is more difficult unless detailed subsurface information is available. GPS positioning/tracking equipment is available and can be attached to self-powered equipment to locate pre-identified subsurface deposits, track areas treated, and reoccupy treatment lines.

4.0 Mechanical Sand Beach Cleanup Practice Review

4.1 Introduction

The Platform A Blowout in the Santa Barbara channel in 1969 resulted in the oiling of 35 miles of the California coastline and the mortality of 3600 birds, ten seals and dolphins, and countless fish and marine invertebrates. Many consider that event as a major impetus to the environmental awareness movement in the United States. In reaction to this event, new regulations were promulgated and oil spill research and development efforts initiated on the part of industry and the federal government. Part of the resulting Research and Development (R&D) effort focused on shoreline cleanup tactics, including treatment of sand beaches using mechanized equipment, which consisted primarily of earthmoving equipment which forms the basis for mechanized sand beach cleanup to this day. For this reason, the Phase 1 practice review was extended as far back as 1969.

4.2 Literature Review

The literature review focused on event case histories sand beaches and use of mechanized cleanup tactics was reported. International as well as domestic cases were included. The review also included searches for applicable equipment, research and development projects and oil spill equipment manufacturer literature.

Document sources examined included, but were not limited to, the following:

- Proceedings of the International Oil Spill Conference (1969 to 2011);
- NOAA Summaries of Significant U.S. and International Spill – Oil Spill Case Histories 1967–1991;
- NOAA Interactive Oil Spill Maps (for more recent data);
- Proceedings of the Arctic Marine Oil Spill Program (AMOP);
- CEDRE – Major Oil Spill Summaries;
- International Tanker Owners Pollution Federation, Limited, Oil Spill Case Histories;
- Australian Maritime Safety Authority (ASMA) Major Spills in Australia;
- Oil Spill Solutions, Case Histories and Tactics;
- World Catalogue of Oil Spill Response Products (various editions);
- Oil Spill Equipment Manufacturers' Literature (various);
- Beach Cleaning Equipment Manufacturers' Literature (various); and
- Other Equipment Manufacturers' Literature.

In conducting the literature review, it was quickly realized that details of mechanical sand beach cleanup operations were generally not well documented, if documented at all. Table 4.1 presents a summary of those spill events which were identified as involving some level of mechanical beach cleanup. Listing in this table does not mean that use of mechanical tactics comprised the primary response. In fact, mechanical tactics were often secondary. Nor does the reporting of a tactic or piece of equipment indicate that the tactic or piece of equipment was or was not effective. The listing is, however, believed to be indicative of situations and general mechanical tactics, but is not intended to be an exhaustive examination of all historical events.

Table 4.1 Historical Oil Spills Involving Mechanical Cleanup Tactics on Sand Beaches

Date	Name/Location (Reference)	Size/Oil Type	Mechanical Procedures Used
12/16/11	TK Bremen, France (Reference: Cedre website – Spills)	1103 bbl (150 tonnes) IFO 120 293 bbl (40 tonnes) Marine diesel	• Surf washing
4/21/10	Deepwater Horizon Gulf of Mexico, U.S. (References: NOAA Incident News website; NOAA BP Oil Spill Archive website; Restore The Gulf website; Gulf of Mexico Restoration website; Gulf Update website; Owens et al., 2011a,b; Santner et al., 2011a,b; VanHaverbek et al., 2011)	4,900,000 bbl (666,400 tonnes) Southern Louisiana crude	• Commercial beach cleaners • Trackhoe, FEL, bulldozer excavation • Portable sand washing and screening plants • Tilling • Sediment relocation
3/11/09	Pacific Adventurer Australia (Reference: AMSA website)	Heavy Fuel Oil	• Excavation by backhoe, FEL • Commercial beach cleaners
12/8/04	MV Selendang Ayu Alaska (References: Shirgenata et al., 2008; NOAA Incident News website)	8024 bbl (109 tonnes) IFO 380	• Tilling • Berm relocation
7/27/03	Tasman Spirit Pakistan (Reference: Cedre website – Spills)	198,529 bbl (27,000 tonnes) Iranian crude	• “Mechanical” shoreline cleanup (Not otherwise specified)
11/15/02	MV Prestige Spain (References: Cedre website – Spills; NOAA Incident News website)	228,524–595,588 bbl (61,000–81,000 tonnes) Heavy Fuel Oil	• Mechanical where possible • Oleophilic roll machines • Commercial sand screeners • Surf washing
3/29/01	Baltic Carrier Denmark (Reference: Cedre website – Spills)	20,580 bbl (2,799 tonnes) Heavy Fuel Oil	• Mechanical recovery (track hoes, FEL) • Coarse sediment washing
7/5/00	TB Penn Narragansett, RI (Reference: NOAA Incident News website)	300 bbl (40.8 tonnes) #6 Fuel Oil	• Sediment agitation using FEL
12/12/99	Erica France (References: LeGuerroue et al., 2003; Cedre website – Spills)	147,059 bbl (20,000 tonnes) #6 Fuel Oil	• Tilling (deep harrowing) • Screening belts to remove tar balls to 30 cm
5/14/96	Chevron Pipeline Spill Hawaii (Reference: NOAA Incident News website)	1000 bbl (136 tonnes) #6 Fuel Oil	• Mechanical tilling of coarse sand

Date	Name/Location (Reference)	Size/Oil Type	Mechanical Procedures Used
3/31/94	TV Seki & Baynuna UAE (Reference: Pearson et al., 1994)	761,905 bbl (103,612 tonnes) Iranian Light Crude	• Mechanical beach trials • Berm relocation • Tilling
1/7/94	TB Morris Berman San Juan, Puerto Rico (References: NOAA Incident News website; Petrae, 1995; Stanton, 1995)	#6 Fuel Oil	• Sand removal
8/10/93	Bouchard 155, Tampa Bay, Fla. (References: Owens et al., 1995; NOAA Incident News website)	7810 bbl (1062 tonnes) #6 Fuel Oil	• Motor graders, front end loaders • Surf washing • Tilling
4/1/91	Haven, Italy (References: Curl et al., 1992; Cedre website –Spills; NOAA Incident News website)	1,029,412 bbl (140,000 tonnes) Crude oil	• “Mechanical” shoreline cleanup (Not otherwise specified)
2/13/91	Sanko Harvest W. Australia (References: Curl et al., 1992; NOAA Incident News website)	4400 bbl (598 tonnes) Fuel Oil	• Graders and FEL used on heavily oiled beaches
1/19/90	Arabian Gulf Kuwait (Reference: Curl et al., 1992)	8,000,000 bbl (1,088,000 tonnes) Kuwait crude	• Berms and trenches • Mechanical (not otherwise specified)
12/29/89	Aragon Portugal (References: Curl et al., 1992; Cedre website –Spills; NOAA Incident News website)	175,000 bbl (21,525 tonnes) Mexican Maya crude	• Mixed mechanical recovery (Not otherwise specified)
7/30/84	Alvenus Calcasieu R Louisiana (References: Curl et al., 1992; Cedre website – Spills; NOAA Incident News website)	65,000 bbl (8,840 tonnes) Venezuelan Merecy and Pilar crude	• Shallow excavation (Fleets of motor graders used)
11/12/83	Olympic Alliance English Channel (References: Curl et al., 1992; Cedre website – Spills)	87,000 bbl (11,832 tonnes) Iranian Light crude	• Mechanical equipment (Not otherwise specified)
9/28/83	Sivand England (References: Curl et al., 1992; NOAA Incident News website)	48,000 bbl (6,528 tonnes) Nigerian crude	• Excavation using FEL
2/19/83	Ocean Eagle San Juan, Puerto Rico (Reference: Curl et al., 1992)	70,000 bbl (9520 tonnes) Venezuelan crude	• Mechanical used (Not otherwise specified)
10/2/80	Hasbah 6 Qatar (References: Curl et al., 1992; NOAA Incident News website)	100,000 bbl (13,500 tonnes) Crude	• Excavation/mechanical used (Not otherwise specified)
11/1/79	Burmah Agate Galveston, TX (References: Curl et al., 1992; NOAA Incident News website; Thebeau, 1981)	Nigerian crude	• Used FEL to pick up manual piles – removed too much sand

Date	Name/Location (Reference)	Size/Oil Type	Mechanical Procedures Used
3/13/79	Sea Valiant France (Reference: Cedre website – Spills)	221 bbl (30 tonnes) #6 Fuel Oil	• Mechanical shoreline cleanup (Not otherwise specified)
3/6/78	Amoco Cadiz Brittany, France (References: Curl et al., 1992; Bellier, 1979; Bocard, 1979; Hann, 1979; NOAA Incident News website; Cedre website – Spills)	1,619,048 bbl (220,191 tonnes) Arabian/Iranian Lt crude/Bunker C	• Vacuum trucks/wagons • Trench/sumps • Surface scraping • Excavation • Tilling • Sediment relocation
1/9/78	Brazilian Marina Brazil (References: Curl et al., 1992; NOAA Incident News)	73,600 bbl (10010 tonnes) Kuwait crude	• Excavation by FEL
5/12/76	Urquiola Spain (References: Curl et al., 1992; Cedre website – Spills; NOAA Incident News website)	73,300 bbl (9969 tonners) Lt Arabian, Bunker Fuel	• Use of mechanical equipment inc. graders, dozers, FELs: not successful and mixing at depth reported
2/2/76	STC 101 Chesapeake Bay, Virginia (References: Curl et al., 1992; NOAA Incident News)	5959 bbl (810 tonnes) #6 Fuel Oil	• Removal using FELs
1/18/73	Oregon/Arizona Standard California (Reference: Curl et al., 1992)	20,400 bbl (2,774 tonnes) Bunker C	• Mechanical (debris and oiled sand removal • Mixing at depth
7/22/72	Tomano Casco Bay, Maine (References: Curl et al., 1992; NOAA Incident News website)	2380 bbl (324 tonnes) #6 Fuel Oil	• Heavy equipment (Not otherwise specified)
2/4/70	Arrow Nova Scotia (References: Curl et al., 1992; NOAA Incident News website)	77,000 bbl (10,472 tonnes) Bunker C	• Mechanical used but mixed oil into sediment scrapers not effective
4/30/69	Hamilton Trader Liverpool, England (References: Curl et al., 1992; Cedre website –Spills; NOAA Incident News)	4000 bbl (544 tonnes) #6 Fuel Oil	• Mechanical (Not otherwise specified)
1/28/69	Platform A Blowout Santa Barbara, CA (References: Curl et al., 1992; NOAA Incident News website)	100,000 bbl (13,600 tonnes) Calif. crude	• Mechanical, oiled straw and limited excavation
3/18/67	Torrey Canyon England (References: Curl et al., 1992; Cedre website – Spills)	860,000 bbl (116,960 tonnes) Kuwait crude	• Mechanical, including bulldozing

4.3 Case Studies

This section examines several case histories focusing on incidents in which sand beaches were oiled and mechanical cleanup tactics were utilized. These cases were selected given the availability of operational information and the value to provide as representative a description of conditions and tactics as possible within the limitations of the available data.

The following Incidents are included:

- The Deepwater Horizon Oil Spill (2010), Gulf of Mexico (GOM), USA (deep water well blowout),
- The Tampa Bay Oil Spill (1993), Florida (vessel collision),
- The Pacific Adventurer (2009), Australia (vessel grounding),
- The Amoco Cadiz Oil Spill (1978), France (vessel grounding),
- The MV Prestige Oil Spill (2002), Spain (vessel sinking),
- The Alvenus Oil Spill (1984), Louisiana (vessel grounding), and
- The Urquiola Oil Spill (1976), Spain (vessel grounding).

The following case history discussions present: 1) Incident Description; 2) Shoreline Cleanup Strategy; and 3) Mechanized Beach Cleanup Tactics and Equipment.

Deepwater Horizon Oil Spill: 2010–2012

Description: Explosion/fire on the Deepwater Horizon semi-submersible platform in the Gulf of Mexico (GOM) on 20 April, 2010, resulting in a chronic oil spill over an 87-day period during which approximately 4.9 million barrels (666,400 tonnes) of south Louisiana sweet midrange paraffinic crude oil was released into the GOM. This type of oil has a relatively low persistence and material reaching the shoreline underwent significant evaporative loss and emulsification while at sea. The amount of time the oil remained at sea varied significantly and influenced the characteristics of emulsions which reached the shoreline. Emulsions that remained at sea for longer periods were more stable and typically formed relatively cohesive sandy balls, paddies and layers. Emulsions that were at sea for shorter periods were less stable and tended to collapse and penetrate into the sand. This phenomenon was observed in Louisiana and other areas to the east. In some cases, such as Grand Isle, LA, both conditions occurred. Oil in these two forms required different treatment tactics. In addition, as the event progressed, weathering of material on the shoreline resulted in sand/emulsion accumulations becoming firmer and surface oil became buried by storm activity and natural coastal processes. Ultimately, some 400 miles (644 km) of sand beaches in Louisiana, Mississippi, Alabama, and the Florida panhandle in were oiled.

Shoreline Cleanup Strategy: Coastal erosion is a well-known issue along the Gulf Coast. Concerns were expressed regarding destabilization and acceleration of shoreline erosion in known problem areas as a result of response activities and removal of sand. In response to these concerns, criteria for shoreline cleanup tactics were established by the Unified Command that included:

- Removal of as little sand as possible;
- Treatment and restoration of amenity beaches for recreational use as soon as possible; and
- Maintenance of beach stability in the event of storms.

Mechanized Cleanup Tactics: An extensive review of conventional and potentially useful mechanical tactics was conducted, and promising tactics were tested to evaluate their applicability. Primary tactics cleanup tactics that were used relied heavily on manual recovery procedures and extensive use of small mechanized beach cleaning equipment, with a primary objective of minimizing removal of excess sand. Although larger equipment was used in selected situations where deeper treatment was required, for the most part, environmental concerns precluded the application of these large pieces of construction equipment.

Mechanized tactics utilized can be classified as including: 1) tactics that focused on physical removal and offsite disposal; 2) application of in-situ tactics in which sand was treated in place with clean material returned directly to the beach; and 3) ex-situ tactics where material was physically removed, treated on site, with cleaned sand returned to the location from which it was removed. These tactics are described below:

Physical Removal Tactics

- Track hoes: Long-reach track hoes were used effectively in recovery of sand/emulsion mats in the lower intertidal and shallow subtidal zones;

- Front-End Loaders (FELs): FELs were used for surgical removal of localized oil layers (surface and buried). FELs were also used for general transport and loading of materials onsite and for offsite disposal;

- Commercial Beach Cleaners: One type of commercial beach cleaner which utilized fixed screens was modified for use as a small scraper by replacing its screen with a solid metal plate. The modified equipment was used effectively for recovery of thin surface oil emulsion layers deposited on Grand Isle beaches in Louisiana.

In-situ Treatment Tactics

- Commercial beach cleaners: A number of types of commercial beach cleaners were utilized during the response to recover screenable sand/emulsion accumulations, including fixed screen, traveling belt screens, and rake configurations. Early in the response, sand/emulsions were fragile (friable) and tended to break into pieces, the smaller of which were not recoverable. This effect was encountered with all types of beach cleaners, in particular rakes. Operation of equipment at night, when temperatures were cooler and sand/emulsion accumulations were more cohesive, improved recovery efficiency. Night operations were continued until it was determined that the accumulations had weathered sufficiently to allow return to day time operations. Estimated recovery efficiencies of 80 to 90 % were reported (Owens, Taylor and Castle, 2011). A basic limitation of the commercial beach cleaners is their practical treatment depth, which was in the range of 3 to 6 inches (7.62 to 15.24 cm). Commercial beach cleaners were effective for near surface recovery.

- Adapted Technologies: With the goal of increasing the depth of screening that could be conducted, several other types of equipment were explored. One of these was the Sand Shark. The Sand Shark consisted of a commercial, tracked, force-feed loader. Although not designed for excavation, this equipment was capable of processing sand to a practical depth of up to 12 inches (30.48 cm). Excavated material was transported by conveyor belt to a portable screening device towed behind the loader. Recovered material was collected in a hopper with clean sand returned directly to the beach. The Sand Shark was effective but slower than the commercial beach cleaners.

A commercial pipeline padder also was tested but had limited use. A pipeline padder is a pipeline construction device used to screen rocks and larger particles from excavated pipe trench material so that material passing the screen can be safely used as pipeline backfill. Similar to the Sand Shark, this system consists of a loader-type device capable of digging to a practical depth of at least 12 inches (30.48 cm) with an onboard screening system. The device was effective, but had a very low operational speed, was very noisy, and received limited use.

- Mechanical Mixing: Mechanical mixing was conducted with a variety of towed agricultural plowing and tilling equipment. Depending on the equipment, mixing depths of several feet could be obtained. The process is intended to breakup and mix oiled sediments so that they may be better removed by natural processes. This equipment was effective. Selected agricultural plows were also evaluated to see if they could bring deeper buried oil/sand accumulations to the surface where they could be collected using commercial beach cleaners. Results of these evaluations were inconclusive.

- Sediment Relocation/Surf Washing: Sediment relocation/surf washing involved using construction equipment to move oiled sand to the lower intertidal zone where it would be washed by wave and tidal action. This tactic was used for cases of lightly oiled sediments that could not be otherwise treated, and for final polishing of material treated by the sand treatment plant operated on Grand Isle, Louisiana (see below). The sand relocation/surf washing treatment was considered effective.

<u>Ex-situ Treatment Tactics</u>

Ex-situ treatment consisted of excavation of oiled sand followed by processing to remove oil at centrally located portable treatment plants. Processed sand was then returned to the general area from which it was excavated. Two types of treatments were utilized:

- Centralized Sand Washing Plant; and

- Centralized Sand Screening Plants.

Centralized Sand Washing Plant: At Grand Isle, stained sands were mechanically excavated and treated using a portable MiSWACO sand screening/washing system. This system was assembled and operated locally on a nearby supratidal/backshore area.

Stockpiled oiled sand removed from the shoreline is introduced to the system with a front end loader. The loader bucket is equipped with a screening device to help in the initial removal of any debris that may by mixed in the sand. The sand first passes across a vibrating screen-mounted on feed hopper which feeds a 12 inch (30.48 cm) auger. The sand is carried by the auger to a mixing hopper where it is introduced to the first of a two stage where it is mixed with a cleaning solution. The sand settles out and is slowly agitated and transported the through the tank by the auger. Overflow is discharged into a second compartment in this tank which contains air sparge tubes. The air sparge tubes release tiny bubbles into the cleaning solution that help float suspended oil to the top.

Overflow is gravity fed into an oil-water separator where floating oil is skimmed and transported to a holding tank for removal. Remaining sand is removed and transported by another auger to the second stage of the cleaning process. This stage is similar to the first but utilizes a surfactant cleaning solution. Overflow from this stage discharges into a clean (free from solids and oil) water tank. The processed sand is then transported by auger to a dump truck for return to the shoreline (MiSWACO, 2010; Schlossman, 2011).

The system operated from mid-July to early November 2010 when it was demobilized. Average through put was 290 cubic yards per day with a typical TPH output of <500 ppm. In excess of 30,000 yd^3

(221.7 m^3) of sand were processed. Processed material contained small amounts of residual oil. Sand was subsequently further treated (polished) by sediment relocation. The combined tactic was considered effective.

Centralized Sand Screening Plants

Screenable oil was eventually buried (primarily in Alabama and Florida) by natural processes to depths greater than could be recovered using shallow screening tactics. Some of this material was recovered manually, but in public, amenity beach areas this material was located and treated through a campaign entitled Operation Deep Clean. Operation Deep Clean (ODC) was undertaken during the period November 2010 to March 2011 to remove subsurface shoreline oil from Alabama and Florida sand beaches.

The ODC technique involved uncovering deeper buried layers by pushing the clean overburden to the backshore using construction equipment including small bulldozers and treating the freshly exposed oil/sand layers using either: (1) existing recovery equipment (commercial beach cleaners and special purpose units such as the Sand Shark); or (2) excavation of material using construction equipment and transport to centralized mobile screening plants for processing. In some cases, plows were used to break up hardened layers to facilitate their recovery. The screening plants produced two streams, one containing oil residue SRBs and trash (with minor sand), which went to offsite disposal, and one containing material that passed through the screens (largely clean sand), which was returned to the point of excavation. The returned sand and the overburden material on site were graded to the original shoreline contour. Tire and tread marks were then graded smooth. Operation Deep Clean was considered effective.

Tampa Bay: 1993

Description: A three vessel collision on August 10, 1993 at the entrance to Tampa Bay, Florida resulted in a spill of approximately 7810 bbl (1,965 tonnes) of No 6 Fuel Oil from the Tank Barge Bouchard B-155. Approximately 23.3 km of high amenity oceanfront fine-grained sand beaches were oiled. The initial oiling was limited to the beach surface but within several days parts of this surface layer were buried by a 15 to 30 cm (5.9 to 11.9 in) layer of clean sand.

Shoreline Cleanup Strategy: With the approach of the Labor Day holiday, pressure to clean the beaches was high. The spill management team established a Technical Committee to advice on strategies and tactics to develop a cleanup plan (Owens et al., 1995). This science-based Technical Committee involved local academics from the Coastal Research Laboratory at the University of South Florida who had long-term data on the dynamics of the affected beaches.

Removal of the overlying clean sand, followed by removal of the buried oil would have required a massive and time consuming manual cleanup effort. The necessary time frame could be achieved with assistance from mechanical tactics. Concerns were expressed over beach destabilization resulting from excessive sand removal. Working with the Corps of Engineers, calculation of the amount of sand that would be removed was determined to be unlikely to result in beach instability, so the decision was made to expedite cleanup using a combination of manual and mechanical cleanup tactics.

Mechanical Tactics: Initially the oil did not penetrate deeply into the fine-grained sand and manual removal was selected as the best choice to minimize clean sand removal. Up to 1500 people were used to shovel oiled sands into bags, lift the oil layer into front end loaders using shovels, or rake scattered oil and/or tar balls. The burial of the oil required additional tactics that included:

- Manual pickup with material placed in piles for later pickup in areas with light surface oiling;

- Manual pickup with material placed directly into front end loader bucked was used for more heavily surface oiled areas;
- Motor graders were used where buried layers (and overburden) could be side cast into a windrow for subsequent pickup using front end loaders;
- On steeper sections of beach front end loaders were used with their backs to the water to lift the buried oil layer into the buckets of a second team of loaders for removal;
- After removal of the oiled sediments (manual or mechanical), any residual stained sand was pushed into the surf zone for surf washing, using a front end loader; and
- The cleaned areas frequently had residual stained sand and were tilled to a depth of 1 m (3.28 ft). The sediments were then relocated to the water line during low tides for final polishing.

This combination of strategies and tactics successfully cleaned the oiled sand beaches to a level that was acceptable to the local government in time for the Labor Day holiday. The mechanical component of the operation involved 103 front end loaders and 13 motor graders to remove the oiled sediment from the beaches and more than 350 trucks to haul the material. Approximately 27,000 m^3 (35,313 yd^3) of oiled sand were removed in less than 5 days. This volume removed averages to1.9 m^3/m (2.49 yd^3/1.31 yd) by length of shoreline or 1.4 m^3/m^2 (1.83 yd^3/1.20 yd^2) by area. Follow up beach observations indicated that this removal had virtually no impact on short- or long-term beach processes, stability, or erosion (Owens et al., 1995).

Pacific Adventurer, Queensland, Australia: 2009

Description: On March 11, 2009, the 23,737 dwt cargo ship Pacific Adventurer was holed on its port side near the engine room and damaged a starboard bunker fuel tank below the waterline. It was estimated that over 1,979 bbl (270 tonnes) of heavy fuel oil were lost. The oil impacted significant portions of the SE Queensland coast, including high amenity shorelines. Most of the shorelines consisted of sand beaches and large amounts of oil were buried as a result of weather and sea conditions (AMSA, 2012).

Shoreline Cleanup Strategy: Manual recovery formed the primary strategy to minimize the removal of excessive clean sand. This strategy was supported by the used on tractors and loaders and other machinery to handle material recovered. Surgical removal of oil and oiled sand was conducted to a lesser degree using construction equipment and commercial beach cleaners (sand sifters).

Mechanical Tactics: Cleanup operations went on for approximately 2 months using a total of 2500 people. Although tactics relied heavily on manual recovery, mechanical cleanup that involved shallow excavation using FELs and track hoes was successful. Commercial beach cleaners (towed traveling screen and walk-behind types) were used effectively, but to a limited degree. Approximately 22,388 bbl (3000 tonnes) of oiled sand were removed, according to the equipment manufacturer (Beach Tech).

T/V Amoco Cadiz, France: 1978

Description: On March 16, 1978, The T/V Amoco Cadiz grounded on rocks off Portsall on the Brittany Coast of France. The ship broke up, releasing the entire cargo of 1,619,048 barrels (220,838 tonnes) plus ships bunkers. The release included both Arabian Light and Iranian Light (API 33.8) as well as Bunker C (API 7-14). Approximately 200 miles (322 km) of shoreline, including many sand beaches, were impacted. Oiling included heavy pooling along the shoreline. Initially, stranded oil did not penetrate into beach sands. Eventually, however, buried oil was detected at depths of up to 20 inches (50.8 cm), including two or more subsurface layers due to reworking of sediments (NOAA, 2012).

Shoreline Cleanup Strategy: Response strategy was divided into three stages (Bellier, 1979):

- Removal of floating oil, at sea and along the shoreline;
- Removal of debris on the shoreline; and
- Shoreline cleanup.

Mechanical Tactics: Heavy seaweed accumulations complicated attempts at collection of thick and pooled oil, requiring their removal prior to treatment of the beach itself. Oiled seaweed removal was accomplished manually with rakes and with the use of mechanized equipment such as farm tractors/wagons and front end loaders. Many techniques were evaluated. Primary mechanical tactics used on sand beaches included (Hann, 1979):

- Decanting of oil from debris collected with front-end loaders in lines backshore pits;
- Construction of trenches in the beach using motor graders and front end loaders, and using same to scrape surface oil into them for recovery;
- Use of Front-end loaders to scoop up oil and oiled material and place in dump trucks;
- Excavation of oil sand with disposal offsite;
- Treatment of sand with sorbents and talc (recovery primarily by flushing and vacuum recovery);
- Sediment relocation (push into surf); and
- Plowing and harrowing (tilling) with removal by natural wave action.

Oiled sand constituted a large percentage of the massive quantity of waste generated during the response (Bocard, 1979). Putting the amount of emulsified oil involved into perspective, Hann (1979) estimated that 78,678 1800-gallon (6814 l) vacuum trucks would have been required to hold the 3,938,468 bbl (537,207 metric tonnes) of material spilled (not including seaweed, debris, sand and other material). Due to the magnitude of the shoreline problem, it was difficult to judge the efficacy of the shoreline operations. Much of the stranded oil was likely removed by natural processes.

T/V Prestige, Spain: 2002

Description: After being refused haven in French, Spanish and Portuguese ports, the damaged tanker Prestige sank off the Spanish coast on November 19, 2002, releasing over 476,190 bbl (64,952 tonnes) of heavy fuel oil. Due to the cold water, oil remaining in the sunken hull leaked slowly over time, and much of it remained on board. Initially oiling was limited to the shoreline surface only. Over time, burial of oil (multiple layers) was reported. It is estimated that approximately 80 % of the cargo was spilt or removed.

Shoreline Cleanup Strategy: The primary shoreline cleanup strategy was based on manual recovery. Thousands of volunteers (up to 10,000 per day) were organized to help clean the affected shoreline.

Recovery efforts were supported by the use of mechanical equipment where practical for the handling of recovered material.

Mechanical Tactics: Mechanical tactics used on the oiled sandy beaches included oleophilic roll machines, commercial sand screener devices of various sizes, and sand washing.

- Oleophilic Roll Machines. Production equipment is available. Units are attached to the front of tractors or are available as smaller walk-behind units. Both types have limited onboard storage capacity. Application is limited to viscous surface oil. Insufficient information was available to evaluate the effectiveness of these devices.

- Commercial Beach Cleaners. Included use of 48 Beach Tech devices during response efforts. These devices were effective in the recovery of weathered oil and oil/sand accumulations in the upper sand layers (to 6 inches: 15.24 cm).

- Sand Washing. Insufficient information was obtained for evaluation of this tactic – it is presumed to have been successful.

Alvenus, Louisiana: 1984

Description: 65,000 bbl (8,866 tonnes) of Venezuelan Merey and Pilar Crude oil were spilled and stranded on the sand shorelines along the Bolivar Peninsula and Galveston Bay, Texas.

Shoreline Cleanup Strategy: Primary strategy was containment and removal of free oil using skimmers and vacuum equipment. Mechanical and manual tactics were used along the shoreline.

Mechanical Tactics: Beach cleanup was accomplished using road graders to move newly beached oil to above the high tide zone. Graders were most efficient when used together in staggered formation, moving from the intertidal area to backshore storage areas. Oiled sand collected in the storage area was loaded in dump trucks for transport to offsite disposal facilities. This operation involved as many as 50 motor graders and 100 dump trucks. Wave and tidal remobilization of sunken oil in the subtidal zone required continual re-cleaning of shorelines.

The graders were only available for a short time period and did not remove all of the stranded oil. The mixed oil-sand surface layer that remained was up to 6 inches thick with >50 % oil and was reworked on a rising tide to produce baseball bat size “rollers” in the swash zone that continued to re-oil the beaches for many weeks.

T/V Urquiola, Spain: 1976

Description: As much as 220,000 bbl (30,008 tonnes) of light Arabian crude oil were released off the Spanish Coast on 12 May 1976. The floating oil became emulsified and mixed with floating seaweed, making recovery difficult. These accumulations were up to 1.2 meter (3.95 ft) thick in some places. Recreational and other shorelines were heavily oiled, with oil penetrating several feet into the intertidal sediments in some areas.

Shoreline Cleanup Strategy: Cleanup focused on manual recovery combined with mechanical tactics in attempting to remove the oil as rapidly as possible.

Mechanical Tactics: Bulldozers and front-end loaders were used unsuccessfully, resulting in repeated working of beaches and forcing the oil deeper into the sediments. Removal of excessively large amounts of sand by repeated and improper application of equipment raised concerns of destabilization of the beaches, although no documentation of this actually happening were identified.

The most successful cleanup operation involved combining manual and mechanical tactics, including digging of trenches above the high tide line with machinery and using manual labor to sweep or hose floating oil into the trenches where it could be recovered using vacuum trucks.

4.4 Historical Shoreline Cleanup Manuals

Shoreline cleanup issues received considerable attention in Europe and Canada following the 1967 T/V Torrey Canyon and 1970 T/V Arrow oil spills, respectively. Of particular significance to operational aspects of mechanical beach cleanup were the initiation by the United States government of Research and Development projects following the 1969 Santa Barbara blowout and the 1972: Oregon/Arizona Standard oil spill that generated four pioneering study reports:

- **Evaluation of Selected Earthmoving Equipment for the Restoration of Oil-oiled Beaches** (Sartor and Foget, 1970);
- **Preliminary Operations Planning Manual for the Restoration of Oil-contaminated Beaches** (URS, 1970);
- **Manual of Practice for Protection and Cleanup of Shorelines**, **Vol. 1 Decision Guide, Vol. 2. Implementation Guide** (Foget, Schrier, Cramer and Castle, 1979); and
- **Restoration of Beaches Contaminated by Oil** (Gumtz, 1972).

These documents provide detailed information on the selection and operation of shoreline cleanup tactics, focusing on sand beaches and use of construction equipment. Basic equipment and tactics described in these documents have not changed significantly and form the basis for current mechanical cleanup practices on sandy beaches. This is not to imply that tactics presented have always been implemented correctly. Mistakes have occurred and tend to be remembered. Nonetheless, modern-day responders can learn from misapplications and for that reason, a review of selected older cases has been included in this study. In the context of these early field trials and bench tests for oiled sand beaches, three papers from the Proceedings of the 1971 Joint Conference on Prevention and Control of Oil Spills (published by the American Petroleum Institute, Washington, DC) could be regarded as state-of-the-art if repeated today:

- **Evaluation of Selected Earthmoving Equipment for the Restoration of Oil-Oiled Beaches** (Sartor and Foget, 1971);
- **Froth Flotation Cleanup of Oil-Oiled Beaches** (Gumtz and Meloy, 1971); and
- **A Hot-Water Fluidization Process for Cleaning Oil-Oiled Beach Sand** (Mikolij and Curran, 1971).

Subsequent to the above studies, a number of functional procedural manuals and guidance documents that address mechanized sand beach cleanup tactics were developed. Much of the material in these manuals is repetitive and draws on the early studies noted above. For the most part, these manuals arrive at the same conclusions and offer the same recommendations and guidelines. They provide an indication of the importance placed on the shoreline operations by industry and governments beginning in the early 1980s, spurred initially in part by a series of large tanker spills that oiled coasts in the late 1970s: 1974

Metula (Chile), 1976 Urquiola, (Spain); 1978 Amoco Cadiz (France), and 1979 Burmah Agate (USA). These documents include:

- **Inland Oil Spill Cleanup Manual (**CONCAWE, 1981);
- **A Field Guide to Coastal Oil Spill Control and Clean-Up Techniques** (CONCAWE, 1981);
- **Oil Spill Cleanup of the Coastline – A Technical Manual** (Warren Spring Laboratory, 1982);
- **Oil Spill Response: Options for Minimizing Adverse Ecological Impacts** (API, 1985);
- **Response to Marine Oil Spills** (ITOPF, 1987);
- **Oil Spill Response Field Manual** (Exxon Production Research Company, 1992);
- **Evaluation des techniques de nettoyage du littoral suite à un déversement de pétrole** (CEDRE, 1993);
- **Shoreline Countermeasure Manual for Temperate Coastal Environments** (NOAA, 1992);
- **Canadian coastal environments, shoreline processes and oil spill cleanup** (Environment Canada, 1994);
- **Oil spill clean-up of the coastline — A technical manual** (Marine Pollution Control Unit, 1994);
- **Field Guide for the Protection and Cleanup of Oiled Shorelines** (Environment Canada, 1995);
- **Options for Minimizing Adverse Environmental Impacts of Freshwater Response** (API, 1995);
- **Beach Protection and Cleaning Equipment and Techniques for Oil Spill Response** (Marine Spill Response Corporation, 1995);
- **Standard Guide for Describing Shoreline Response Techniques** (ASTM Standards, 2002);
- **A Field Guide to Oil Spill Response on Marine Shorelines** (Environment Canada, 2010);
- **Characteristic Coastal Habitats: Job Aid: Choosing Spill Response Alternatives** (NOAA, 2010);
- **Characteristics of Response Strategies: A Guide For Spill Response Planning in Marine Environments: Job Aid** (NOAA, 2010);
- **Guidance on Waste Management During a Shoreline Pollution Incident – Operational Guidelines** (CEDRE, 2011); and
- **World Catalogue of Oil Spill Equipment** (various editions).

5.0 Current Practice

5.1 Mechanized Sand Beach Cleanup Strategies

A variety of strategies have been used successfully for cleanup of sand beaches. These include manual recovery, flushing procedures and mechanized cleanup. Depending on circumstances, these strategies can, and have been implemented individually and in combination to meet the demands of each situation.

Based on information provided by the literature review and experience of the authors, mechanized sand beach strategies can be grouped as follows:

- **Debris and Bulk Oil Removal:** In some cases, heavy debris accumulations may prevent access to the oil and may clog or otherwise interfere with equipment operation. In such cases debris removal may be required prior to initiating other treatments. Cases may also be encountered where oil is deposited or pooled on the beach surface, but does not penetrate into the sand (for example on hard packed wet sand). In this situation, it may be possible to recover significant amounts of bulk oil with minimal, or no, removal of sand;

- **Excavation:** Physical removal of oiled sand, and in particular, subsurface oil-sand mixtures, may be appropriate if other options cannot separate the oil or reduce the oil concentrations to acceptable levels;

- **In-situ Treatment:** In situ treatment refers to oil mixed with sand which can be removed, treated or cleaned without removing sand from the beach. Mechanical tactics include mixing (tilling) and screening or raking (where the treated sand is re-deposited in the location from which it was removed. In-situ treatment also includes the movement of oiled sand to lower portions of the intertidal zone for washing by natural processes; and

- **Ex-situ Treatment:** Ex-situ treatment refers to excavation and off-backshore/supratidal treatment with mobile screening plants, washing plants, or thermal treatment plants. Treated material is then returned to the beach for further processing or disposal at the point of excavation.

These strategies are listed in Table 5.1, which also presents strategic objectives for each category and the general tactical approach commonly used.

5.2 Selection of Tactics

Tactics identified in Table 5.1 can be implemented using a variety of equipment types. The same equipment can be utilized for different tactics, although adjustments in operation may be required. Table 5.2 presents a preliminary matrix for identification of tactics and equipment based on a number of easily determined criteria. This table will be refined as additional detail is developed in Phase 2 of this study and will be included in the Phase 2 Manual of Practice for Mechanical Cleanup of Sand Beaches.

Table 5.1 Mechanized Sand Beach Cleanup Strategies and Tactics

Strategy	Strategic Objective	Tactical Approach
Debris and Surface Bulk Oil Removal	Debris Removal	• Mechanical Rakes • Earth-moving Equipment
	Surface Bulk Oil Removal	• Trenches and Pits • Vacuum Systems • Oleophilic Devices • Earth-Moving Equipment
Excavation	Precision Removal of Localized Material or General Excavation	• Earth-moving Equipment
In-situ Treatment	Screenable Materials	• Commercial Beach Cleaners • Combination Construction and Mobile Sieving Equipment
	Mechanical Mixing	• Construction Equipment • Agricultural Equipment
	Sediment Relocation	• Construction Equipment
Ex-situ Treatment	Portable Screening Plants	• Sand and Gravel Processors
	Portable Washing Plants	• Water Wash • Chemical Wash
	Thermal Treatment Plants	• Incineration • Thermal Desorption

Table 5.1 Mechanized Cleanup Tactics Applicability Matrix

		Debris and Surface Bulk Oil Removal						Excavation	In-situ Treatment				Ex-situ Treatment		
		Debris		Surface Bulk Oil											
		Beach Rakes (Debris only)	Construction/Logging Equipment	Oleophilic Beach Cleaners	Collection Trench/Pit	Vacuum Systems	Construction Equipment		Comm. Beach Cleaners	Const Equip – Towed Sieves	Mechanical Mixing	Sediment Relocation	Portable Sand & Gravel Plants	Portable Washing Plants	Thermal Treatment
Depth (m/ft)	Surface														
	<05/<0.16	na	na	na	na	na	na								
	<1.0/<3.28	na	na	na	na	na	na								
	<2.0/<6.56	na	na	na	na	na	na								
	>2.0/>6.56	na	na	na	na	na	na								
	Debris	na						na							
Oil	Pooled	na	na					na							
	Fluid	na	na												
	Emulsions		na												
	Screenable		na												
	Non-screenable	na	na												
	Pavement	na	na	na	na	na	na								

		Debris and Surface Bulk Oil Removal						Excavation	In-situ Treatment				Ex-situ Treatment		
		Debris		Surface Bulk Oil											
		Beach Rakes (Debris only)	Construction/Logging Equipment	Oleophilic Beach Cleaners	Collection Trench/Pit	Vacuum Systems	Construction Equipment		Comm. Beach Cleaners	Const Equip – Towed Sieves	Mechanical Mixing	Sediment Relocation	Portable Sand & Gravel Plants	Portable Washing Plants	Thermal Treatment
Dist depth	Saturated	na	na	na	na	na	na						na	na	na
	Layer(s)	na	na	na	na	na	na						na	na	na
	Irregular	na	na	na	na	na	na						na	na	na
Sand	Dry														
	Wet														
	Saturated														na
Grain size	Fine-med	na		na		na	na								
	Coarse	na		na		na	na								
	>Granules	na		na		na	na								
Beach Morphology	Backshore/Upper IT												na	na	na
	Flat												na	na	na
	Berm				na								na	na	na

		Debris and Surface Bulk Oil Removal						Excavation	In-situ Treatment				Ex-situ Treatment		
		Debris		Surface Bulk Oil											
		Beach Rakes (Debris only)	Construction/Logging Equipment	Oleophilic Beach Cleaners	Collection Trench/Pit	Vacuum Systems	Construction Equipment		Comm. Beach Cleaners	Const Equip – Towed Sieves	Mechanical Mixing	Sediment Relocation	Portable Sand & Gravel Plants	Portable Washing Plants	Thermal Treatment
	Cusps				na								na	na	na
Treatment Rate	Slow Medium Rapid	R	M	S-M	R	M	M	M-R	M-R	M-R	M-R	M-R	S-M	S	S
Environmental	Low Medium High	L	L-M	M	L	L	M	L-H	L	L	L-M	L-M	L-M	L-M	L-M
Cost	Low Medium High	L	M	M-H	L-M	M-H	M-H	M-H	L-M	L-M	L-M	L-M	HH	H	H

- Green: Generally Applicable
- Yellow: Case-by-case Applicability
- Red: Not Generally Applicable
- na: Criteria Not Applicable

5.3 Description of Tactics

5.3.1 Debris Management

Accumulations of debris (logs, drift wood, seaweed/wrack, trash and other materials) frequently accumulate on beaches and become oiled. Typically such materials accumulate in the upper intertidal and backshore areas, and their presence can significantly complicate cleanup efforts. If practical, these materials should be removed, protected, or temporarily relocated before they are oiled. Note that some forms of debris (such as seaweed and wrack for example) may be important to the local ecology.

Historically, removal of significant debris accumulations has been accomplished either manually or using mechanical equipment. Mechanical pickup can be conducted for smaller size materials using commercial beach cleaners in situations where their operation is feasible. Raking-type devices are generally most advantageous for this application. Mechanical equipment (front end loaders) has also been useful for pickup of seaweed/wrack and trash with minimal disturbance and removal of clean sand. An example of typical beach debris is shown in Figure 5.1. In the event debris includes large size material such as logs and trees (or anything that cannot be removed using manual or commercial beach cleaners), use of 4-in-one buckets on front end loaders and logging grapples may be appropriate (Figure 5.2). Logs have become an integral part of the beach dynamics in many areas and provide a stable defense again storm-wave erosion, particularly the Pacific Northwest of the U.S., Alaska and Canada. Log removal may destabilize a beach and require government agency approval.

5.3.2 Surface Bulk Oil Removal

Stranded oil may remain on the surface of well compacted and damp sand beaches, allowing recovery without significant disturbance of underlying clean material. A variety of mechanized tactics can be used, including vacuuming, herding oil into depressions and/or excavated trenches and sumps for recovery, and use of oleophilic beach cleaners.

Figure 5.1 Typical Small Beach Debris

Source: www.maritimeNZ.gov.nz

Figure 5.2 Removal of Logs

5.3.2.1 Vacuum Recovery

Several types of vacuum devices are available, including small portable or trailer-mounted units, vacuum trucks, and some commercial vacuum devices. All vacuum systems are sensitive to concentrations of debris which can result in clogging of intakes and hoses, with resulting downtime.

Portable Vacuum Systems: A small capacity vacuum unit with a single collection wand is shown in Figure 5.3. These units can be used on beaches inaccessible to larger equipment. Most are designed to empty into drum-size containers which can be changed on site, allowing the primary device to continue operation while filled containers are removed from the beach. The small wand and hose diameter make these devices particularly subject to fouling with debris. Small self-powered tracked units are also available.

Trailer and Skid Mounted Vacuum Systems: Larger capacity trailer and skid-mounted models can generally be provided by larger oil spill response organizations. These devices must be taken off the beach for off-loading when full. Their use may be limited by beach access and trafficability (using gross vehicle weight). A trailer-mounted vacuum system with a single surface wand is shown in Figure 5.4.

Recovery of surface oil from sand using a vacuum system is shown in Figure 5.5. In this case, recovery using the open end of the hose is used, rather than with a wand.

Vacuum Trucks: Vacuum trucks can be used for surface oil recovery and are available in most areas. Their use on beaches is also limited by beach trafficability, based again on gross vehicle weight. Sizes suitable for shoreline applications (considering weight and maneuverability) range from 6 to 140 bbl. (0.8 to 19.1 tonnes) in tank capacity, depending on local conditions although larger sizes are available. Vacuum truck hose diameters are larger than those in portable devices, and are capable of accommodating larger debris, although clogging is always possible. A variety of wands are available to facilitate recovery of thin layers of fluid oil, and multiple wands can be linked by manifolds. A vacuum truck operating on a beach berm is shown in Figure 5.6.

Source: www.Aquaguard.com

Figure 5.3 Use of Portable Vacuum System to Recover Oil

Source: www.Elastec.com

Figure 5.4 Trailed Mounted Vacuum Device Showing Recovery Wand

Source: NOAA

Figure 5.5 Vacuuming Oil off Fine Compacted Sand – Tampa Bay

Source: NOAA

Figure 5.6 Application of Vacuum Truck to Recovery of Surface Oil – Tampa Bay 1993

On several occasions, commercial street cleaning trucks have been tested for recovery of surface tar balls on hard-packed flat beaches. A unit tested along the Texas Coast during the Ixtoc I oil spill is shown in Figure 5.7. This application was successful but the tar ball density was so low that manual recovery was more economically feasible. Note that this type of sweeper uses a vacuum head, which can be lowered to the beach surface, and its brushes were not utilized.

Source: RCE Inc

Figure 5.7 Use of Commercial Street Vacuum to Recover Tar Balls

5.3.2.2 Mechanized Herding with Trench/Sump Recovery

Fluid surface oil layers can be herded manually using squeegees or with machines including front end loaders and motor graders. This tactic is normally restricted to hard-packed flat beaches capable of supporting heavy equipment without mixing oil deeper into the beach. Figure 5.8 shows a motor grader herding surface oil to a collection point.

Operation of heavy equipment in this mode requires precise control of the bucket or moldboard depth settings to minimize unnecessary removal of underlying clean sand. It may, however, be necessary to remove a small amount of clean sand. Oil is pushed or directed to excavated sumps, trenches or depressions for recovery by tank or vacuum truck. Effectiveness of this tactic on motor graders can be improved by bolting a rubber squeegee to the moldboard. Addition of a squeegee provides a flexible seal on the packed sand surface, improving its surface conformance. Rubber squeegees are used for paving operations and snow removal and are available from heavy equipment accessory suppliers. They can also be manufactured from used conveyor belts and bolted onto the machinery. In this case, thicknesses should be adjusted so that the cutting edge is not rigid, but also not so flexible that it folds under the bucket or moldboard when the machine is moving. Collected oil should be recovered as soon as possible to reduce the possibility of the trench or sump filling with sand during tidal changes. Other attachments such as mold board containment gates (Ironex Supply Ltd) may also assist in the precise control of herded oil and oiled sand.

(Source: ETech Intl)

Figure 5.8 Use of Motor Grader to Herd Surface Oil to Sump for Recovery

5.3.2.3 Oleophilic Recovery Devices.

A number of devices have been proposed or developed over the years specifically for cleaning flat surfaces, such as sand beaches. A comprehensive survey of these devices was conducted by MSRC in its Technical Report: Beach Protection and Cleaning Equipment and Techniques For Oil Spill Response (Taylor et al., 1995) and in the papers "On the Evaluation of Mechanical Beach Cleaning Equipment Designed for Beach Cleanup" (Taylor and Belore, 1981) "A Review of Mechanical Beach Cleaning Machines" (Taylor et al., 1994), and "Specialized Mechanical Equipment for Shoreline Cleanup (Taylor and Owens, 1997). Attempts were made to evaluate the current status of many of the pieces of equipment, and it is believed that many are no longer in business or manufacturing these products. This is possibly attributable to the economics of this type of product. The commercial market for this type of machinery is very small and development and production costs are high. It is also believed that many of the devices listed are prototypes or limited production items, and few have been proven in actual spill responses.

A few devices have, however, been used successfully and currently have at least limited availability. These include oleophilic roll and brush-type devices. Oleophilic roll cleaners have been experimented with for a number of years but have not gained large popularity due to their limited application. Nevertheless some are in current production, including the foreign manufactured devices illustrated in Figure 5.9. These machines are available in two sizes, as shown. The smaller has a 1.2 m (3.9 ft) swath and is designed to be pushed or pulled by quad vehicles or small tracked devices. The larger version, intended for pushing in front of a tractor, has a swath of 4 m (13.1 ft). Both were reportedly used successfully on flat sand beaches during the Erica and Prestige oil spills (LeGuerrous, 2008; Little and Fichant, 2007).

Brush-wheel type bucket skimmers are also currently commercially available. In these, brushes pick the oil off the surface and empty it into buckets that are attached to equipment booms or cranes. They are normally used for recovery of fluid oil from pits or shallow water, but some are configured in a form that allows them to be worked over flat surfaces, including compacted sand beaches. An example brush bucket skimmer is shown in Figure 5.10.

Source: CEDRE

Figure 5.9 Oleophilic Drum Beach Cleaners

Source: LAMOR

Figure 5.10 Oil Recovery Brush Bucket

5.3.2.4 Support of Manual Cleanup

Construction equipment is also frequently used to support manual surface cleanup. Front-end loaders of various types are typically used as local collection bins and for transport of collected material to trucks or stockpile areas. Off-road trucks, including articulated vehicles, are also applicable to the support of sand beach cleanup efforts. A typical support effort is depicted in Figure 5.11.

Source: NOAA

Figure 5.11 Mechanized Support for Manual Cleanup Efforts

5.3.3 Excavation

5.3.3.1 General

In situations where unacceptable levels of oiling are present in beach sands and cannot be removed effectively using alternate tactics, excavation may be required. Although smaller amounts can be removed manually, larger and deeper oiled sediments or oil layers require the use of machinery. Excavated material may be processed locally, with clean sand returned to the beach or it may be treated or disposed of offsite. Beach excavation is normally conducted using heavy equipment designed for earthmoving. This equipment can include motor graders, scrapers, bulldozers, excavators, loaders, backhoes, drag lines and related machinery. For purposes of this discussion, excavation is divided into two categories: precision removal and bulk removal. Although these categories have different objectives and utilize the same types of equipment, they may differ in how equipment is operated.

5.3.3.2 Precision Removal

Oil may be concentrated in linear near-surface bands, buried layers and irregular concentrations which contain sufficient material to warrant their physical removal (excavation). Deposits of oil of this nature can be removed mechanically with minimal loss of surrounding or overlying clean sand, if the location of the material is fairly accurately known and the proper equipment is selected and carefully operated.

Equipment requirements and tactics are determined by the dimensions and depth of the oily deposits, flatness and trafficability of the beach, size and maneuverability of the equipment, and shoreline access. Selection must be based on incident-specific conditions. Several scenarios are described as follows to illustrate the general applicability of equipment to commonly encountered situations.

Saturation of Near Surface Layers Along Mid to Upper Intertidal Zone, Flat Beach

Motor graders and scrapers can be used for removal of oiled surface layers up to approximately 15 cm (6 inches) per pass on flat sand beaches which can support their weight. Machinery is typically operated parallel to the shoreline, working with the tide in all cases. If motor graders are used, moldboards should be set to just below the depth of oiling. Starting at the seaward extent of the oiled zone, windrows are cast in succeeding passes, working the material toward the backshore. Multiple motor graders can be used in overlapping patterns. Recovery of the resulting windrows can then be accomplished using elevating scrapers, front end loaders, force-feed loaders or similar equipment. Elevating scrapers may provide the quickest method of windrow recovery and transport to backshore stockpile areas. Operations should be timed to have all windrowed material removed by high tide for each period of operation. In Figure 5.12, a motor grader is shown creating an oiled sand windrow.

Source: E. Owens

Figure 5.12 Use of Motor Grader to Concentrate Oil

In Figure 5.13, an elevating scraper is shown loading a windrow generated by motor graders.

Source: RCE Inc

Figure 5.13 Application of Elevating Scraper to Recover Windrow

Surface layers on flat beaches can also be removed directly using scrapers. Elevating paddlewheel scrapers are preferred, but bowl scrapers can also be used, as shown in Figure 5.14. Tracked and wheeled excavators such as the Gradall shown in Figure 5.15, or bulldozers using angle blades can also be used, although treatment rate are slower. Excavators can dump directly into trucks, but material recovered using bulldozers requires a two-step process with loaders.

Precision cuts require that the operator have excellent visibility of the equipment's cutting edge. Visibility for some equipment, including scrapers and bulldozers may be limited, and observers on the beach may be necessary to direct operations.

In the event that the depth of oiling exceeds practical limits for a single equipment pass, multiple passes may be conducted. Observations should be made in this event to ensure that such actions are not mixing the oil deeper into the sand.

Source: NOAA

Figure 5.14 Bowl Scraper Recovery

Source: E Tech Intl

Figure 5.15 Removal of Near Surface Layer Using Gradall Excavator

Irregular Buried Oil Layers in Lower to Middle Intertidal Zone

Irregular surface topography (berms and cusps) is common in the lower to middle intertidal zone. Precision excavation in these areas requires use of smaller and more maneuverable equipment, such as front end loaders and excavators. Front end loaders are highly maneuverable and can be used effectively to expose and remove buried layers. They can be operated normal to the shoreline, with the operators back to the water, in situations where beach slope prohibits parallel operation. A representative operation using front end loaders working in tandem (excavation and material transfer) is shown in Figure 5.16.

Precision excavation of small oil accumulations can also be conducted using excavators from the land side. Several large track hoes used for excavation of oil mats at the tidal interface during the MC 252 response are shown in Figure 5.17. Tracked machines are preferred for operation on soft or irregular surfaces and near the waterline. Note also the long reach of these machines, allowing them to operate back from the shoreline and to excavate below the waterline.

Note on Application of Bulldozers: bulldozers were one type of construction equipment used in beach cleanup during the late 1960s and early 1970s. During this period tactics for their use were not well developed and their use frequently resulted in mixing of oil with deeper clean material and unnecessary removal of clean sand. Unfortunately, the stigma associated with early bulldozer mistakes lingers to the present, and their use is not always viewed favorably. In reality, the issue is the manner in which the equipment is used rather than the equipment itself, so that with proper operation, bulldozers can be used successfully for precision and bulk excavation in many situations. Figure 5.18 depicts a small bulldozed used for very shallow removal of oiled sand.

Source: E. Owens

Figure 5.16 Precision Excavation Using Front End Loaders

Figure 5.17 Track hoes Used for Excavation of Tar Mats at Tidal Interface

http://www.nad.usace.army.mil/Media/images.aspx

Figure 5.18 Selective Removal of Sand using Small Bulldozer

5.3.3.3 Bulk Removal

Bulk removal operations may be appropriate in cases involving large areas and deep oiling. Excavations of this type require less precision and can be implemented using normal excavation procedures and equipment. Equipment can include bulldozers, excavators, and drag lines. Larger equipment can be utilized. Operations near or below the beach water level (which may vary with tidal stage) can complicate excavation. In extreme cases, such as the remediation of released distillate into the Guadalupe Sand Dunes in California, sheet pile shoring and tidal water cutoff and dewatering may be necessary (California Coastal Commission, 1994). Bulk removal represents an extreme solution. Although it may occasionally be appropriate during the emergency response, it is more likely that emergency phase operations would be limited to containment, with actual bulk removal implemented in a non-emergency remediation phase.

5.3.4 In-situ Treatment

5.3.4.1 General

As used in this document, in-situ treatment encompasses mechanical tactics that are conducted on the beach. These tactics include removal of solid and semi-solid using screening technology, sand mixing (tilling), and sand relocation (surf washing).

5.3.4.2 Screenable Materials

Spilled oil is subject to processes that include emulsification and weathering. These processes commonly form solid to semi-solid residues commonly known as tar balls. When oil and emulsions strand on shorelines, they continue to weather and may also mix with sand forming a surface oil residue that is, or will, weather to a state where it is cohesive enough that it can be physically separated from clean sand by raking or screening.

Commercial Beach Cleaners

A number of mechanized beach cleaners were developed in the 1960s to remove solid materials (litter, seaweed, shells, glass, rocks, and so on) from high use sand beaches. Currently there are multiple manufacturers and models of commercial beach cleaners available, domestically and internationally. These devices serve the dual role of being able to recover trash and stranded oil from the surface and upper 10 to 15 cm (4 to 6 inches) of sand beaches, and are receiving increasing popularity for cleanup of screenable oil on sand beaches.

Beach Cleaner Methods of Cleaning: Most beach cleaning machines employ one of two primary debris collection methods: mechanical raking or screening (sifting). They are generally manufactured in a variety of configurations and sizes. Configurations include:

- Self-powered units;
- Units that can be towed. Farm tractors are generally recommended as they can provide the hydraulic/mechanical power to the run the device (Power Take Off and hydraulic supply); and
- Smaller walk-behind self-powered units.

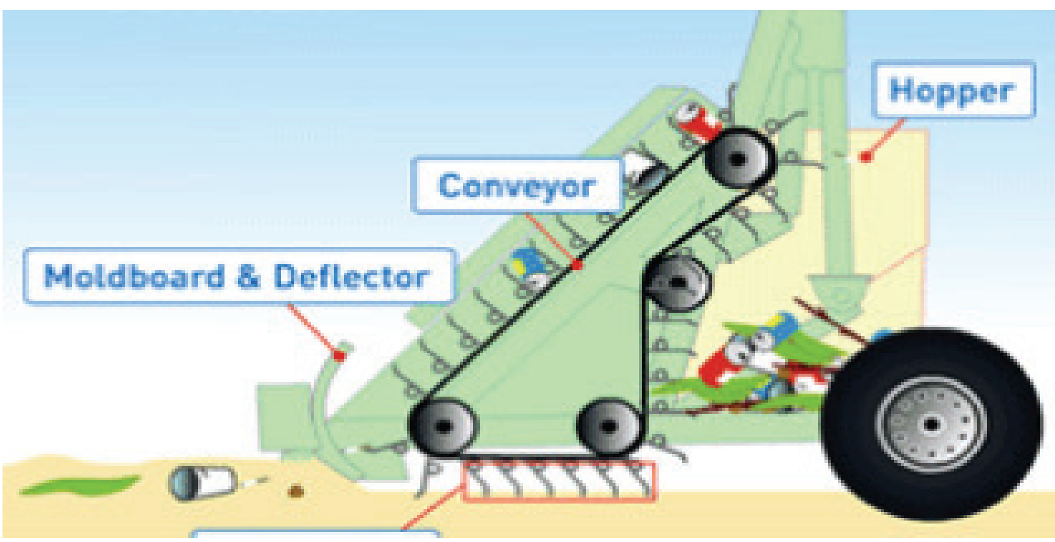
Towed rotary screen devices were manufactured historically, but it is not believed that they are currently available. Following are descriptions of the currently most common configurations.

- **Rake-type Beach Cleaners Mechanical** raking devices have rows of offset tines that rake through the sand on the beach, combing materials from under the sand's surface onto a conveyor that transports the debris (minus sand) to a collection hopper. Functional cleaning depths are determined by the length of the tines and typically range from 0 to 15 cm (0 to 6 inches).

  A typical raking configuration using tines is shown schematically in Figure 5.19. This design uses a moldboard to flatten the surface of the incoming beach and has a deflector to direct raked debris or tar balls on to the conveyor where it is carried to a hopper. The conveyor shown consists of solid plates, but perforated plates are available, adding a screening function to the device and reducing the amount of sand it recovers. The machine is also equipped with a hydraulic device to raise and empty the hopper.

  A towed rake-type beach cleaner is shown in Figure 5.20.

- **Screening Type Beach Cleaners** Beach cleaners that employ screening technology typically utilize either fixed or travelling screens. Material is fed to the screen using an adjustable moldboard, front-mounted rotating tines, or other mechanism to pick up sand and debris for presentation to the screening mechanism. In the self-powered machine shown in Figure 5.21, a moldboard removes the upper 2 to 15 cm (1 to 6 inches) of sand and debris and deposits the material on the lower end of a fixed screen. Material is then pushed up the screen using a flighted conveyor belt. The fixed screen is typically equipped with an oscillatory or vibratory mechanism and particles smaller that the screen openings (including sand) are returned to the beach. Larger solid particles are then pushed up the screen and deposited in a hopper. In some models, the screens can be replaced by solid steel plates and the unit is then capable of recovering thin layers of sand and oil. In this configuration, the units form, in effect, a small elevating scraper that is capable of excavating thin surface layers.



Source: www.barber.com

Figure 5.19 Rake-type Beach Cleaner Schematic

Source: www.barber.com

Figure 5.20 Rake-type Beach Cleaner

Source: Cherrington

Figure 5.21 Commercial Beach Cleaner with Fixed Screen

Another configuration uses a traveling wire mesh screen that is available in various sizes. The screen is fed by feed brushes, a moldboard, or other mechanism. The screen allows small particles to return to the beach while carrying larger solids to the hopper. These units can be equipped with vibratory devices or brushes as shown in Figure 5.22 to facilitate breakup of friable accumulations and return of sand to the beach. A representative towed screen-type beach cleaner is shown in Figure 5.23.

Other configurations include a self-propelled, traveling screen-type beach cleaner (Figure 5.24) and a walk-behind type (Figure 5.25). The walk-behind machine screens using oscillatory fixed screens.

Figure 5.22 Rotating Screen with Brushes to Breakup Sand Accumulations

Source: Beach Tech

Figure 5.23 Commercial Beach Cleaner (Traveling Screen)

Source: Beach Tech

Figure 5.24 Self-propelled Beach Cleaner

Source: Gravely

Figure 5.25 Walk-behind Beach Cleaner

Beach Cleaner Operational Variables Modern Beach-cleaning machines generally can be adjusted in terms of (but not limited to):

- Forward speed;
- Depth of moldboard (cut);
- Belt speed (if so equipped);
- Belt angle;
- Screen size; and
- Adjustable oscillating or vibratory screens.

In normal beach cleaning operations, the primary objective is to remove debris as rapidly as practical. In oil spill cleanup, aggressive operation can break down friable oil accumulations allowing them to pass through screens or rakes so that they are returned to the beach as smaller particles, which are harder to recover. It is essential in the application of these machines that the operational parameters of each type be adjusted to the properties of the oil being recovered. This may require a certain amount of trial and error to achieve the optimum configuration, including adjustment of screen size, where possible. The most efficient recovery tactic, in fact, may require less aggressive operation of the machine. In addition, the condition of the oil and the moisture content of the sand can be expected to change as time passes, requiring additional adjustments. In most cases, the oil and oil/sand mixtures harden with time, making them more recoverable and allowing more aggressive operation with time.

The previous discussion categorizes beach cleaners as "rakes" or "screens". In reality, a number of the currently most available devices are capable of operating either in raking, screening or combined modes, primarily by adjusting moldboard depth or adding or deleting perforated plates. One design even operates as a mini elevating scraper if its perforated screen is replaced by a solid plate. Table 5.3 presents a selection of representative commercial beach cleaner types and summarizes their operational modes, method of picking up sand and debris, and their screening mechanism, if any.

Table 5.3 Characteristics of Representative Mechanical Beach Cleaner

Type	Operational Mode			Pickup Type				Screen Configuration			
	Rake	Screener	Scraper	Tined Drum	Tined Belt	Flighted Belt	Moldboard	None	Fixed	Perforated Conveyor	Chain Link Conveyor
Manufacturer A: Towed	X	OPT			X			X		OPT	
Manufacturer A: Walk-behind	X	X		X					X		
Manufacturer B: Towed	X	X		X			X				X
Manufacturer B: Walk-Behind	X	X		X			X		X		
Manufacturer C: Self-powered		X	X			X	X	OPT	X	OPT	
Manufacturer C: Towed		X	X			X	X	OPT	X	OPT	

Adapted Mobile Sand Screeners

Several combination excavation and screening devices were tested during the Deepwater Horizon oil spill response. These devices included the following:

- **Sand Shark**. The Sand Shark consisted of a force-feed loader towing a self-contained power screen trailer. The force feed loader was designed to pick up and load windrowed material, snow, and other unconsolidated surface material. The basic design has been in service since at least the early 1970s, and was considered in some of the early beach cleanup research. During the Deepwater Horizon oil spill this concept was tested and found to be capable of excavating sand to operational depths of up to 25 cm (10 inches) (Owens, 2011). In addition to excavation, it was used to tow a trailer-mounted vibratory fixed screen normally used by the mining industry. The combined package was capable of excavating oiled sand, separating non-friable sand/emulsion accumulations, and returning clean sand to the beach in a single operation. Multiple units were assembled and widely used in the response. A typical Sand Shark is shown in Figure 5.26.

Figure 5.26 Typical Sand Shark

- **Pipeline Padder**. A pipeline padder device was developed by the pipeline construction industry to remove large rocks from windrows of material excavated during pipeline trenching operations. The device screens out large pieces of rock and other material that could damage a buried pipeline and allows the finer material to be used for bedding. A representative pipeline padder was tested during the Deepwater Horizon oil spill and determined to be capable of excavating to a depth of 30 to 45 cm (2 to 18 inches) and screening out non-friable sand/emulsion accumulations. The equipment was very noisy, had a very slow speed of advance, and was not widely used. Other sizes and types of equipment for screening pipeline bedding exist. The pipeline padder tested is shown in Figure 5.27.

Source: Ozzies.com

Figure 5.27 Pipeline Padder

Operation of equipment adapted from other industries is subject to the same types of adjustment of operating parameters and oversight as described for commercial beach cleaners. The performance of the Sand Shark qualifies it for consideration in future sand beach spill responses. This innovative combination of existing technology suggests that other applicable equipment may be available for future spill responses, and that examination of related equipment used by other industries should be conducted.

5.3.5.3 Mechanical Mixing

Mechanical mixing (or tilling) involves the breakup of surface oil and oil/sand that has penetrated into the beach or been buried in the subsurface (Owens and Sergy, 2004), Clean overburden can be moved aside temporarily to expose the subsurface if significant quantities are involved, but the mixing process does not involve the relocation of the oiled material being treated. The resulting exposure of mixed and aerated material to the atmosphere, wave, and tidal processes is intended to accelerate both physical removal and degradation (weathering).

Mechanical tactics that can be used for mixing are based primarily on the depth of the oil and include:

- **Shallow (0 to15 cm: 0 to 6 inches):** Surficial layers can be mixed using raking type beach cleaners, agricultural tilling and disking equipment (towed by farm-type tractors);
- **Moderate (0 to 70 cm: 0 to 28 inches):** Mechanical mixing at moderate depth can be accomplished using larger tractor-towed agricultural moldboard plows and disking equipment (Figure 5.28). Bulldozers and motor graders can be used with multiple rippers as well, but may not mix and aerate as effectively as agricultural equipment;
- **Deep (>70 cm: 28 inches):** Deeper oiling may require larger agricultural or excavation equipment (Figure 5.29); and
- **Buried Pavement:** The breakup of a buried pavement can be accomplished using heavy equipment equipped with rippers or scarifiers. Depending on the properties of the pavement, recovery of broken pieces may or may not be necessary.

Figure 5.28 Shallow to Moderate Depth Mixing by Agricultural Plowing

Figure 5.29 Deep Mixing

5.3.4.4 Sediment Relocation

Sediment relocation involves the physical movement of material from one location to another with the intent of accelerating natural physical removal of oil from the sand into the water column where it is rapidly dispersed and broken down biologically. This process will also breakup and aerate the oiled sand. The tactic usually involves movement of material from a higher elevation on the beach to a lower portion of the intertidal where wave action washes the material. Sediment relocation has been achieved successfully on many spills throughout the world, including the Deepwater Horizon oil spill (Owens, 1995, 2011; Owens and Sergy, 2003). Relocation typically is conducted using heavy equipment, such as front end or skid steer loaders and bulldozers, sized to meet the needs of the situation. Examples of sediment relocation are shown in Figure 5.30 and 5.31.

5.3.5 Ex-situ Treatment

5.3.5.1 General

Ex-situ treatment refers to local treatment tactics in which oiled sand is removed, treated on the backshore or off-site, and the treated sand is returned to its original location. Several groups of mechanized tactics are discussed, including use of centralized screening plants, portable washing plants, and portable thermal treatment plants.

5.3.5.2 Centralized Screening Plants

Centralized screening may be appropriate in cases where the treatment of material that is deeper than can be reached using other screening tactics exists. This tactic involves excavation of material to be treated, transport to a centralized portable screening plant, processing, and return of treated material to the point of excavation. In addition to extending treatment depth by allowing use of larger excavation equipment, this tactic is also applicable to situations where removal of visible oil must be expedited, as greater volumes can be moved and treated faster, and/or stockpiled locally and processed over time.

Portable screening plants are available in various sizes from the construction and sand and gravel industries. Units can be as small as the shaker table attachment to a belt loader shown in Figure 5.32. Various screen sizes are normally available and can be matched to the size of the target particles.

Larger portable plants are also available. For example, centralized screening was conducted during the Deepwater Horizon oil spill to process material excavated during Operation Deep Clean. Figure 5.33 shows the layout of a portable treatment operation during this operation.

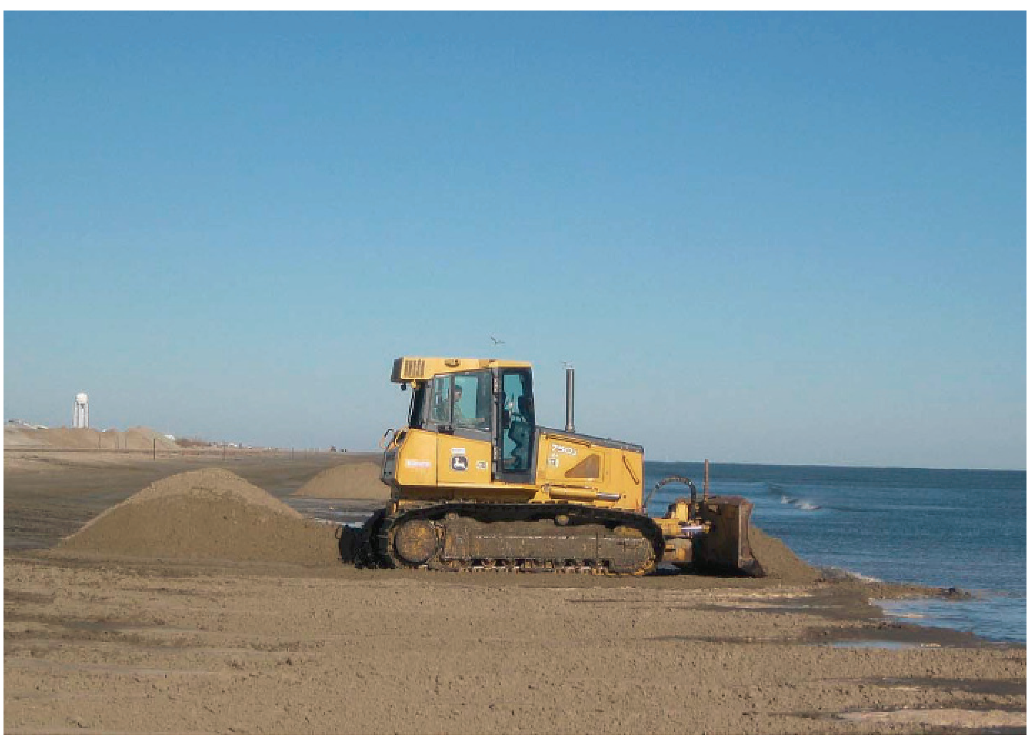
5.3.5.3 Portable Washing Plants

A variety of portable sand washing plants that can be transported to the spill scene and used in backshore locations are available. Historically, there is little documentation of the on-scene use of these devices for oil spills. These plants range from small truck-mounted units to relatively high through-put plants. Cement trucks have been used on occasion as small-capacity sand washers.

The use of portable on-scene washing plants was evaluated during the Deepwater Horizon oil spill. Small portable plants were identified, but typically all have very low throughput and were not investigated further. A larger system having a much larger throughput was investigated, bench-scale tests were conducted, and the unit was permitted and put into operation in Grand Isle, Louisiana.

Source: E. Owens

Figure 5.30 Sediment Relocation using Front-End Loader



Source: E. Owens

Figure 5.31 Sediment Relocation Using Small Bulldozer

Source: RCE Inc

Figure 5.32 Portable Shaker Table Screening Operation

Source: www.mysanantonio.com

Figure 5.33 Operation Deep Clean Mobile Sand Screening Plant

Elements of the process included a shaker/sieve to remove debris and large oil particles and two washing units. The system was operational from mid-July to early November 2010. The entire system was demobilized due to Hurricane Bonnie and on several occasions its use was temporarily suspended by thunderstorms when lighting presented a safety issue. Otherwise the system ran an average of 2/3 of the time per day, with a maximum uninterrupted run of more than 60 hours. Average daily throughput was 290 yd^3 (221.7 m^3) and a total of approximately 30,000 yd^3 (22,938 m^3) of material were treated. The amount of oil extracted ranged from 2 to 16 bbl (.27 to 2.18 tonnes) per day (excluding large oil particles extracted by the screening process). Typical total petroleum hydrocarbon (TPH) content of the output material was <500 ppm. Processed material was subsequently further treated by sediment relocation in the area of excavation (Owens, 2011). A photo of the layout of this operation is shown in Figure 5.34.

Application of on-scene sand washing plants must consider issues including:

- Effectiveness of treatment (bench-scale testing is necessary);
- Through-put rate (Is predicted through-put rate compatible with anticipated amounts of material needing treatment?);
- Permitting Requirements;
- Political and Public Sensitivity; and
- Economic Feasibility.

Source: Shigenaka 2010; OSAT-2

Figure 5.34 Portable Sand Washing Plant

5.3.5.4 Thermal Treatment

This discussion of thermal treatment options focuses on portable technology capable of treating oiled sand on scene, with the intent of returning clean sand to the area from which it was removed. The discussion does not include in-situ burning, portable trash incinerators, or permitted stationary facilities, such as those which are involved in hazardous waste remediation. Two types of thermal treatment are discussed: incineration and thermal desorption.

Incineration: On-scene incineration of contaminated sand using technology such as portable rotary kilns is common practice for remediation of petroleum hydrocarbons and hazardous materials at land-side locations. Historically, the technology has been considered for use on oil spills; however, no documented shoreline examples its application were identified in this study. Tests of incinerators have been conducted by Environment Canada, including a portable rotary kiln and a fluidization bed incinerator. Operation of on-scene mobile incinerators will require permitting. The ability of mobile incinerators to meet emissions standards and incident-specific end-point criteria is expected to be variable, and dependent on incident-specific conditions. Unless pre-existing permits are in place, obtaining a permit can be involved and time-consuming, even under emergency conditions. Treatment and disposal options were reviewed during the Deepwater Horizon response by the Department of Environmental Protection in Florida (DEP, 2010). No permitted mobile facilities were identified in Florida and thermal treatment options were not further considered.

For perspective, a portable incineration plant is shown in Figure 5.35.

Thermal Desorption: Thermal desorption is a physical separation process that is designed to remove low boiling point contaminants, such as petroleum hydrocarbons, by heating them to temperatures ranging from 200 to 1000°F (90 to 600°C) and causing them to vaporize. As an initial step in the process, incoming materials are processed to remove debris and excess water. Oiled materials are then heated in a rotary drier, thermal screw or similar device to volatize residual water and organics. Produced vapors are then processed in a gas treatment system. Off gasses are burned in an afterburner, collected on activated carbon, or recovered by condensation. Treated soils are tested to determine how well the process worked and whether treated materials can be re-deposited on site or if alternate treatment or formal disposal is required.

Source: www. wwequip.com

Figure 5.35 Portable Incinerator

Based on the operating temperature of the desorber, thermal desorption can be divided into two groups: high temperature thermal desorption (HTTD), which operates at temperatures from 320 to 600°C (600 to 1000°F), is commonly used for remediation of halogenated hydrocarbons such as PCBs and pesticides; and low temperature thermal desorption (LTTD), which operates at temperatures of 90 to 320°C (200 to 600°F), has proven successful for removal of petroleum hydrocarbons in all types of soil (EPA 4.25). LTTD requires less fuel and is typically more cost-effective than HTTD.

A major limitation to the implementation of this technology for emergency on -scene use on oil spills involves the limited availability of permitted units. For example, this option was evaluated during the Deepwater Horizon oil spill response by the State of Florida for oily soils/sediments treatment (not boom material or other plastics) (FLA DEP, 2010). Florida's rules require minimum temperatures, residence times, emission limits and monitoring requirements to minimize air emissions. Florida currently has five permitted stationary soil treatment facilities allowed to treat petroleum oiled soil in accordance with Rule Chapter 62-713, Florida Administrative Code (FAC). During the Deepwater Horizon response, there were no facilities located in Northwest Florida and use of the permitted Florida facilities would require lengthy transport of waste materials. Florida Rule Chapter 62-713 does include provisions for permitting mobile treatment units, but there were no mobile units permitted to operate in Florida at the time.

LTTD has demonstrated the potential for oily sand treatment in onshore situations and should be considered in evaluation of options for larger shoreline oiling events. As was the case with mobile sand washing plants, permitting, economics, and other issues must be considered in evaluating the use of this tactic.

6.0 Improvements to Mechanical Oiled Sand Beach Cleaning

6.1 Prospective Advances in Equipment Technology

Historically the mechanical cleanup of oiled sand beaches has relied heavily on tactics and equipment borrowed from other industries. These industries include earthmoving, sand and gravel processing, mining, commercial beach cleaning, hazardous waste management, industrial vacuum recovery systems, and others. The mechanical equipment associated with these industries is diverse and generally available on short notice, thus eliminating the need for large capital investments for the development and manufacturing of limited-use equipment. Although equipment in these industries is constantly undergoing improvement, as witnessed in the development of commercial beach cleaners, these industries are generally mature and **significant** advances and new conceptual designs in the foreseeable future are unlikely.

A variety of mechanized devices intended **specifically** for oiled sand beach cleanup have been proposed historically. The majority of these have involved oleophilic devices intended for surface oil recovery, sand washing devices, and screening machines. Many of these devices did not progress beyond the prototype stage, although some have been manufactured in limited quantities, and some are currently available. No truly new and promising technologies were identified for mechanized sand beach cleanup during an extensive investigation of alternative technology conducted during the Deepwater Horizon response or during this study.

An important point in evaluating the potential for the development of new technologies in this area is the economics of specialty, single-purpose equipment. From a commercial point of view, the market for mechanized beach cleaners is very limited and acceptable alternative equipment can be rented for short-term operations. The development and production of new machinery is expensive and the resulting products may sit inactive in a warehouse for many years between uses, if they are used at all. As a result, there is minimal economic incentive for development and manufacture of such equipment, and many of the organizations that have attempted to produce these devices have either gone out of business after a short period, or have discontinued product lines that have not been commercially viable.

Regardless, some level of breakthrough technology for mechanized beach cleaning is, and always will be, possible. Monitoring for new ideas and products should continue.

6.2 Alternate Technologies

Existing sand beach cleanup tactics have made good use of current potentially viable technologies; however, the full magnitude of the existing resources has not been completely tapped. An example of this was the development of the Sand Shark during the Deepwater Horizon response. This apparatus cleverly combined two pieces of existing technologies in a previously untested and practical configuration. The basic design element of the Sand Shark has been available since the early 1970s and consists of a force-fed loader to tow and feed a trailer-mounted screening system adapted from the mining industry. The system doubled the depth to which screenable oil could be treated in-situ. An additional example of adapting existing technology during the Deepwater Horizon response was the permitting and use of the MiSWACO soil washing system, which was designed to wash oiled sand from tar sand operations in Canada.

Cursory examination of equipment used in other industry suggests that additional innovative use of ideas and equipment from other industries may be adapted for supporting oiled sand beach cleanup. Industries of interest include, but are not limited to, pipeline construction, mining, industrial vacuum systems, and hazardous waste management operations.

6.3 Selection and Management of Tactics and Equipment.

An important area where significant short-term gains are possible involves improvements in the manner in which existing tactics are selected and managed. Not all historical attempts at mechanized beach cleanup can be categorized as successful. Less than optimal performance commonly has been associated with factors including: 1) improper equipment selection; 2) failure to understand the objective and operational requirements of the selected equipment; 3) lack of adequate supervise implementation of the selected tactic; and 4) failure to observe and react to changes in conditions.

Improvements can be based on better understanding of the factors that affect efficiencies, including: the changing properties of the spilled oil; shoreline sedimentary processes and transport (and how they impact cleanup tactics); environmental factors; proper adjustment of equipment operating parameters to conditions encountered (including training of operators), and monitoring performance in light of changing conditions. This understanding can be translated into tools such as response strategy guidelines for decision-makers and manuals of practice for selection and implementation of sand beach mechanical tactics.

7.0 Conclusions and Recommendations

7.1 Institutional Knowledge

Oil spill environmental awareness was triggered in the United States by the 1969 Santa Barbara Oil Spill. In the aftermath of that event, a number of oil spill control programs were initiated. These included research and development studies in the 1970s regarding mechanized beach cleaning tactics and equipment, including evaluations of the application of earthmoving equipment and various approaches to cleaning oiled sand. Research and development activities have continued sporadically since then, usually in the aftermath of large shoreline oiling events. Continuity between these efforts and the lessons and experience they provided has, in effect, been lost because triggering events were often many years apart. Nonetheless, a key conclusion of this review is that there exists an extensive body of sand beach cleanup and treatment experience gained from over 40 years of shoreline response operations and trials (Section 4.4). This knowledge provides a solid basis for the development of improvements to existing technology and for identification of other existing technologies that could be adapted for treating oiled sand beaches.

Recommendation:

Review the existing literature for key studies that capture the existing institutional knowledge base. This material should be digitized, indexed, and made available to the oil spill response community as the majority of this literature is not in electronic form and is not readily accessible for general use.

7.2 New Technology

Mechanized beach cleaning has focused around earthmoving technology and this is unlikely to change significantly for reasons previously described. New sand beach cleanup or treatment tactics and machines have been proposed over the past decades, but few have progressed beyond the prototype stage and fewer have been commercially produced. Of the few current production items in this category, brush bucket skimmers and oleophilic roll devices do show application for treatment of the surface of oiled sand beaches and should be considered as developing technologies. Because there are alternative tactics and equipment that do not require capital investment, the market for new sand beach cleanup equipment is likely to remain low into the foreseeable future.

Recommendation:

Innovative breakthrough designs are always possible, but the timing of these events is unpredictable. Advances in new technology should always be monitored, but priority at this time should be given to further research into new adaptations of existing technology and the development of improved management decisions and operational guidance. Phase 2 of this project is planned to include the development of manuals and guidance documents covering these areas.

7.3 Expanded Application of Alternate Technology

Traditional mechanized sand beach cleanup and treatment relies heavily on readily-available equipment such as graders, bulldozers, front-end loaders or track hoes that are commonly and extensively used for earth-moving and debris removal, as well as larger portable sand, gravel, and soil washing devices. With the exception of beach debris removal equipment, alternate technologies, both in terms of tactics and equipment, have not been completely examined or evaluated for potential innovative applications.

Recommendation:

Evaluation of alternative technologies should be conducted routinely. A limited review of the more obvious candidate industries (earthmoving, pipeline construction, earthmoving, mining, portable sand and gravel processing, vacuum systems, agriculture, and selected hazardous waste practices) will be conducted as part of Phase 2 of this study. Tactics and equipment of high potential application may be considered for testing through mechanisms such as Phase 3 of this study or other sources of funding.

7.4 Improved Management Practices

The misuse of mechanical equipment has occurred occasionally during beach cleanup operations leading to misconceptions regarding the applicability or effectiveness of that equipment. Much of the potential for misuse can be eliminated by understanding the processes involved and by the education of managers and operators in the correct implementation of specific tactics and equipment. Areas where improvements are possible include:

- **Decision-making Information**: More informed tactical decisions can be made if there is better understanding of the environmental consequences of tactics involving heavy equipment and sand movement (and procedures for their evaluation);

- **Operational Factors**: Better understanding of the environmental and engineering parameters that control the application of effective tactics and equipment;

- **Operations Management**: Improvement of consistent management practices; and

- **Performance Indicators**: Establishment of parameters to measure the effectiveness of tactics and equipment.

Recommendation:

Selection and implementation of treatment strategies for oiled sand beach cleanup appear to be intrinsically straightforward; however, beaches are dynamic and are important environmentally and frequently as recreational or amenity resources. Response decisions and the selection of appropriate tactics should be science-based, in a manner similar to decisions regarding oiled marsh/wetland or bedrock intertidal habitats.

Phase 2 of this study plans to upgrade the traditional decision-making process incorporating knowledge obtained from recent spill experience. Practical upgrades will be developed in the form of guidance documents and decision-making guidance. For mechanized sand beach treatment, the decision process must consider coordination with other forms of beach treatment (manual, flushing, bioremediation, etc.). Phase 2 documents will provide operational guidance that will include: description of operational factors that need to be considered in the deployment of specific equipment types on sand beaches; guidance on operational tactics; and methods for monitoring and adjusting the performance of various tactics and equipment (performance indicators).

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