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OIL CONTAMINATED BEACH CLEANUP

By

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A review of representative oil spill incidents supplemented by personal and telephone interviews with persons involved in beach cleanup operations as on-scene coordinators or as cleanup operators has been made to evaluate cleanup methods suitable for future operations. The selection of procedure and equipment for beach cleanup was found to depend on the amount of oil, the characteristics of the oil as it hits the beach, and the type of beach contaminated. The most effective beach cleanup procedures and equipment have been (cont)

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identified and tabulated in terms of selected beach classifications. Recommendations for future work to remove deficiencies of existing techniques are included.

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INTRODUCTION

Federal legislation and Executive Orders place liability for complete environmental restoration after an oil spill upon the particular industries or Federal agencies responsible for the mishap. While development has been initiated within the Navy for oil containment/recovery systems, little effort has been directed to the development of methods and equipment for beach cleanup. There is a critical need for such development since beaches usually have a high public use factor and correspondingly high financial liability for damage. In the interim period, it is useful to adopt the best available methods used in previous beach cleanup operations. CEL* was tasked by the Supervisor of Salvage to review beach cleanup operations of the past, identify the various cleanup methods and equipment that have been used, and recommend the methods and equipment of record that are most suitable for restoration of various classes of beaches. Available information is to be used by the Supervisor of Salvage in compiling a manual for beach cleanup. This report presents the results of the effort.

BACKGROUND

Oil spills, such as that from the Torrey Canyon, have attracted world-wide attention. Because of increased dependence of the United States on imported petroleum and the corresponding shipping and handling of oils, it can be expected that accidental oil spills of considerable magnitude will continue to occur. The lack of research studies in beach cleanup precludes the direct development of satisfactory equipment, methods, and procedures for such operation. Considerable experience, however, has been gained in previous cleanup efforts.

On 18 March 1967, the tanker Torrey Canyon, carrying 117,000 long tons of oil, ran aground on Seven Stone Reef off the south coast of England [1,2]. Seven hundred thousand barrels of crude oil were washed ashore in England and some drifted to the beaches of Brittany, France. In England, detergents were used almost exclusively to emulsify the oil with the seawater. Since the dispersing agents were more toxic than the oil treated, severe destruction of biota resulted. In Brittany, large sumps were dug at the rear of the beaches and the oily sand was deposited therein. Sands sank to the bottom of these sumps and the oil floated to the surface and was skimmed off. Such operations require large expenditures of both time and manpower. As many as 2,300 soldiers were involved in the beach cleanup operation in Brittany.

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On 3 March 1967, the tanker Ocean Eagle was grounded within the harbor of San Juan, Puerto Rico [3]. She carried and discharged 83,400 barrels of Leona crude oil. As a result, 16 miles of recreational and commercial beaches and the entire harbor were heavily contaminated. Two hundred seventy men were deployed to remove contaminated sand from beaches. Bulldozers and graders were used. Oily sand was trucked away and replaced with fresh material. Detergents were tried, but they turned the beach into quick sand and their use was discontinued. Minstron talc and Ekoperl-33 sorbent materials were used and found to be effective for removing oil from the sand. Sorbent materials such as these, however, increase the amount of handling necessary and caused malfunctioning of pumps and other hydraulic machinery.

On 28 January 1969, an offshore drilling platform near Santa Barbara, California, had a blowout through a natural fault [4-6]. At least 100,000 barrels of oil leaked out before the head was capped. Forty miles of residential and recreational coastline were contaminated. Straw was spread to soak up the oil deposited on the beaches. Up to 1,000 men and trucks were used to collect the contaminated materials and transport them to an inland dump. Burning of oil-soaked straw on the beaches was attempted but was discontinued due to smoke, odor and heavy rain. Spraying of cold and hot water as well as steam cleaning and sand blasting were attempted in cleaning rip rap areas. Sand blasting was the only treatment found effective for cleaning rocks.

On February 4, 1970, the tanker Arrow struck Cerebus Rock near Chedabucto Bay, Nova Scotia, Canada [7-9]. She broke up, sank, and released 65,000 barrels of bunker-C oil. Of the 150 miles of contaminated shoreline, 30 miles were cleaned. Several types of mechanical equipment were used in cleanup. Wheeled front-end loaders were used successfully to cut under the spoiled sand and lift it out without disturbing the clean subsurface. Road graders were unsuccessful for working on the sloped gravel beaches. Bulldozers were unsuccessful because they spilled contaminated material around the blade, and mixed the spoiled sand with the clean areas that lay in their path. Tracked vehicles were unsuccessful because they tended to mix the contaminated surface material deeper into the beach.

On January 18, 1970, the Oregon Standard collided with the Arizona Standard in San Francisco Bay [10-12]. The two tankers spilled 20,000 barrels of bunker-C and contaminated about 50 miles of shoreline, of which about 10 miles of sand beaches were cleaned using road graders and scrapers. It was found that road grader/motorized elevating scraper combinations were the most efficient for removing contaminated sand film when the oil penetration is limited to less than 1 inch. For oil penetrations greater than 2 inches, the motorized elevating scraper operating singly is more efficient. These operational experiences verify the findings of Reference 13.

On 22 July 1972, the tanker Tomano struck a submerged ledge in Ceao Bay, Maine and released 100,000 gallons of oil [14]. Several miles of beaches on the mainland were lightly contaminated, and about 1 mile of sand and rock shore was severely contaminated on Long Island. A crane-operated dragline and a bulldozer were used to remove the surface of the beach down to a depth of 6 to 12 inches. A 6-cu. yd. front-end loader was used to transport the accumulated spoil to a barge mounted clam shell crane that transferred the spoil into a second barge for transport to a dump site. The barge crane was used to compensate for the extreme tidal movement in the ocean. Hot water jet was used on rock outcropping to remove adhering oil. This treatment left a uniform black discoloration on all the rocks. An attempt was made to burn the oil off the rocks with a flame thrower but was discontinued when spalling became excessive.

These are some of the representative oil spills involving significant effort of beach cleanup. They and other spills involving beach cleanup operation are summarized in Table 1 and described in more details in Appendix A.

Beaches along the California coast are subject to contamination from natural oil seeps. In Reference 15, a study was performed on natural contamination along the Southern California coastline. The most severe contamination was observed at Coal Oil Point where on one occasion the measured amount of oil on the beach reached 3 oz/sq ft over a 500-sq ft test area. This amount of contamination is unusual but occurs under certain combinations of wind and current.

Oil on beaches is dispersed and degraded by natural processes. The natural processes found most effective in dispersal of oil from contaminated beaches are wave action and biodegradation. Severe weather conditions and wave action tend to remove surface oil from rocks and beaches. A severe storm has been found to disperse the majority of contamination from an open beach. Such processes have been found less effective for protected coves and bays.

Biodegradation of the trapped or absorbed oil accomplishes the ultimate cleaning of a beach. There are many varieties of bacteria, yeasts, and protozoa which consume hydrocarbon materials. These forms of life perform slowly and may take years to remove the final traces of oil from a heavily contaminated beach.

Very little effort has been directed to the research of beach cleanup technology. Of the methods studied, most are either too expensive to be practical at this time or have not been proven in actual field conditions. Note that most beach contamination involves very large quantities of contaminated material, e.g., cleanup of a 5-mile stretch of beach involved removal of 6,000 cu yd of contaminated sand. Treatment of this amount of sand requires a long period of time, and the costs are high. Treatment of beach sand to remove oil can be justified only where beach sand is a scarce and costly commodity. Disposal is a frequent problem, and some studies have been made in the on-site cleaning of sand.

An investigation into restoring beach material by incineration was made by Envirogenics Company funded by the EPA [16]. Results indicate that the process is technically feasible only if the sand contains more than 6% oil and less than 6% water. The clean sand did not recover its original color and a slightly greyish tone persisted.

Table 1. Type and Amount of Contamination of Various Oil Spills

Appendix A	Ship Involved	Location	Amount of Oil Spilled	Type of Oil	Length of Beach, miles	Gal Oil per mile	Beach Material	Equip/Method Used in Cleanup Operation
A-1	Torrey Canyon	Seven Stones, Reef, England	700,000 bbl	Kuwait Crude	242	91,000	sand	Detergent, clean-on-site (beach sump), manual
A-2	Ocean Eagle	San Juan, Puerto Rico	83,400 bbl	Leona Crude	16 (and entire harbor)	—	sand	Manual, bulldozer, graders, dispersant, sorbent
A-3	Offshore drilling platform	Santa Barbara Channel, CA	100,000 bbl or more	Crude	40	78,000	sand, rock	Straw, manual, skiploader, bulldozer, grader, burning hydraulic, steam, sandblast*
A-4	Arrow	Chedabucto Bay, Nova Scotia	65,000 bbl	Bunker-C	150	13,000	sand, gravel	Bulldozer, skid shovel, wheeled front-end loader,* road grader
A-5	Delian Appollon	St. Petersburg, FL	20,000 gal	Bunker-C	10	2,000	sand	Sorbent, manual, Corexit 7664
A-6	Oregon Standard and Arizona Standard	San Francisco, CA	20,000 bbl	Bunker-C	50	12,600	sand	Manual (rock), graders,* elevated scraper* (sand)
A-7	Polycommander	Vigo, Spain	16,000 ton	Crude	25	170,000	sand, rocks	Mechanical shovel, sand blasting, sand compressor
A-8	USNS Towle	New York Harbor, NY	900 bbl	Bunker-C	3.5	8,100	sand	Front-end loaders*
A-9	USS Manatee	San Clemente, CA	229,466 gal	Naval special fuel oil	75	3,100	sand	Front-end loaders*
A-10	Oil Lagoon	Douglasville, PA	6,000,000 gal	Sludge oil	30	200,000	—	Front-end loaders*
A-11	Tomano	Portland, ME	100,000 gal	No. 6 Fuel	7 (1 mile severely)	100,000	sand, gravel, rocks	Dragline, front-end loader, bulldozer, hot water jet, flame thrower, hay

*Found satisfactory or effective.

Meloy Laboratories under EPA funding completed a design and fabrication of a prototype beach sand cleaning device using the froth flotation process [17]. The process is based on the principle that sand is preferentially wetted by water rather than oil. When oil-coated sand is placed in water and agitated violently, the oil particles were dispersed into the process water for subsequent removal and separation. Testing had indicated that better than 95% of the oil can be removed from the sand.

P.G. Mikola of the University of California [18] and E.J. Curran of the Standard Oil Company of California investigated another EPA funded phenomenon which occurs when a fluid (liquid or gas) passes upward through a bed of solid particles. When the drag forces caused by the upward motion of the fluid just counter balances the weight of the particle, the bed is said to be fluidized. Cleaning efficiencies in excess of 95% might be expected in a 20-ton/hour model.

Two basic problems were encountered during operational testing. The broad particle size distribution prevalent in typical beach sand made it difficult to achieve uniform fluidization and stratification, and elutriation resulted. (Elutriation is the selective removal of fines from the bed due to these fines becoming intimately mixed with the recovered oil phase.) When this happened, the density difference between the recovered oil and water was decreased significantly, rendering the gravity oil-water separator ineffective.

ACCOMPLISHMENTS

A detailed review of eleven representative oil spill incidents has been completed to extract pertinent information on methods and equipment used for beach cleanup. This information was supplemented by personal and telephone interviews with personnel involved in the cleanup operation as on-scene coordinators or as cleanup operators. The study included a review of research efforts, associated with special methods and equipment for beach cleanup.

The selection of procedures and equipment for beach cleanup was found to depend on the amount of oil, the characteristics of the oil as it hits the beach, and the type of beach contaminated. The characteristics of the oil as it reaches the beach is related to the type of oil spilled, the sea environment, and the elapse time the oil is adrift. The slope of the beach was found to be indicative of the material the beach is composed of and, therefore, related to appropriate methods and equipment that may be most effectively used to decontaminate the beach material.

Based on the above results, the most effective beach cleanup procedures and equipment have been identified and tabulated in terms of selected beach classifications. Certain deficiencies in adapting existing techniques and equipment have become apparent from this study. Recommendations for future work that could remove such deficiencies have been included.

DISCUSSION

Beach Characteristics

Since beach cleanup operation depends significantly on the types of the beach involved, it is useful to describe some of the common characteristics of beaches. Thus, some selected standard beach terminology, materials normally found on beaches, and common beach geometry are briefly discussed in this section.

Beach Terminology. The nomenclature of beach features has been established by engineers and geologists [19] (Figure 1). Some of the pertinent nomenclature is listed below:

Backshore: The zone between the foreshore and the coastline.

Bar: An elongated slightly submerged sand body, made bare at low tide.

Beach: The zone of unconsolidate material extending landward from mean low water line to the place where there is a change in material or physiographic form.

Berm: The nearly horizontal part of a beach inside the sloping foreshore.

Foreshore: The sloping part of the beach lying between the berm and the low water mark.

Longshore bar: A sand ridge or ridges, extending along the shore outside the trough, that may be exposed at low tide or may occur below the water level in the offshore.

Nearshore: A relatively narrow zone extending seaward of the shoreline and somewhat beyond the breaker zone.

Offshore: The breaker zone directly seaward of the low tide line.

Materials. Different materials for beaches usually result in different features in profiles (Figure 2). In particular, there is a strong correlation between beach foreshore slope and grain size. Table 2 shows the average beach face slopes and sediment diameters.

Striking differences exist between the gravel beaches, coarse sand beaches, and fine sand beaches. The typical gravel beach has a ridge on the backshore where the waves have piled up the gravel sometimes as much as 20 feet above normal high tide. Ordinarily there is no appreciable berm in the gravel beaches, and the foreshore slopes continuously seaward. Often the slope, however, is interrupted by a step near the low tide line. In many beaches this step is sand covered.

Table 2. Average Beach Foreshore Slopes and Sediment Diameters

Type of Beach Sediment	Size (mm)	Average Slope of Beach Face (degrees)
Very fine sand	1/16-1/8	1
Fine sand	1/8-1/4	3
Medium sand	1/4-1/2	5
Coarse sand	1/2-1	7
Very coarse sand	1-2	9
Granules	2-4	11
Pebbles	2-64	17
Cobbles	64-256	24

Coarse sand beaches may have berms but these berms slope landward, often at considerable angles. The foreshore is steep, although somewhat less so than found in gravel beaches. Coarse sand beaches are soft which makes them poor for walking and for vehicle traffic.

Fine sand beaches differ from the others chiefly in having very gentle foreshore slopes. The sand is typically hard packed on the foreshore and is likely to be hard enough to support an automobile or to land a small airplane.

The selection of appropriate beach cleanup methods and equipment depends on the type of beach involved, in particular, the material the beach is composed of, its location and accessibility, the ocean wave and wind conditions the beach is subjected to, and the self-replenishing ability (of the beach material).

For the purpose of beach cleanup operation, the materials are classified as follows:

Sand

Gravel (stones 1/8 to 2-1/2 inches in diameter)

Cobbles (stones larger than 2-1/2 inches in diameter)

Boulders

Most of the beaches are made of sand or cobble. It should be noted, however, that a beach may change in composition with season and in time. Some beaches develop only during seasons with small waves and disappear during the seasons of high waves, whereas other beaches change in height and width during the stormy season. The type of beach involved, therefore, must be ascertained as part of the survey in the early preparation stage of a cleanup operation.

The porosity of the beach material, for example fine sand vs. coarse sand or gravel, can be a pertinent factor in the depth of oil penetration. A qualitative demonstration of this was found from an experiment conducted previously at NCEL.

Figure 3 shows a representation of a beach of fine sand that is wetted by water. The capillary action has caused the water to move upward into the sand. A light oil (JP-5) was then introduced onto the sand as shown in Figure 4. Note that the penetration occurred only in the dry areas, and that the wetted sand prevented the oil from penetrating the beach area. The preferential wetting of water and the small porosity in fine sand rendered the wet sand to be impervious to oils, especially oils heavier than JP-5. This phenomena has been observed frequently where a heavy oil is deposited on a sand beach. If the beach sand is sufficiently fine, even light oils may not penetrate the beach after it has been saturated with water.

The higher the porosity of the beach structure, the deeper will be the oil penetration. If the beach surface is open and porous, and if the oil (such as JP-5 and diesel fuels) flows freely, deep penetration of the beach surface can be expected.

Location and Accessibility. If the beach is remotely located and inaccessible, thorough cleanup of the beach in a short period of time might not be practical. Access to the beach may be restricted by the lack of roads, or roads inadequate for the passage of mechanical removal equipment. Rocks or groins will prevent easy maneuvering of mechanical equipment, or a beach may be too small to permit the use of mechanical equipment. A beach may have such a steep slope that conventional earth-moving equipment become ineffective because the spilling of contaminated sand out of the conveyor [9]. Physical constraints such as these may be the primary factors which will decide the type of equipment to be used for removal of oil. Manual cleanup may be the only practical method in some cases. Note that often building of temporary roads to allow the use of mechanical equipment may be more economical than using manual labor.

Natural Environment. It is difficult to clean a contaminated beach completely regardless of effort and intention. Natural action of wind, rain, wave, sun, together with chemical and biological degradation fortunately are effective in assisting the oil removal process. Beaches such as those in Santa Barbara have been aided by nature in the final cleanup.

Self-Renewal Ability. While most beaches are relatively stable, some beaches are constantly being eroded, and others have continual sedimentation. When the latter is the case, replacement of contaminated material that is hauled away will be assisted by natural processes. On the other hand, if the beach is in the process of eroding away by natural seasonal action cleanup effort may be aided.

Beach Contamination Classification

Along with types of beaches, the procedure for cleanup also depends on the extent and type of contamination. For beach cleanup, it is the properties of the oil as it hits the beach that are important. Thus, both the age and the original properties of oil dictate the characteristics of the oil to be dealt with. An aged No. 4 oil, for example, may exhibit characteristics close to those of Number 6, a much heavier oil, due to the evaporation of the volatile components. Emulsification greatly alters the properties of the oil. Wave actions can turn an oil into a water-in-oil emulsion that is stable and resistant to degradation [1,2].

In general, the lighter oils tend to penetrate more easily into the beach surface and, therefore, result in more contaminated material to be removed. On the other hand, part of the light oil is removed by evaporation.

From Table 1, it can be seen that, with the exception of extreme cases, the length of beach contaminated is loosely related to the amount of oil spilled. For a spill of less than 100,000 gallons the extent of beach contamination would likely be not much above 10 miles. Also, it appears that only when the amount of oil spilled exceeds 1,000,000 gallons when a contamination of more than 100 miles of beaches occurs. Now a shoreline of less than 10 miles normally does not contain sections of beaches significantly different in characteristics. A spill of under 100,000 gallons may be therefore considered localized and thus involves only one type of cleanup technique. A spill of less than 10,000 gallons can be considered small since the amount of beach involved will be minimal.

An approximate classification of the beach contamination can be based on the amount of oil spilled as follows:

(1) A spill of less than 10,000 gallons of oil is small and will likely involve less than 10 miles of beaches.

(2) A spill of between 10,000 to 100,000 gallons is moderate and will likely involve beaches less than 100 miles in length.

(3) A spill of more than 100,000 gallons is large and may involve more than 100 miles of beaches.

The above classification is not precise due to several factors. The data available are approximate only. Sometimes they are based on admissions by the individuals responsible for the spills; other times they are based on estimates made by the government agencies. In addition, better correlations can be made if the types of oil and the dynamics of the sea along the shore can be taken into account. Suggestion on how to improve such a classification will be discussed in a later section.

Methods and Equipment for Beach Restoration

Basically, methods used for restoring the beaches to acceptable conditions involve the removing of contaminated sediment and replace with like materials or dispersing the contaminant or contaminated materials [20]. The following methods have been tried:

- Dispersion Processes
  - Emulsification with detergents
  - Steam cleaning (for piers, rocks, etc.)
  - Sand blasting (for rocks, etc.)
  - Hydraulic dispersal
  - Mixing and burying on-site
- Removal Processes
  - Burning
  - Adsorption by straw, and other sorbent materials.
  - Mechanical removal of contaminated material
  - Sand cleaning on-site
  - Biodegradation

These are discussed in detail below.

Emulsification. Removal of oil from sand and rocks and dispersal back into the sea has been accomplished effectively using detergents. However, even when nontoxic detergents are used, the oil forms an emulsion which is toxic to the biota. Detergents effectively remove oil from sand and rocks but the resulting emulsion of oil and water tends to drain down into the beach structure, increasing the degree of contamination and making the problem of ultimate beach cleanup more difficult. The National Oil and Hazardous Substances Pollution Contingency Plan [21] bans the use of detergents on any shoreline. Therefore, the use of detergents cannot be considered as an acceptable means of beach cleanup.

Steam Cleaning. Steam (or hot water) cleaning of rock outcroppings has been used for removing surface oil. The oil is loosened by the jet and drops to a lower elevation, where it will eventually be dissipated by the action of the sea. This procedure does not remove the contaminant from the environment, but it does remove most of the coating of the oil from the rock. A part of the loosened oil may be collected from the water surface using surface oil recovery devices for disposal after the steam cleaning operation. This process will leave a black coating of residual oil on the rock surfaces [4].

Sand Blasting. Sand blasting was used at the Santa Barbara oil spill to remove oil from a rip rap rock wall. It was reported to be slow, but it was the only process that effectively removed the oil stains from the large rocks. To minimize the amount of sand blasting, the excess oil was first removed by hydraulic process. The sequence of operations was:

Manual removal of debris

Washing with pressurized water

Sand blasting

Using this process, a worker could clean a strip of rock beach 60 to 80 feet by 8 feet in a day's time [4]. This process is slow and costly [12].

Hydraulic Dispersal. High-pressure water jets have been used for oil removal. In dispersing the spilled oil from the Tomano, a boat-mounted monitor nozzle supplied with water at 200 psig was able to remove oil from piers and piling in the vicinity of the spill [10].

Mixing and Burying On-Site. Heavy deposits with low penetration have been manually removed and deposited in trenches at the back of the beach. Where light contamination is widespread, mechanical equipment has been used to decontaminate a beach by: (1) Promote evaporation (for lighter oils such as Number 2 fuel); (2) Enhance biological degradation (for heavy oils and residue of light oils); and, (3) Dilute remaining contaminated materials to acceptable proportions.

For light oil, instant and deep penetration can occur. The only effective method of decontaminating this type beach is to expose the contaminated material to sunlight and wind as much as possible. It can be done by either a harrowing plow or a beach cleaning machine.

This method has been also used in cases involving heavier oils to break up patches of the oil and mix them with sand [20]. The process improves the appearance of the beach and speeds the biological degradation, evaporation and emulsification of the oil.

Burning. At the Santa Barbara spill, burning of oil and straw on the beach was attempted, but the procedure was discontinued due to excessive smoke and odors [4].

A high intensity flame was used to remove adhering oil from rocks, but the procedure was clumsy and hazardous. Severe spalling occurred on the surface of the rock resulting in a hazard to the operators and disfigurement of the environment [7,8]. Burning accumulated oil deposits on the beach has seldom been successful due to poor ignition and difficulty in maintaining combustion. The smoke and odor produced limit the use of such procedure.

Sorption. A number of sorbents have been used in beach cleanup operations. Materials such as straw, urethane foam, sawdust and peat moss have been used to some extent. The material that has been used in the greatest quantities for the cleanup of spilled oil is straw. Sorbents such as straw are most beneficial when deposited prior to the arrival of floating oil. It tends to collect oil and prevent its deep penetration into the sand, thus facilitating cleanup.

Sorbent materials can complicate the recovery process by fouling pumps and filters. In rocky areas, straw can gather among the rocks and make the removal of the oil more difficult [7]. Note that the sorbent material is a form of contaminant itself and must be removed from the beach surface.

Mechanical Removal. Up to 99% removal of oil contamination can be accomplished either manually or by using mechanical equipment to physically remove the oil from the beach. Physical removal typically involves the removal of the oily contaminant, and any beach material which adheres to the oil. In most such cases, the volume or weight of sand or other materials removed has been large. Manual removal is normally used in areas with light contamination, and mechanical removal is used in areas with extensive contamination. A combination of manual and mechanical removal processes is frequently used where light to moderate contamination exists over a wide area of the beach.

Manual Procedures. Manual removal of oil contamination is effective where the contamination is cohesive and can be moved either by rakes or by shovels. Where the areas of contamination are widely separated, a man carrying a box or bag recovers contaminated material, and then drops the material at the central site to be transported by truck. An average man can remove about 120 to 160 pounds of debris per hour. Manual removal is typically used in rocky areas and around tide pools where mechanical equipment cannot operate. It may also be considered for the cleanup of a remote beach which is inaccessible to motorized equipment.

Mechanical Systems. Because of their effectiveness and the relatively high cost of manual labor, mechanical systems have been used for the cleanup of contaminated beach sites wherever possible, particularly for beaches with a contaminated area of significant size.

Items of equipment found to be effective for various situations are:

Motorized graders

Elevating scraper

Front-end loader

Bulldozer

Dragline

Dump truck

The effectiveness of these items of equipment depends on the type of beach involved. In the Tomano spill, barges were used to haul the spoil away and clam shell buckets were used to load the material onto the barge. Details of characteristics and optimum use of the equipment, singly or in combinations, are discussed in the section ''Mechanical Equipment for Removal of Contaminated Material.''

Sand Cleaning On-Site. Sand can be cleaned on-site by depositing sand into sumps dug near the beach. Sand will sink into the bottom and the oil will float to the surface and can be skimmed off. Such process requires much manpower and time. A sand cleaning device has been developed [17] but its practical usefulness has not been evaluated.

Biodegradation. Oil is subjected to biological degradation by natural bacterial action which is rather slow. Its rate can be accelerated by introducing bacteria known to attack petroleum. Such a method, however, is still in laboratory study stage.

Disposal of Contaminated Material

The normal method of disposing of removed contaminated beach material has been to transfer the material to a suitable landfill site. Commercial sites have been used, and sites have been created. Sites are typically selected where drainage of oil from the site is not a problem. Sites generally require approval by the local control agency responsible for such procedures. In California, e.g., the local control agency is the Regional Water Quality Control Board.

An alternative method of disposal of oily sand and gravel has been to use them as construction (such as surface paving) materials. Temporary dump sites have been used for intermediate storage of the removed materials. Polyethylene lining has been recommended to prevent contamination of ground water.

Mechanical Equipment for Removal of Contaminated Material

Virtually all types of mechanical euqipment have been tried in beach cleanup operations. Some are totally unsatisfactory, and none is optimum for all situations. In this section, a number of equipment items considered satisfactory for the more common beach cleanup operations are described.

Motorized Graders. Motorized graders are designed to move material short lateral distances by side casting process and not for hauling material in the direction of travel. For removing a thin film (1/2 to 1 inch) of oily sand, this equipment, in combination with motorized elevating scrapers is the most efficient [11,13]. In such operations, the graders are used to cut and remove surface layers of beach materials to form large windrows, which are picked up by the elevating scraper. When oil penetration is deeper than one inch, graders should be used only when other equipment is not available. Graders do not work well when rocks are present or on relatively steep slopes. Rocks should be first removed by front-end loaders or draglines.

Motorized Elevating Scrapers. Motorized elevating scrapers are utilized to pick up material from the surface and haul short distances for dumping and spreading. They are more efficient than standard non-elevating scrapers for picking up materials such as sand. These machines are the most efficient for picking up windrows left by graders. Also, for moderate oil penetration (1 to 9 inches) [11,12], elevating scrapers working alone are quite effective. Sartor et al [13] found that adding a baffle plate to each side of the bowl behind the elevator flights will close the gaps and reduce substantially the spillage of materials.

Wheeled Front-End Loaders. Front-End loaders are designed for digging, loading and limited transport of material. They can be used for removing windrows left by graders, but they are not so effective as motorized elevating scrapers. They can also be used to remove material when oil penetration is too deep (9 inches) for motorized elevating scrapers [12]. Wheeled front-end loaders are relatively mobile for this type of operation. When the beach is not sufficiently firm, track type can be used. For such cases, however, bulldozers are more effective. Front-end loaders can also be used for removing small rocks.

Bulldozers. These machines are designed to push a large quantity of material in the direction of the vehicles. Spillage known to occur around the blade and their tracks will grind contaminated material into the beach. For moving large amounts of material, however, such as the case of deep oil penetration (9 inches), and when the beach is not sufficiently firm for wheeled front-end loaders, this machine is quite effective [12,14].

Draglines. Draglines can be used to remove small rocks. Because of the longer reach, however, they can also be used to remove material near the waterline when the beach is so soft that even tracked vehicles such as bulldozers may sink into the ground.

The approximate average rates for some of these equipment have been obtained based on test data from References 10 and 17 and are presented in Table 3.

Table 3. Cleaning Rate for Various Equipment

Equipment	Approximate Rate (hr/acre)
Combination of motorized grader and motorized elevating scraper	3
Elevating scraper	3
Combination of motorized grader and wheeled front-end loader	6
Combination of motorized grader and tracked front-end loader	30
Bulldozer	50

Note that the rate alone is not sufficient to indicate the effectiveness. The ability, such as that of motorized graders, to remove the thin film of contaminated materials without taking excess amounts of clean sediment should also be taken into consideration.

CONCLUSIONS

A review of beach cleanup operations has been made. Most of the documents reviewed do not give sufficient quantitative data for the purpose of developing precise criteria for selection of procedures and equipment, or for estimating cost, equipment and manpower required. Sufficient data, however, were obtained for the purpose of selecting a number of procedures which are considered satisfactory in previous cleanup operations. These should be adequate for most of the cleanup operation.

No effective techniques have been developed to remove oil from rocks. Washing with hot water can remove most of the oil from the rock surface, and the remainder can be removed by sand blasting, which is, however, slow and expensive.

Contaminated cobbles can be removed by using draglines and front-end loaders.

For beaches with sand and gravel sediment, the contaminated materials can be removed by various mechanical equipments. The selection depends on the depth of oil penetration:

1. For oil penetration of up to one inch, combined use of road graders and motorized elevating scrapers is most efficient.

2. For oil penetration from 1 to 9 inches, use of motorized elevating scraper only is more efficient.

3. For oil penetration depth of greater than 9 inches, wheeled front-end loaders and bulldozers can be used, wheeled front-end loaders being more effective for firm ground and bulldozers more effective for softer ground.

In general, fine sand and gravel beaches can be expected to be firm, whereas coarse sand beaches are soft and thus not likely to be able to support wheeled vehicles. The coarser the material and the lighter the oil, the deeper the oil penetration. Amount of oil is a factor in the penetration depth.

The above apply mostly for heavy oils. For light oils on rocks, most of the contaminant will be evaporated. When light oil soaks into finer material, evaporation can be enhanced by the use of beach cleaning machines or harrow plows. These procedures/equipment are summarized in Table 4.

The use of detergents increase the penetration of the oil and results in more contamination of the beach than originally existed. The detergents emulsify the oil in water, which makes it more toxic to the biota.

The quantity of oil spilled and the extent of the beach contamination are related factors which affect the procedure selected for beach cleaning. Contamination of beaches from natural oil seeps has been measured at oil concentrations varying from 0.01 to 3 oz/ft^2 of beach surface (based on a 500 ft^2 area of measurement) [11]. Such a concentration of oil represents a severe local contamination, but the materials have been found to disperse in a few days by natural processes.

In the Torrey Canyon spill, oil concentrations up to 30 oz/ft^2 of sand were observed [1]. Covering the oil with fresh clean sand was found to prevent normal hydraulic drainage of the beach, and ultimately resulted in accelerated beach erosion.

Sorbent materials provides sorption surface for the oil upon arrival at the beach, but on standing, the oil tends to drain into the sand. Disadvantages of sorbents are the costs and problems involved in gathering and disposing of the material.

Sand cleaning procedures are not sufficiently advanced to be considered for immediate use in beach cleanup. With further development, these processes may be advantageous for cleaning beach areas.

Burning of oil on a contaminated beach has not been effective. It is difficult to ignite the oil and to maintain the combustion. Complete combustion is not usually achieved and the residue is a heavy black mixture of tar and charcoal. The use of a torch or flame thrower to remove oil from rock outcroppings causes spalling which is hazardous to the operators and disfigures the rock surface.

Table 4a. Method/Equipment for Cleanup of Sand and Gravel Beaches

Size of Area	Type of Oil	Depth of Penetration	Type of Beaches		
			Fine Sand	Coarse Sand	Gravel
Large	Heavy	shallow (1/2’’ to 1’’)	Grader + ES	Grader + ES	--
		moderate (1’’ to 9’’)	ES	ES	ES
		deep (>9’’)	--	Bulldozer	WFEL* or Bulldozer
	Light	--	Harrow plow or beach cleaning machine		
Small	Heavy	--	Manual removal and replacement of sand		
	Light	--	Manual removal, rake		

Notes: ES - Elevating scraper.
WFEL* - Wheeled front-end loader, for firm ground only.

Table 4b. Method/Equipment for Cleanup of Beaches With Cobbles and Boulders

Oil	Cobbles	Boulder
Heavy	Draglines or WFEL for large area. Manual removal for small area	Hydraulic and steam cleaning followed by sand blasting
Light	Hydraulic	

Severe wave action has been found to remove oil from contaminated rocks in a few months, and accelerates the breakup and dispersal of oil on sandy beaches. Biodegradation of oil is a secondary process that is continuously in progress. Biological processes are slow, but in combination with dispersal forces eventually remove the visible evidence of oil contamination.

RECOMMENDATIONS

To provide data for a beach cleanup manual, the following studies should be considered.

1. Prediction of Oil Penetration Depth. Oil penetration depth is the most significant criterion for selecting method-equipment for removing contaminated sand and gravel. It will be useful if such a depth can be estimated prior to arrival of the oil and/or the beach cleanup coordination.

The oil penetration depth is dependent on the amount, type, and age of oil spilled and the porosity of the beach material. Quantitative relationship between these parameters can be obtained by theoretical/empirical computation of the movement and aging process of the spilled oil and experimental study of the dynamics of oil on a porous medium using models (properly scaled) of various beaches.

2. More Complete Information on Previous Operations. Time and funding of present effort preclude the use of an extensive data gathering which will enable the estimate of time, manpower required, and cost. Such information can be obtained from individuals involved in previous cleanup operations by a written survey via a set of carefully prepared questionnaires followed by personal or phone interviews.

3. Use of Piston Film as Oil Preventive Measure. In addition to the use of an artificial berm to minimize the damage to the backshore area, other measures may also be taken to minimize the degree of contamination to the beach. Application of piston film into the water near the shoreline may reduce the amount of oil washed ashore and allow the removal of oil while it is still on the water surface.

The effectiveness of piston film in such applications can be established by theoretical analysis based on data obtained on the characteristics of piston film/oil in wave and wind environment.

4. Prediction of Contamination. The movement of spilled oil depends on the currents, winds, and wave action and the degree of contamination of the beach depends on the characteristics of the oil and the beach involved. A method is needed to predict where the oil will hit the beach and the probable characteristics of the oil upon arrival (which depends on the type of the oil when it is spilled, the sea environment, and

the length of time adrift.) Combined with results of Recommendation Item 1, the type and extent of contamination can be predicted and hence the proper manpower/equipment can be mobilized for the appropriate cleanup procedure.

5. Effective Beach and Harbor Oil Barrier. Because of huge expenditure involved, removing the spilled oil from water surface is preferrable to cleaning the beach after it is contaminated. For this reason, it is useful to study whether it is feasible to protect beaches from oil contamination using mechanical barriers.

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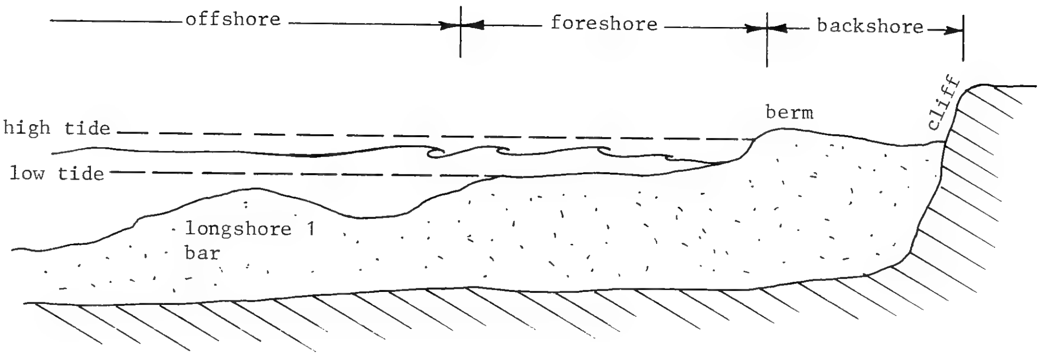

Figure 1. Terminology and some of the characteristics of beaches.

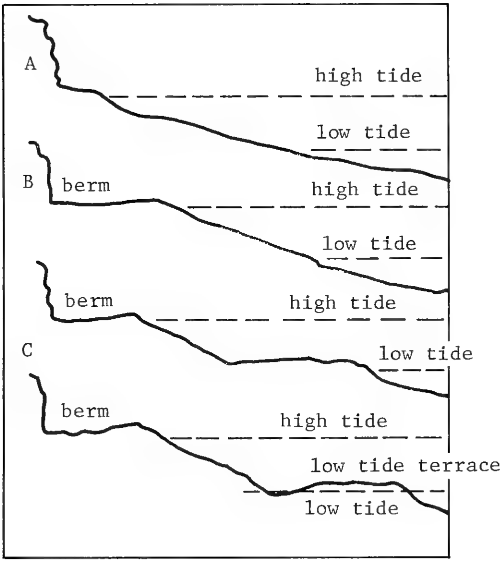

Figure 2. The principal types of beach profiles.

Figure 3. Representation of a sand beach showing capillary action of sand.

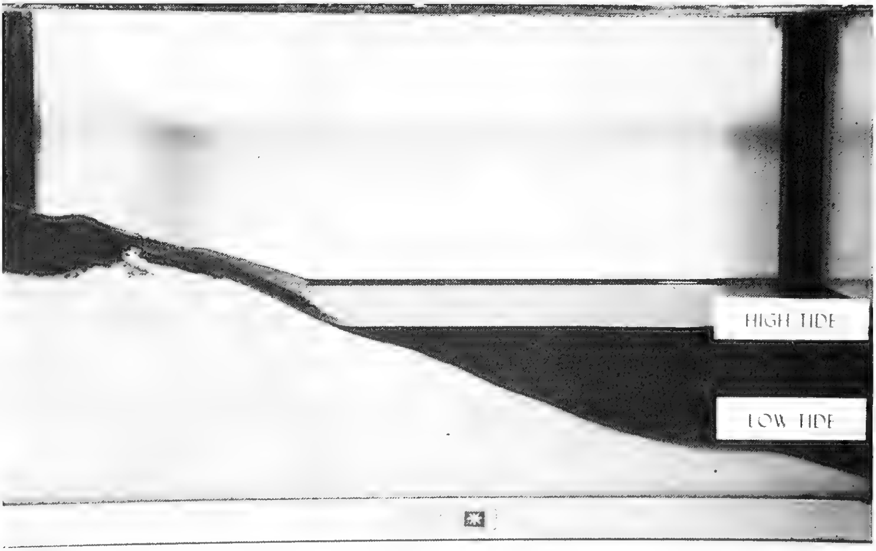

Figure 4. Representation similar to Figure 3, with oil added, showing contamination of dry sand.

Appendix A

MAJOR OIL SPILL BEACH CLEANUP PROCEDURES

Tables A-1 to A-11 summarize major oil spills which have occurred in the past in which a significant effort was made to remove contamination from the shore area. The following tables describe briefly the procedures used for beach cleanup.

Date	Incident	Table
19 Mar 1967	Torrey Canyon (tanker)	A-1
3 Mar 1968	Ocean Eagle (tanker)	A-2
28 Jan 1969	Santa Barbara Oil Spill	A-3
4 Feb 1970	Arrow (tanker)	A-4
13 Feb	Delian Appollon (tanker)	A-5
18 Jan 1971	Oregon Standard-Arizona Standard Collision (tankers)	A-6
Mar 1971	Polycommander (tanker)	A-7
14 Jul 1971	USNS Towle	A-8
Aug 1971	USS Manatee (tanker)	A-9
23 Jun 1972	Schuylkill River Flood	A-10
22 Jul 1972	Tamano (tanker)	A-11

Table A-1. Beach Cleanup Procedure for Torrey Canyon (Tanker) Oil Spill

Item	Remarks
Date	18 March 1967
Location	Seven Stones Reef, England
Produce Spilled	Crude oil, Kuwait
Quantity	700,000 barrels
Circumstances	Tanker with 117,000 long tons of cargo ran aground
Extent of Contamination	A total of 242 miles of shoreline contaminated in England and France.
Cleanup Procedure	British used detergents almost exclusively to clean beach areas; severe destruction to marine life resulted in those areas that were heavily treated. In Brittany 2,300 soldiers were used to assist in beach cleanup. Large sumps were dug at rear of beach, and oil plus sand was deposited there. Solids sank to the bottom of the sump and the oil was skimmed off and removed with tank trucks.

References 1-2

Table A-2. Beach Cleanup Procedure for Ocean Eagle (Tanker) Oil Spill

Item	Remarks
Date	3 March 1968
Location	San Juan, Puerto Rico
Product Spilled	Crude oil, Leona
Quantity	83,400 barrels
Circumstances	Tanker grounded, and discharged cargo
Extent of Contamination	Sixteen miles recreational and commercial beaches and the entire harbor were heavily polluted.
Cleanup Procedure	Two hundred seventy men were used to remove contaminated sand from beaches. Bulldozers and graders were used, and the spoil was trucked away. Fresh sand was brought to replace that which was removed. Dispersant was used on the beaches, which turned the beaches into quicksand. Use of detergents was terminated. Used Minstron talc and Ekoperl-33 on beaches and found that it was effective for cleaning sand.

References 3, 22

Table A-3. Beach Cleanup Procedure for Santa Barbara Oil Spill

Item	Remarks
Date	28 January 1969
Location	Santa Barbara Channel
Product Spilled	Crude oil
Quantity	100,000 barrels or more
Circumstances	Drilling platform blowout through natural faults
Extent of Contamination	Forty miles of residential and recreational coastline.
Cleanup Procedure	Straw was spread on the deposited oil. Up to 1,000 men and 125 pieces of mechanical equipment were used to collect the contaminated material and transport it to an inland dump. Skip loaders, bulldozers, graders, and trucks were used. Burning of oil-soaked straw on the beaches was attempted but stopped because of smoke. Burning was hampered by heavy rain. Attempted to clean rip rap area by washing with cold water and hot water, steam cleaning and sand blasting. Sand blasting was the only treatment that effectively cleaned the rocks.

References 4-6

Table A-4. Beach Cleanup Procedure for Arrow (Tanker) Oil Spill

Item	Remarks
Date	4 February 1970
Location	Chedabucto Bay, Nova Scotia
Product Spilled	Bunker-C
Quantity	65,000 barrels
Circumstances	Tanker struck cerebrus rock, broke up and sank releasing oil from forward part of ship.
Extent of Contamination	About 150 miles of shoreline were contaminated of which 30 miles of beach were cleaned.
Cleanup Procedure	Deep Cove: A bulldozer was used to remove contaminated sand. Spilled contaminated material became thoroughly mixed with clean beach sand. Arichat: A contractor used a fixed blade bulldozer (tracked) and a skid shovel to remove contaminated sediment to a depth of 12 to 18 inches. The bulldozer proved unsatisfactory as the material pushed forward by the blade was mixed with clean uncontaminated material. Spillage around the blade was ground into the beach by the tracks of the vehicle. Blackduck Cove: Contract used a fixed blade bulldozer (tracked) and a wheeled front-end loader to remove 4,500 cubic yards of sandy beach material. At the extremities of the beach the bulldozer often sank above its tracks in silt and mud resulting in thorough mixing of contaminated material with clean material.

References 7, 9

Table A-5. Beach Cleanup Procedure for Delian Appollon (Tanker) Oil Spill

Item	Remarks
Date	13 February 1970
Location	St. Petersburg, FL
Product Spilled	Bunker-C
Quantity	20,000 gallons
Circumstances	Ruptured ship spilled oil in harbor
Extent of Contamination	About 10 miles of shoreline contaminated in the vicinity of Tampa and St. Petersburg Harbors.
Cleanup Procedure	The spilled oil contaminated sand beaches and sea walls in harbor. Floating oil was trapped in harbor and caused recontamination. Used sorbents and manual cleaning on beaches. Used Corexit 7664 to clean sea walls.

Reference 22

Table A-6. Beach Cleanup Procedure for Oregon Standard - Arizona Standard (Tankers) Oil Spill

Item	Remarks
Date	18 January 1971
Location	San Francisco, CA
Product Spilled	Bunker-C
Quantity	20,000 barrels
Circumstances	Tankers collided in San Francisco Bay
Extent of Contamination	About 50 miles of shoreline contaminated.
Cleanup Procedure	About 10 miles of sand beaches were cleaned using road graders and scrapers. Mechanical equipment removed oil quickly and efficiently. Six thousand cubic yards of material were removed from a single 5-mile stretch of sandy beach. Clean straw free of oil applied at sea, washed ashore and constituted a second form of contamination. Manual recovery was used on rocky beaches, tide pools, and rock outcroppings.

References 10, 11

Table A-7. Beach Cleanup Procedure for Polycommander (Tanker) Oil Spill

Item	Remarks
Date	March 1971
Location	Vigo, Spain
Product Spilled	Crude oil
Quantity	16,000 tons
Circumstances	Vessel grounded
Extent of Contamination	About 25 miles of shoreline contaminated.
Cleanup Procedure	(1) Removed 3,000 tons from beach with mechanical equipment; (2) used sand blasting to clean rocks; (3) dumped contaminated spoil in an abandoned clay mine; and (4) used 500 men, three mechanical shovels, tank trucks, six Land Rovers and two sand compressors.

Reference 22

Table A-8. Beach Cleanup Procedure for USNS Towle Oil Spill

Item	Remarks
Date	14 July 1971
Location	New York Harbor
Product Spilled	Bunker-C
Quantity	900 barrels
Circumstances	Accidental discharge while fueling due to incorrect connection of valves.
Extent of Contamination	About 3.5 miles of shoreline contaminated at Coney Island
Cleanup Procedure	Berms were built up in the sand beach on the outgoing tide. When the tide returned oil flowed over the top of the berm into the ditch. Water drained away through the sand leaving the oil trapped in the ditch. Front-end loaders were used to scoop the oil out of the ditches. Contaminated material was tracked to a landfill site.

Reference 22

Table A-9. Beach Cleanup Procedure for USS Manatee (Tanker) Oil Spill

Item	Remarks
Date	20 August 1971
Location	San Clemente, CA
Product Spilled	Navy Special Fuel Oil
Quantity	229,446 gallons
Circumstances	Operational oil spill
Extent of Contamination	About 75 miles of shoreline contaminated.
Cleanup Procedure	A command post was set up in the beach area. Seven jeeps, radio equipped, were used to provide communication to cleanup parties. Twelve trucks and 4 front-end loaders were used. Four or five working parties of 25 men were dispatched by bus to contaminated areas. Personnel used rakes, pitchforks, and shovels to transfer oiled sand to front-end loaders. Working parties split into smaller 4-5 man groups, which would leap-frog past one another raking and shoveling debris into piles. In areas where beach was inaccessible to equipment, working parties carried oily residue out in cardboard boxes and loaded it onto stake trucks.

References 23, 24

Table A-10. Beach Cleanup Procedure for Schuylkill River Flooding Oil Spill

Item	Remarks
Date	23 June 1972
Location	Douglasville, PA
Product Spilled	Sludge Oil
Quantity	6,000,000 gallons
Circumstances	Heavy rains from hurricane caused overflow of oil stored in diked lagoons adjacent to river.
Extent of Contamination	About 30 miles of shoreline contaminated.
Cleanup Procedure	Used front-end loader to pick up oil and trash from edge of river bank. Accumulated trash was dumped in railroad hopper cars on a track which ran parallel to the river.

Reference 22

Table A-11. Beach Cleanup Procedure for Tamano (Tanker) Oil Spill

Item	Remarks
Date	22 July 1972
Location	Portland, ME
Product Spilled	No. 6 Fuel Oil
Quantity	100,000 gallons
Circumstances	Tanker struck submerged ledge in Casco Bay, Maine
Extent of Contamination	Several miles of sand beaches on mainland were lightly contaminated. About one mile of rock and sand shoreline was severely contaminated on Long Island.
Cleanup Procedure	North Island: A crane operated dragline and a bulldozer was used to remove the surface of the beach down to a depth of 6 to 16 inches. A 6-yd^3 front-end loader was used to transport the accumulated spoil to a barge which supported two clam shell cranes. The cranes transferred the spoil into a second barge which was used to transport the spoil to a dump site. The barge was required to compensate for the extreme tidal movement in the ocean. Hot water jets were used on rock outcroppings to remove adhering oil. The treatment left a uniform black discoloration on all the rocks. A flame thrower was tested but it caused spalling of rocks, and its use was discontinued. Oil-contaminated seaweeds growing on rocks were cut off and new growth appeared within one week. Portland: Hay was applied to the oil on sandy beaches and then removed manually.

References 22, 14

Appendix B

USE OF BACKSHORE AREA FOR DISPOSAL

Having a disposal site adjacent to the contaminated beach will result in great saving in time and cost for beach cleanup. One can consider creating a dump site in the backshore area adjacent to the location of contamination [25]. An area must be selected that is not subject to erosion. Such an area may meet the requirements that oil drainage would not affect water supplies.

At the selected site, one or more excavations could be made for the disposal of contaminated beach material. The excavated material should be stored adjacent to the excavation as shown in Figure B-1. The procedure is suitable for sand, gravel or rock beaches. The oil-contaminated material removed should have sufficient sand and gravel to stabilize the fill site and prevent flowing.

The land fill excavation should be filled with contaminated spoil to a level that is 2 feet below grade and then covered with the stored beach material. This method of disposal is in accordance with the State of California Department of Water Resources requirements for a landfill site.

The landfill procedure near the site of contamination will result in a considerable saving in cost over the process of transporting the material to a distant landfill site. At the Santa Barbara Spill, the total cost of disposal (hauling, dump fees, road improvement, etc.) is estimated at about $200,000 or $4 per cubic yard. For comparison the cost of operation of a landfill site in the backshore area should be less than $1.00 per yard.

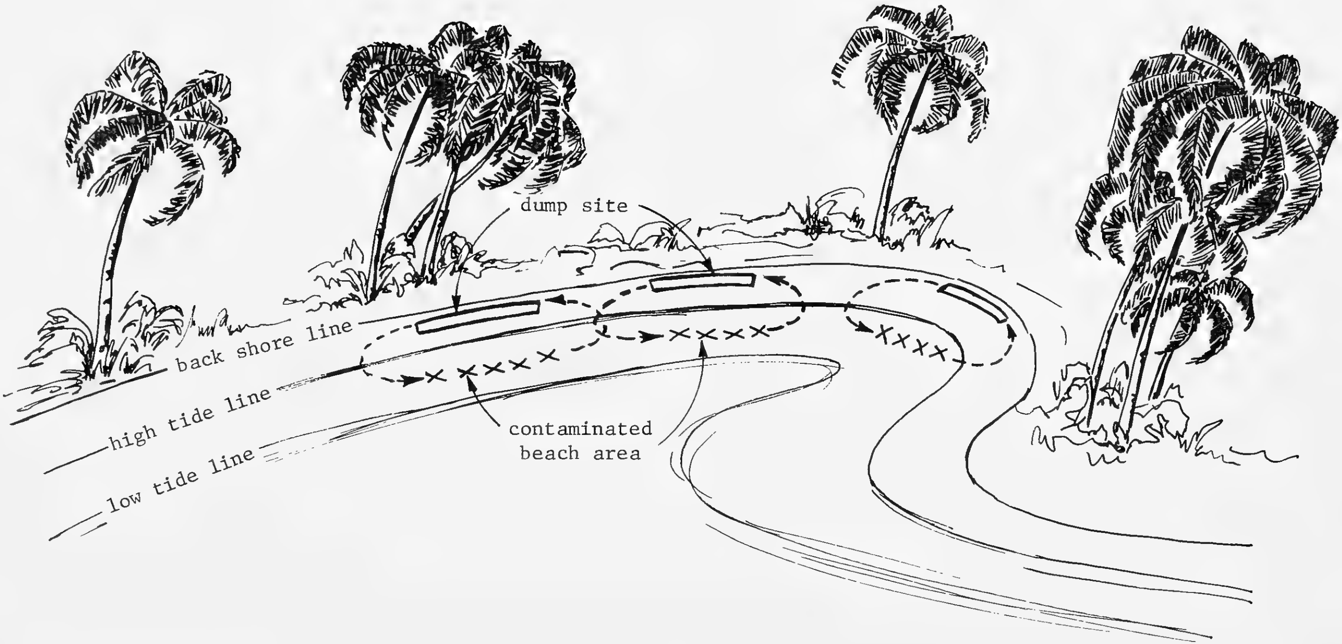

Figure B-1. Diagram of a backshore land fill for contaminated beach material.

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