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Protection, Cleanup and Restoration of Salt Marshes Endangered by Oil Spills

A Procedural Manual

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PROTECTION, CLEANUP AND RESTORATION OF SALT MARSHES ENDANGERED BY OIL SPILLS
A Procedural Manual

by

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Contract No. 68-03-2160

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This manual provides information and guidelines on the best application of protection, cleanup and recovery activities from oil spills to minimize the damage to marshlands and to speed their recovery. Its purpose is twofold. First, it provides a mechanism for the rapid field assessment of marsh type and sensitivity and for the selection of environmentally acceptable protection and cleanup techniques. Second, it provides procedural instructions for the implementation of the techniques identified.

Oil spill On-scene Coordinators and local officials should find this report directly applicable during prior planning and oil spill operations. For further information, please contact the Oil and Hazardous Materials Spills Branch of the Resources Extraction and Handling Division.

David G. Stephan
Director
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ABSTRACT

This manual addresses the response of the protection, cleanup, and restoration phases of spilled oil endangering or contaminating tidal marshlands. The manual follows a step by step approach to response actions. Common to both the cleanup and protective phases are a gathering of general information, knowledge of the characteristics of the spilled oil, identification of the sensitivity and unique features of the endangered marshland, and an investigation of any threat against public and personnel safety. Decisionmaking criteria are provided for both the protection and cleanup.

Special attention is given to the cleanup phase which involves foot and vehicular traffic in the marsh and which may lead to serious adverse impacts. The user is presented with criteria for termination of activities for both protection and cleanup activities. Final sections discuss requirements for debris disposal and restoration of the damaged marsh. Recovery includes evaluation of the need for restoration versus natural recovery, and restoration techniques.

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ACKNOWLEDGMENTS

This manual summarizes a state of the art assessment conducted by URS Company for the U.S. Environmental Protection Agency's Industrial Environmental Research Laboratory, located at Edison, New Jersey. Mr. Robert Castle was Program Manager from January 1975 through June 1977. After June 1977 the work was conducted under the direction of William Van Horn, Program Manager of the Oil and Hazardous Spills Program of URS Company. David J. Maiero served as project manager with technological assessments by O. Leon Crain.

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SECTION 1

INTRODUCTION

Salt marshes can be adversely affected from oil spills and associated cleanup activities. The capability of marshlands to survive and recover from oil spills can, however, be greatly enhanced by directed and intelligent intervention by man. This manual provides information and guidelines on the best application of protection, cleanup and recovery activities from oil spills to minimize the damage to marshlands and to speed their recovery.

The manual is intended to be used in conjunction with existing contingency plans prepared by local or regional agencies and oil co-ops. The manual provides an overview of the problems likely to be encountered from the time oil threatens or enters a marsh until protection and cleanup operations have ended and the restoration process has begun. It assumes that the user has a basic knowledge of oil spill characteristics and attendant technologies, as well as a basic understanding of the coastal environment. However, any additional details necessary for the decisionmaking process should be provided by specialists and local sources of information. The user must recognize certain inherent limitations in the manual. Its contents reflect the state of the art (as of late 1977) of a rapidly evolving technology. Hence, the user should supplement the information in the manual with the new technology as it becomes available.

USE OF THE MANUAL

The use of this Manual is designed to coincide as closely as possible with the sequence of operations encountered in a spill situation. The ordering of the sections in this Manual is based upon the Flow Chart shown in Figure 1. The flow chart serves two functions: (1) to identify the informational and operational sequences in responding to an oil spill, and (2) as a reference for sections of the manual.

Before deciding which actions should be initiated, the user must have certain information available. A checklist is provided in Table 1 to insure proper observations in the field at the time of the spill. This checklist is intended to be taken into the field and notations made on the spot. Qualitative information gathered at the time of the spill is of extreme importance in making operational decisions. This information will be called for in the subsequent sections of the manual.

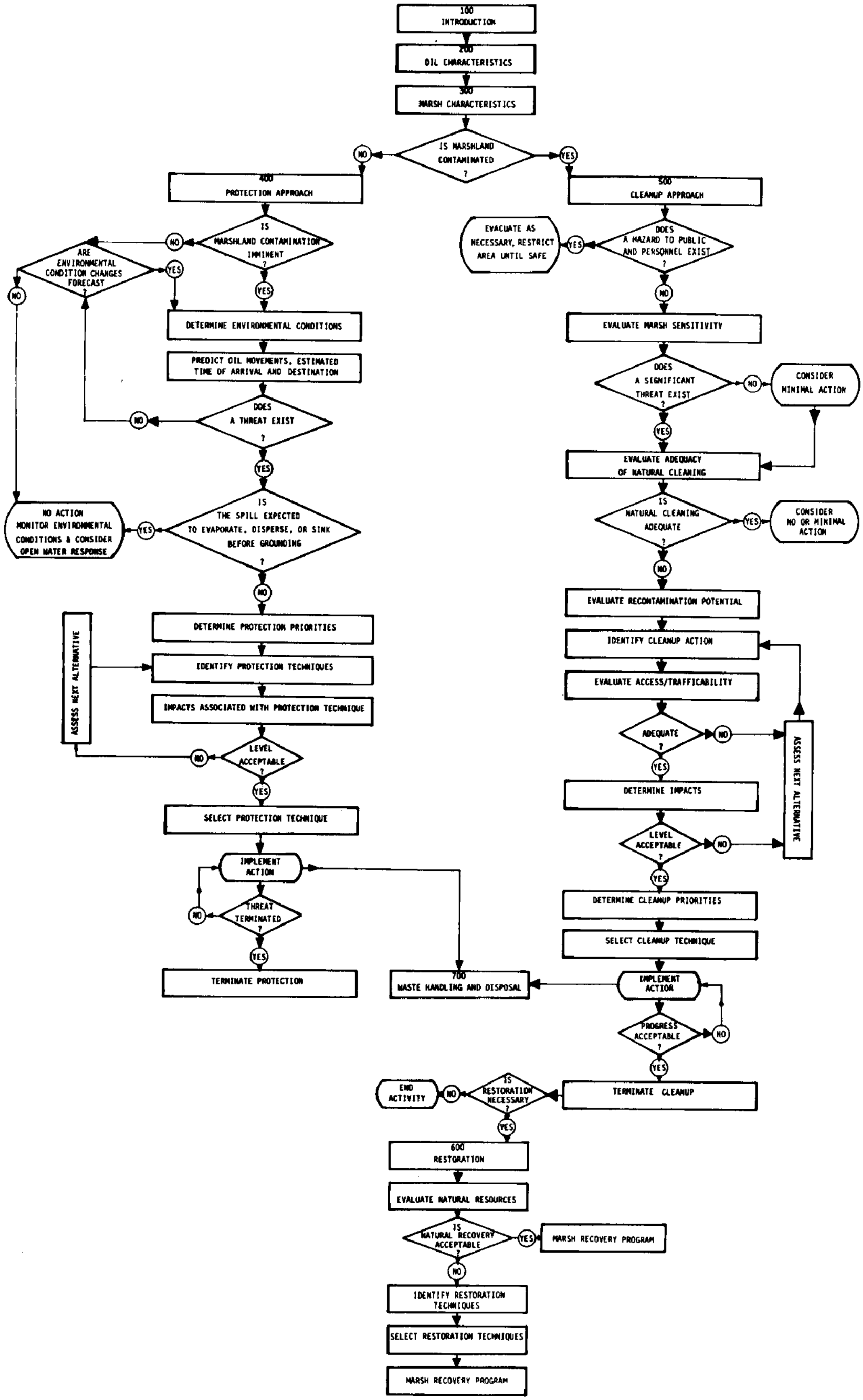

Figure 1. Flow chart.

TABLE 1. FIELD OBSERVATIONS REQUIRED

Oil Characteristics

- Determine if the spilled oil is highly viscose (does not flow easily) or of a low viscosity
- What is the color of the spilled oil when placed in a clean glass container
- What is the odor of the oil (i.e., strong odor)
- Are tarballs, Mousse-like emulsions, other physical phenomena present
- Do volatile components which could lead to fire or explosion appear to be present

Presence of Shorebirds

- Note the presence and relative abundance of wading shorebirds such as cranes, egrets, and herons

Presence of Waterfowl

- Note the presence and relative abundance of open water diving birds such as grebes, ducks and geese

General Status and Behavior of Wildlife

- Note presence, number, and location of dead and/or oiled animals (including fish and other aquatic life)
- Note and describe any unusual behavior, particularly failure of avoidance responses such as withdrawal into hole, closing shell, flying or swimming away when threatened

Plant Characteristics and Distribution

- Height and physical characteristics of vegetation stand
- Areal distribution/zonation of vegetation
- General plant status (seeds, flowers, seasonal dieback, etc.)

Hydrologic and Meteorological Conditions

- Currents -- direction, speed, variations
- Tidal variation, range, predictions
- Air temperature
- Channel, drainage configuration
- Presence of floating debris
- Wind speed and direction
- Weather forecasts

TABLE 1. FIELD OBSERVATIONS REQUIRED (cont.)

Shoreline Characteristics

- o Presence of configurations suitable for containment
- o Slope
- o Nature and amount of shoreline debris
- o Presence of culverts, tide gates, etc. Note on map.

Substrate Characteristics

- o General physical characteristics (i.e., sand, clay, mud, firm, soft, wet, well-drained, etc.)
- o Obvious chemical features (odor and color)
- o Penetration of oil into soil in areas of existing contamination

Backshore Characteristics

- o Possible routes of access
- o Locate possible staging/debris-handling sites

Nature of Human Infrastructure

- o Nature and location of recreational use
- o Commercial use and traffic
- o Shoreline and nearshore land use

Field personnel should continually update the checklist so that it specifically applies to marshes in their geographical area. A portable tape recorder provides a convenient method for recording data.

After the required field observations have been made, the flow chart (Figure 1) may be consulted. In the flow chart, rectangular boxes identify the type of information and corresponding section numbers where details are provided. Diamond shaped boxes, raise questions relevant to choosing an information path in the flow chart. The circular boxes contain a yes or no answer to these questions.

The first major division in the flow chart is determined by answering the question, "IS THE MARSH CONTAMINATION IMMINENT"? The user is then guided to one of two options:

PROTECTION	Section 400
CLEANUP	Section 500

Within each of these options further basic decision points are identified, allowing the user to chart a course of action responsive to the ongoing situation. At the same time the user will be referring to the informational boxes within each option and seeking additional information from the appropriate section in the manual. The flow chart also directs the user to the next phase (Recovery, Section 600) as well as to ancillary or support functions (Debris disposal, Section 700).

SPILL MANAGEMENT GUIDE

This section presents general information to supplement the flow chart, including management and logistical requirements, and a sample log of operations.

Management

The complexity of the management structure required is governed by a variety of factors. It may be dictated by Federal policy, outlined in a contingency plan, or formulated to meet the working needs of the individual contractor. Its structure will also be influenced by the volume of the spill, complexity of the area, and the experience and ability of the labor force.

One individual, either the On-scene Coordinator (OSC), the cleanup contractor, or the representative of the spiller, will ultimately have overall responsibility for management of operations described in this manual. This single person, termed the "coordinator of operations," will have difficulty handling all the operations associated even with a moderate-sized spill; thus, duties must be delegated depending on the situation. Persons with delegated responsibilities will be responsible both for directing the operations of their individual areas, and for providing the coordinator with inputs necessary for making decisions.

Figure 2 is an example of an organizational structure for a major oil spill response team. Not all of the functions shown would be necessary for dealing with smaller teams mobilized for small or moderate spills; these can be eliminated or consolidated in organizing a smaller response management system. The responsibilities of each function are generally to be found in oil spill co-op or local contingency plans.

Particular attention should be given to maintaining communications between the coordinator of operations who is responsible for the overall allocation of men and materials and the area supervisors who are responsible for the actual deployment and maintenance of equipment. It is helpful to schedule periodic briefings between field and management for discussion and solution of specific problem areas.

Utilization of untrained labor is frequently necessary, and always a management problem. Whenever possible, use of untrained personnel should be avoided, since instruction and supervision must be intensive or the effectiveness of such workers will be minimal.

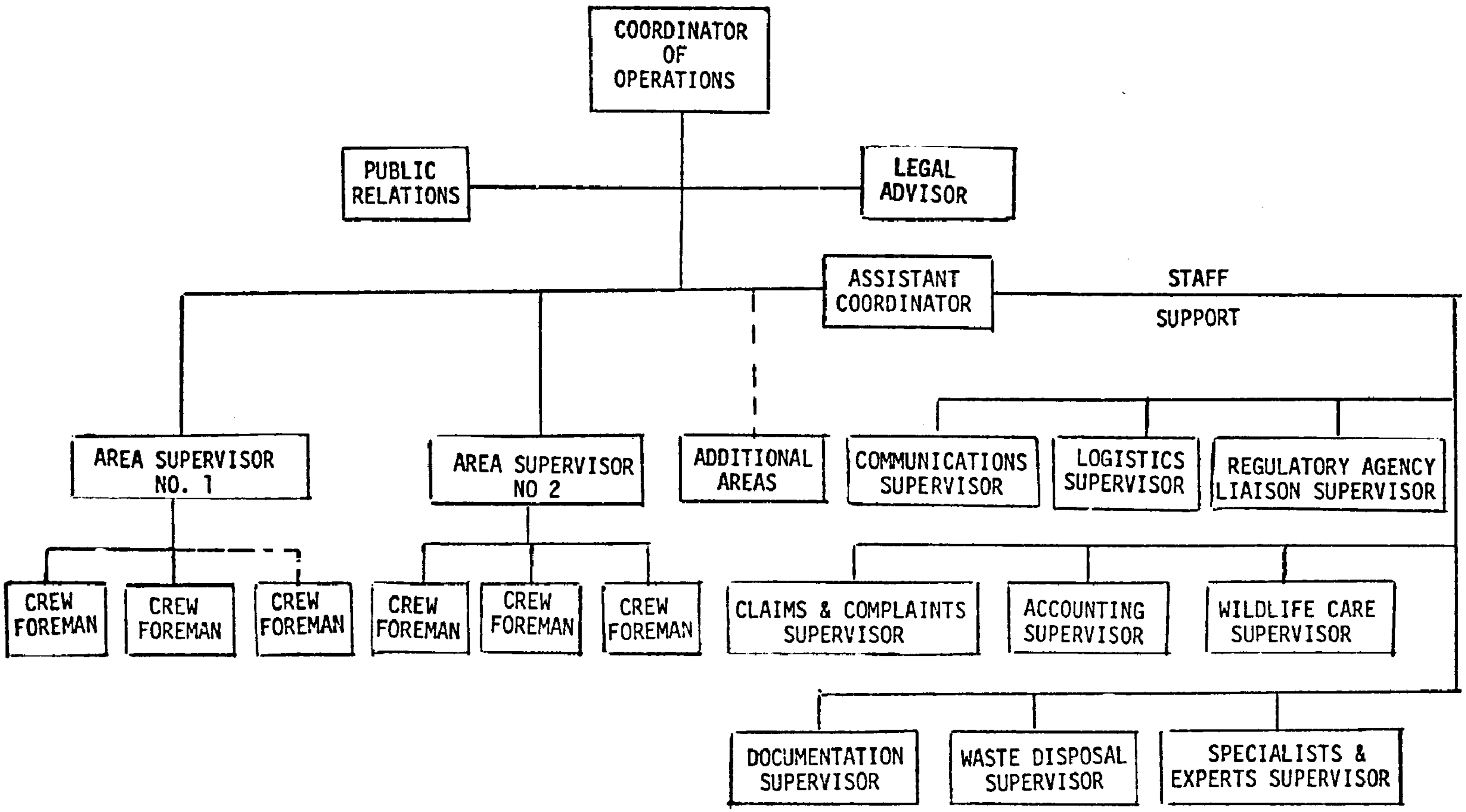

Figure 2. Generalized management structure for major spill response.

Logistics

Logistics involves procurement, transportation, and maintenance for materials, personnel, and support facilities. Without a smoothly functioning logistical support, even the best planned response will be doomed to failure. Equipment must be located and transported to the site. The primary source for locating equipment and materials is the regional contingency plan (RCP) which can normally be obtained from the local or regional Coast Guard Headquarters. Although the accuracy of the RCP is sometimes tempered by the time elapsed since its last updating, it is still probably the most useful first source. The RCP should also identify any local contingency plans and cleanup cooperatives (co-ops). These localized sources are likely to be more up-to-date and may provide specific information and recommendations on the area in question. Local contractors and municipal public works departments can often supply men, equipment, and various other types of support. Efforts should be made to find the closest source of equipment, particularly for implementing a protective action. However, it is important to remember that specialized equipment can be flown reasonably close to virtually any coastal site within 24 hours.

If the spill is of sufficient magnitude or severity to activate one of the Federal plans (i.e., Regional or National Response Plans), the resources of the Federal government become available for use by the OSC.

There is no set formula for evaluation of how much equipment and manpower is required. Each evaluation must be based on preliminary observations and the judgment of the estimator. More than once, equipment has been dispatched that did not function with the type oil spilled, or that could not even be brought to the site. This situation is particularly frustrating in remote salt marsh situations. The costs associated with transport and standby of inappropriate equipment can be largely eliminated with planning.

Over-ordering of equipment is another cost escalating factor. Quantities of equipment should generally be matched to the estimated volume of the spill, the size area to be protected or cleaned, the access to the area, travel time to disposal sites, availability of operators, and so on.

In the case of manpower, excessively large crews seldom work efficiently and, due primarily to their numbers, can cause more environmental damage than smaller, well-organized and instructed crews. The size of the crew must be matched to the job and resources available for their support.

It is seldom, if ever, possible to predict all the requirements for a response based on preliminary evaluations. The requirements will evolve as the operation progresses, but knowing what is available and how long it will take to have it functioning in the field can relieve much of the expense and irrelevant, ineffective activity associated with a constantly changing situation.

Equipment and personnel must be supported to keep operations running smoothly and safely. Machinery and equipment will require maintenance, normally provided by the contractor. If not, other arrangements must be made for insuring proper functioning of all equipment in the field. Included should be: provision for mechanics, parts and lubricants; work space and staging areas; and back up equipment. Support requirements for personnel include food, housing, and transportation. Other personnel support requirements important for health and safety include:

1. Provision and enforcement of use of equipment required by the Coast Guard for boat operations, e.g., life vests, running lights, etc.

2. Provision of a field water supply and, in extremely warm weather, salt tablets.

3. Provision of portable sanitary facilities at the work site and at staging areas.

4. Provision of special protective equipment such as waders, boots, dust masks, etc.

5. Provision of facilities for field first-aid including, in southern marshes, snake-bite treatment kits.

Log of Operations

The importance of keeping a log of operations cannot be overemphasized. In addition to forming the basis for contractors' billings or for checking billings, the log provides a valuable historical documentation of the incident. Two types of logs are recommended -- a daily summarization of activities and a chronological log of events. An example form for summarizing daily activities is shown in Figure 3, and a typical chronological log is shown in Figure 4.

While not intended specifically for this purpose, records of the type suggested commonly find their way into legal proceedings. To be useful and legally creditable, the logs should be as comprehensive as possible and follow a few basic rules.

1. Write down all observations and notes. In the confusion of field operations, nonwritten records can be easily forgotten and omitted.

2. Never take notes on miscellaneous pieces of paper. Use bound notebooks which can become permanent records.

3. The entries into the notebook should be made at the earliest opportunity after each observation, preferably in chronological order. The person entering the record should identify himself and give the date and time of each entry.

4. Document entries whenever possible using maps, sketches, and photographs.

DAILY PERFORMANCE CHECK OFF LIST

Contractor ______________________________

Supervisor ______________________________

Date ______________________________

Job Description ______________________________

____

____

____

____

Materials Utilized ______________________________

____

____

____

____

Equipment:

a ______________ f ______________

b ______________ g ______________

c ______________ h ______________

d ______________ i ______________

e ______________ j ______________

Number of Men on Job ____________

Daily Operations Commenced ________ Hour Secured ______________

Number of Disposal Loads ________

Submitted ______________

Title ______________

Figure 3. Example of daily activity summary.

DAILY LOG

15 July

0830	EPA (Mr. Paul ELLIOT) notified. (RRT alerted).
0900	Helo recon.
1000	Helo recon.
1320	New York City Fire Department notified of the incident by EPA (Mr. Howard LAMP'L). RRT activated.
1345	Phone call between CDR HANSON and CAPT REILLY, USN. USCG will provide OSC if Navy will release unlimited cleanup funds. If not, USCG will advise and assist Navy OSC.
1345	EPA (Mr. Dick DEWLING) notified NY State, NJ State and Interstate Sanitation Commission.
1400	Instructed COTP NYK to take samples from NY Harbor and USNS TOWLE and hand deliver to EPA Lab, Edison, NJ.
1415	Notified EPA samples enroute.
1417	Phone call from CAPT REILLY USN: Navy requests USCG take over as OSC.
1425	CDR R. J. HANSON, USCG designated as OSC.
1428	Phone call to Mr. Lee GREEN, Metropolitan Petrochemical Co., Inc. He will call back upon return.
1440	Initial meeting of RRT at Governors Island, NY
1445	Call to Lee GREEN; still not in.
1445	Call to COTP NYK: directed COTP NYK to tell N.Y.F.D. representative to meet with RRT. Notified LCDR CHITTICK, COTP NYK, on scene at Bayonne, that CDR HANSON was designated as OSC.
1447	Call from Lee GREEN. Instructed him to send "Spillmaster," boom, and boat to S.E. corner Gravesend Bay. Mr. GREEN to meet with RRT.
1448	Call to NYFD about using city personnel for beach cleanup.
1503	NY City Dept. of Parks notified. They will establish four beach patrols. NYFD boat on scene in Gravesend Bay to keep oil out of marinas.
1505	RCC to notify USCGS EAGLE not to anchor in Gravesend Bay.

Figure 4. Example of chronological log.

SECTION 2

OIL CLASSIFICATION

APPROACH

Knowledge of certain physical and chemical properties of a spilled oil is important in the evaluation of environmental effects and in the selection of protection and cleanup actions. In many emergency situations specific information may not be readily available, and field observations alone must be used. In response to varying environmental conditions, spilled oil may respond differently than indicated by standard oil specifications. What is important to the field response is the "in-situ" character of the spilled oil.

To provide a basis for making emergency decisions a classification based on field-observable properties has been developed:

Class A:	Light Volatile Oils
Class B:	Heavy Sticky Oils
Class C:	Waxy Oils
Class D:	Nonfluid Oils

The classification reflects field conditions at the time, but these may change. For example, many oils change behavior -- and hence, their classification -- as temperature changes or weathering proceeds. Representative oils, diagnostic properties, and basic response properties for each of the four classes are summarized in Table 2 and discussed in detail in the following paragraphs.

Class A: Light Volatile Oils

This class typically includes fuel oils and many light crude oils. These materials are generally flammable when fresh and should be approached as potentially dangerous. Class A oils can be identified by high fluidity, clarity, rapid spreading rate, strong odor, and high evaporation rate. They do not tend to adhere to surfaces well and can be largely removed by flushing. Ease of removal by flushing can be experimentally determined by agitating an oiled sample (e.g., plant material) in water.

Table 2. SPILL RESPONSE OIL CLASSIFICATION

Class	Designation	Typical Oil Types	Diagnostic Properties	Response Properties
A	Light oils	Distillate fuel and light crude oils (all types)	Highly fluid, usually transparent or opaque, strong odor, rapid spreading, can be rinsed from plant sample by simple agitation	May be flammable, high evaporative loss of toxic components, assume to be highly toxic when fresh, tend to form unstable emulsions, may penetrate substrates, responds well to most control techniques.
B	Heavy sticky oils	Residual fuel oils; medium to heavy asphaltic and mixed base crudes	Typically opaque brown or black, sticky or tarry, viscous, cannot be rinsed from plant sample by agitation	High viscosity, hard to remove from surfaces, tend to form stable emulsions, high S.G. and potential for sinking after weathering, low substrate penetration, low toxicity-biological effects due primarily to smothering, will interfere with many types of recovery equipment.
C	Waxy oils	Medium to heavy paraffin base crudes	Moderate to high viscosity, waxy feel	Generally removable from surfaces, soil penetration variable, toxicity variable -- may be high in fresh oils, decreased tendency to form stable emulsion
D	Nonfluid oils (at ambient temperature)	Residual and heavy crude oils (all types)	Tarry or waxy lumps	Nonspreading, cannot be recovered with most equipment, cannot be pumped without heating or slurrying, relatively nontoxic, may melt and flow when stranded in sun

The lighter members of this class tend to evaporate entirely and quickly. Heavier Class A oils may partially evaporate, leaving a residue falling into one of the other response classes. Class A oils tend to penetrate porous surfaces and they may be persistent in contaminated substrate. When fresh, all can be considered highly toxic. Generally they form unstable emulsions.

Class B: Heavy Sticky Oils

This class typically includes residual fuel oils and heavier asphaltic and mixed-base crude oils in the fluid state. Characteristically viscous, sticky or tarry, and brown or black in color, they cannot be readily removed from test samples of vegetation by agitation in water. After evaporation of natural light ends and cutter stock the toxicity tends to be low. Biological effects result from the smothering of invertebrates, covering of the photosynthetic surface of green plants and the prop roots of mangroves, and adhering to fur and feathers of animals. Typically the tendency to penetrate substrates is low. Many Class B oils have a specific gravity near or exceeding that of water and may sink. Class B oils which weather to a tar or asphalt-like consistency are then considered as Class D oils. Emulsions may be easily formed and tend to be stable.

Class C: Waxy Oils

This class of oils includes medium to heavy paraffin-base oils and is distinguished by a waxy feel. While adhering to plant and other surfaces, viscous oils of this class tend to be moderately removable by flushing. Their tendency to penetrate permeable substrates varies, increasing as temperatures rise. Their toxicity varies depending on the percentage of volatile components. When weathered or subjected to low temperatures they commonly become solid and fall into the Class D category. Emulsions formed are usually less stable than those associated with Class B oils.

Class D: Nonfluid Oils

This class includes residual and heavy crude oils, and weathered oils which are solid or nonfluid at spill temperatures. In the solid form they are essentially nontoxic. When heated by the sun, these oils may melt and flow, contaminating adjacent areas.

Emulsions

As a result of transporting mechanisms and natural processes, some degrees of emulsification can be expected in most oils by the time they encounter the marsh. In most cases emulsions will not be visually detectable and may be treated as unemulsified oil. Complete emulsions (i.e., Mousse) may create problems in recovery equipment, although the extent of this effect is not well understood. Additionally, some emulsions of this nature may exceed the specific gravity of water, and sink. If this occurs, flushing into open water may be undesirable.

Emulsions compound the problems of handling recovered oil because they increase it's volume. Some emulsions (particularly Class A oils) are sufficiently unstable that onsite coagulation and separation is possible. (Emulsion stability can be crudely assessed in the field by observing how easily and quickly a sample in a glass jar separates.)

Further information on the properties of refined products and crude oils is presented in Appendix A.

SECTION 3

MARSH CLASSIFICATION

MARSH TYPE/SENSITIVITY

A marsh's sensitivity to oil spills is determined by its resource value and vulnerability to damage from contamination. Sensitivity is important in selecting response actions and in establishing cleanup priorities. This section helps the manual user assess marsh type and sensitivity on a case-by-case basis.

It is sometimes believed that an area affected by an oil spill will be destroyed, but this is generally not the case. Rather, there can be a wide range of effects, most of which are not permanently damaging. Initial effects are related to environmental factors and oil type. Effects of response actions are seldom considered, yet they may damage the area more than the contamination itself (i.e., trampling of marsh plants, reaction to dispersants, etc.).

A number of factors are significant in conducting an emergency assessment of the sensitivity of a marsh to an oil spill. A discussion of these factors follows:

Marsh Type

Coastal marshes of the United States can be divided into three biological groups based on their sensitivity to oil spill parameters. Types of marshes have been grouped by morphologic similarity, tidal zonation, and nature of the root system. Named for common or dominant representative plants, these types of marshes include: "reed-like" marshes, "succulent-like" marshes, and mangroves, which are further subdivided into red and black types. Table 3 summarizes these marsh types and their general features.

Reed-like Marsh --
The plants of this marsh are tall, thin, and grass- or reed-like, as shown in Figures 5 and 6. Spartina is a reed-like plant which is dominant in marshlands throughout the United States. In this discussion, Spartina is used as the key example of a reed-like marsh.

TABLE 3. CLASSIFICATION OF MARSHES

	Reed-like Marsh	Succulent-like Marsh	Mangrove Red	Mangrove Black
General Appearance	Tall, thin/grass or reed-like. Up to 7 feet high	Prostrate or low in stature, less than 2.5 feet	Trees up to 60 feet in height usually fringing a marsh, branch-like prop roots	Shrub reaching 10 to 20 feet high
Tidal Zonation	Mean low low water (MLLW) to boundary of water-logged soil. Frequent inundation. Primarily brackish to saline waters. Some fresh waters.	Mid to high intertidal soil occasionally waterlogged and inundated. Highly saline waters	Permanently water-logged soil. Average salinity. Requires inundation	Less waterlogged soils. Higner salinity. Occasional inundation
Seasonality	Generally perennial, autumn and winter dieback	Annual or Perennial succulent, especially in spring and summer, becoming slightly woody in fall and winter. No dieback in perennial types	Evergreen	Evergreen
Reproduction	Seedlings and rhizomes	Seed and creeping shallow root stocks	Seed	Seed
Root System	Dense rhizome mass -- deeper rooted	Shallow root system, shallow rhizomes	prop roots	pneumatophores radiating shallow roots
Geographic Distribution	Between channels and in shallow channels. Along coast and saline inlets and bays on alluvial fans Gulf, East, and West coasts	Adjacent to Spartina marsh to inland side. Sometimes occurring landward of mudflats without Spartina, in diked marshes, and above undercut creek banks in Spartina marshes and on levees. Gulf, East, and West coasts	Fringes marsh. Along caost, in inlets and in interior saline lakes. Florida and Gulf coasts where there is no danger of frost	
Typical Plant Association	Saltmarsh cordgrass, bulrushes, black rush rush	Saltwood, saltwort, saltgrass, saltmeadow cordgrass	Red mangrove	Black mangrove, white mangrove, buttonwood in higher areas

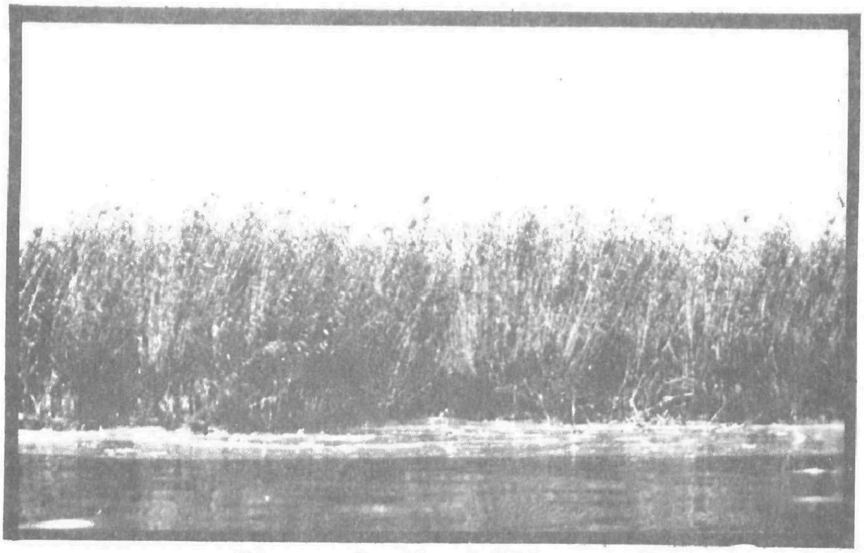

Figure 5. Reed-like marsh.

Figure 6. Reed-like marsh.

The Spartina marsh is limited to the lower intertidal level. Plants grow at a range of intertidal heights beginning near MLLW. The upper limit of the growth of Spartina is determined by frequency and duration of tidal inundation. Thus on steeply sloping shorelines, the zone of Spartina will be narrow; on low, gradually sloping shorelines, such as found along the Gulf Coast, the Spartina zone may be hundreds of yards wide.

Spartina are generally perennial plants. Following an autumn and winter dieback, they reproduce primarily by rhizomes (rhizomes are specialized underground stems which perpetuate the plant between growing seasons), but can also reproduce by seeding. The dense rhizome mass may be 6 inches to several feet thick and provides the stability needed to allow the outer marsh edge to resist wind and wave erosion. As long as the plants are healthy and the rhizome mass intact, a Spartina marsh is an extremely stable entity, with great recuperative powers. When the plants are killed or the rhizome mass broken and damaged, the marsh is less resistant to erosion.

Succulent-like Marsh --

The succulent-like marsh plants grow at higher intertidal levels than reed-like plants in soil that is only occasionally waterlogged and inundated. Figure 7 schematically demonstrates the occurrences of reed-like and succulent-like marshes as a function of tidal elevation and salinity. The succulent-like plants include a number of species which are small and usually less than 2 feet high. Unlike the reed-like appearance of Spartina, these plants are bushy or shrubby. Their branches are fleshy or succulent and are divided into numerous sub-branches ending in short, finger-like projections. Figure 8 provides an illustration of the succulent-like marsh type. Usually, it occurs on higher ground adjoining the reed-like plants as shown in Figure 9; however, succulents can also occur wherever the physiography of the marsh provides shallow ponds which are subject to evaporation after tidal flooding or precipitation runoff. With evaporation, the salinity of these ponds increases and they may become salt pans.

The succulent-like marsh includes annual plants, which reproduce only by seeding, and perennials, which have both rhizomes and seeds. Because this type of marsh occurs at higher tidal elevations, it is far less subject to erosion from tidal currents and runoff. Its rhizome system is, however, still an important means of reproduction of a large proportion of the marsh's plant community.

Red and Black Mangrove Marshes --

Mangroves are trees or shrubs which are found only in tropical and subtropical regions including the coasts of Florida, Hawaii, many U.S. Territories, and some Gulf states. The most extensive continental mangrove marshes occur in Florida and are best developed in the southwestern Ten Thousand Island Region. Further east, around Biscayne Bay,

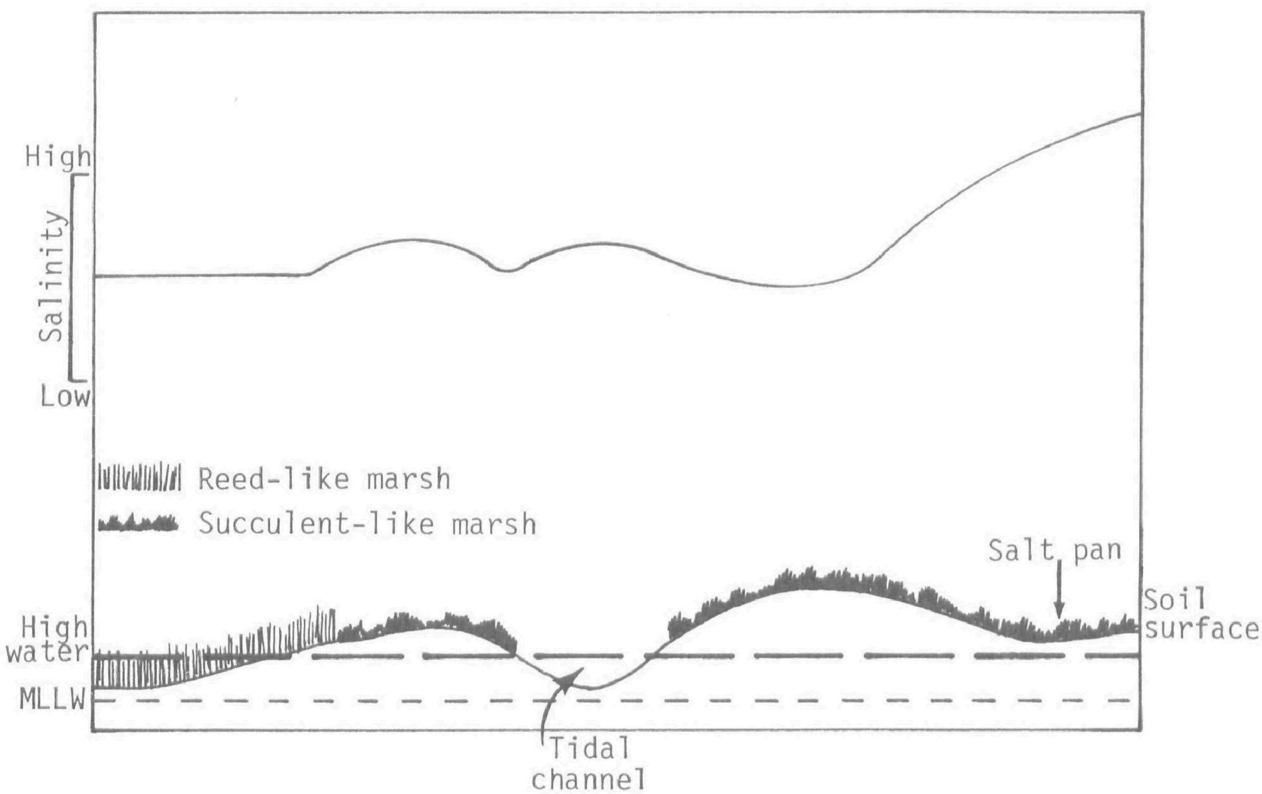

Figure 7. Schematic cross section of tidal salt marsh. The graph shows zonation according to elevation and salinity.

Figure 8. Succulent-like marsh.

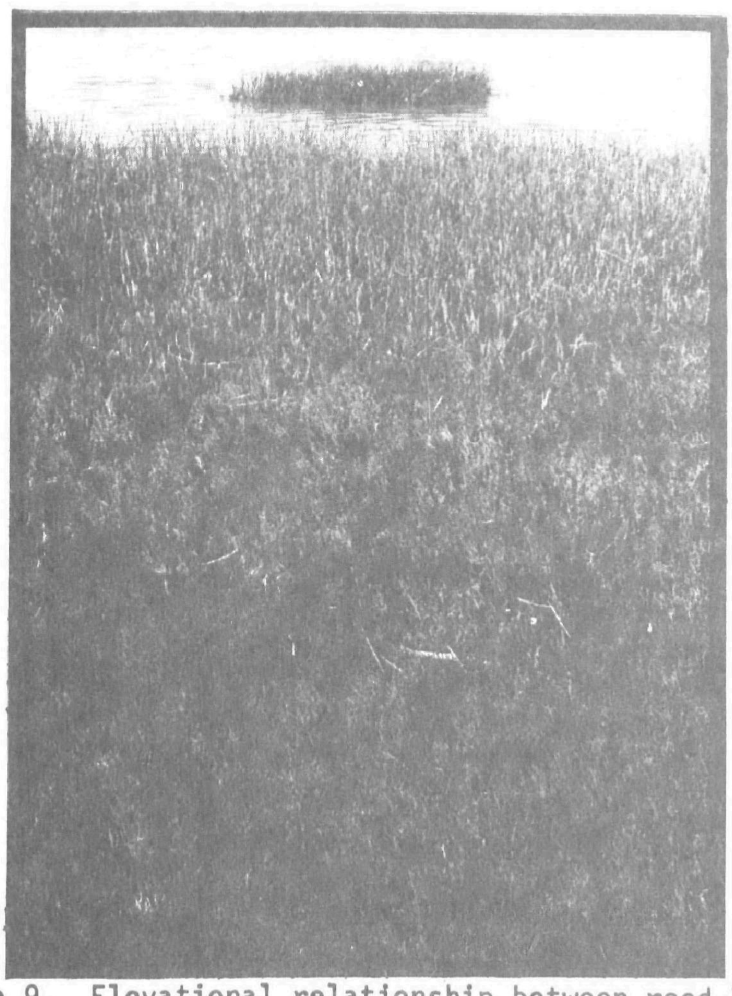

Figure 9. Elevational relationship between reed-like marsh and succulent-like marsh (foreground).

Florida Bay, and the Florida Keys, they are also well developed. There are still extensive mangrove marshes in Puerto Rico, although their number has been reduced by shoreline development.

Mangroves grow best in the brackish waters of estuaries but they also develop well along the outer coastline in seawater, around high salinity lagoons and salt flats, and up rivers and streams where salt water only occasionally reaches. Mangrove marshes in one locality may be only a narrow coastal fringe, but elsewhere they may spread many miles inland up tidal rivers. The mangrove plants require continual inundation by tides.

The mangrove marsh is composed of two major plant types. The red mangrove, characteristically fringing the marsh, is a tree which may grow to 75 feet high. It is easily distinguished by its branch-like prop roots (Figures 10 and 11). The black mangrove is a tree reaching 60 feet in height which grows landward of the red mangrove on less waterlogged ground and in higher salinity. The black mangrove is distinguished by the presence of pneumatophores: branchless, leafless shoots emerging from the ground around each tree (Figures 12 and 13).

The prop roots of the red mangrove and pneumatophores of the black mangrove function as respiratory structures. Mangrove roots and pneumatophores collect and retain debris, thus contributing to the process of soil accumulation and island building. Mangrove sediments commonly become anaerobic with depth.

The different kinds of mangroves sometimes grow in random associations but usually the different species dominate in bands, with red mangroves seaward. This zonation results from differences in preference, tidal coverage, and soil salinity. Figure 14 is a schematic illustration of a cross-section of a mangrove marsh.

Substrate

Like all plants, marsh vegetation requires a medium in which to grow. Marsh plants are especially sensitive to frequency and duration of tidal coverage, which depends on soil surface elevation. If the marsh surface is too low with respect to the water level, only submerged aquatic plants will grow. If it is too high, upland plants will replace the marsh vegetation. Between these limits, the average water level in each portion of marsh is a critical factor in determining which species will be dominant. Thus, change in soil elevation or average water level can result in a change in vegetation cover, create upland out of former marsh, or change the plant composition of a given marsh.

Substrate elevation can be affected by erosion, natural deposition or dredge spoil disposal, earthworks, and similar processes and activities. All marshes are sensitive to these changes. In practice, reed-

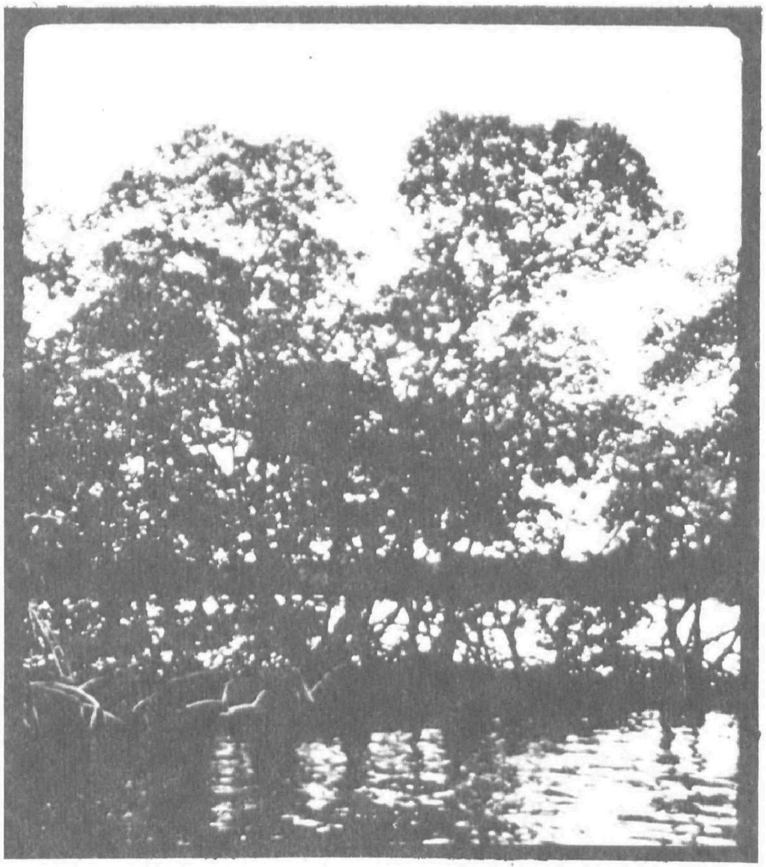

Figure 10. Red mangrove marsh.

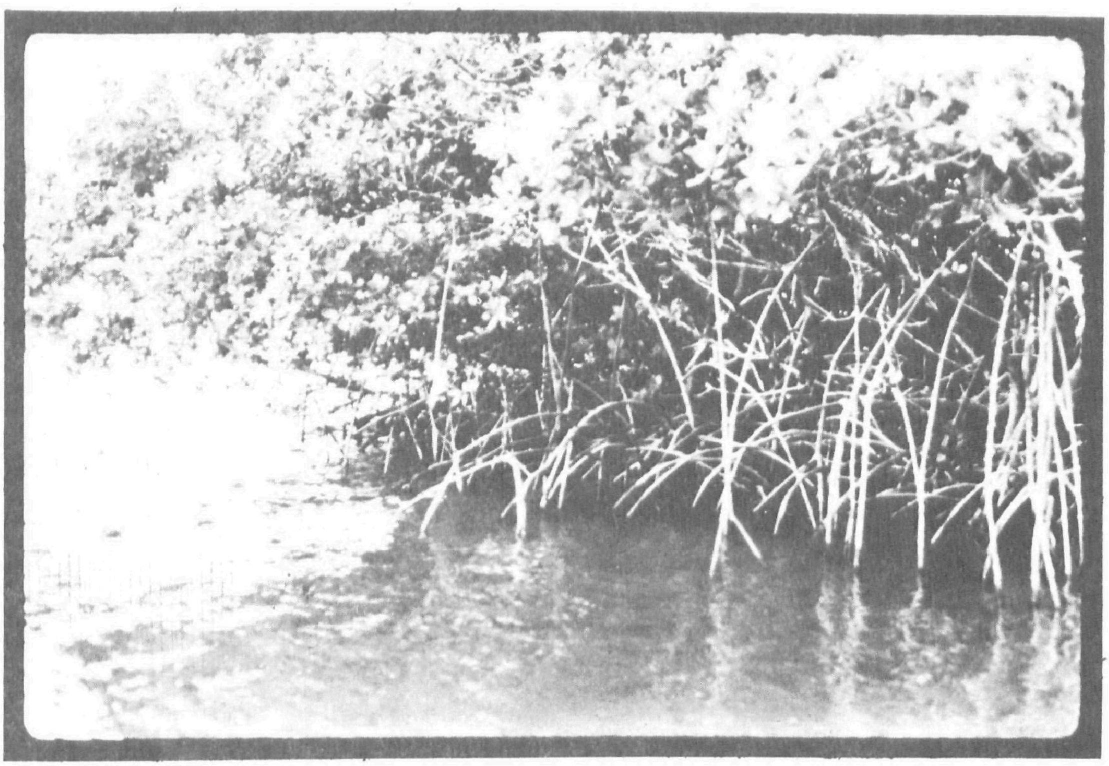

Figure 11. Red mangroves showing prop roots.

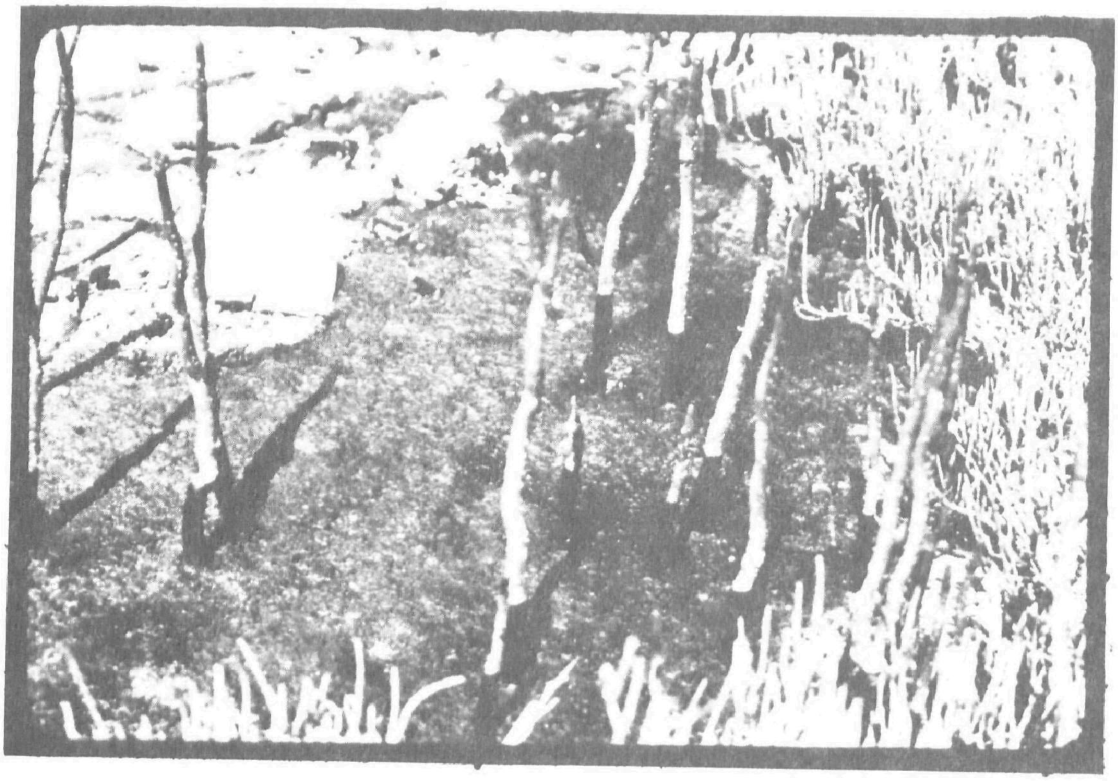

Figure 12. Black mangrove pneumatophores.

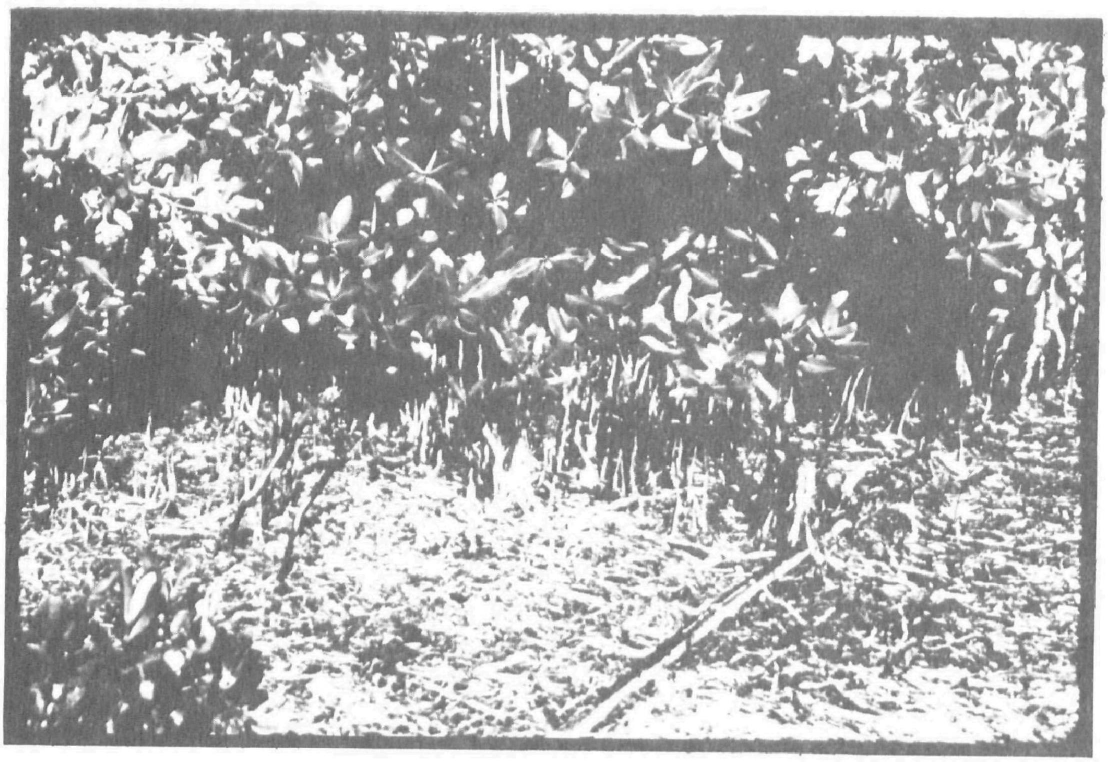

Figure 13. Black mangrove marsh.

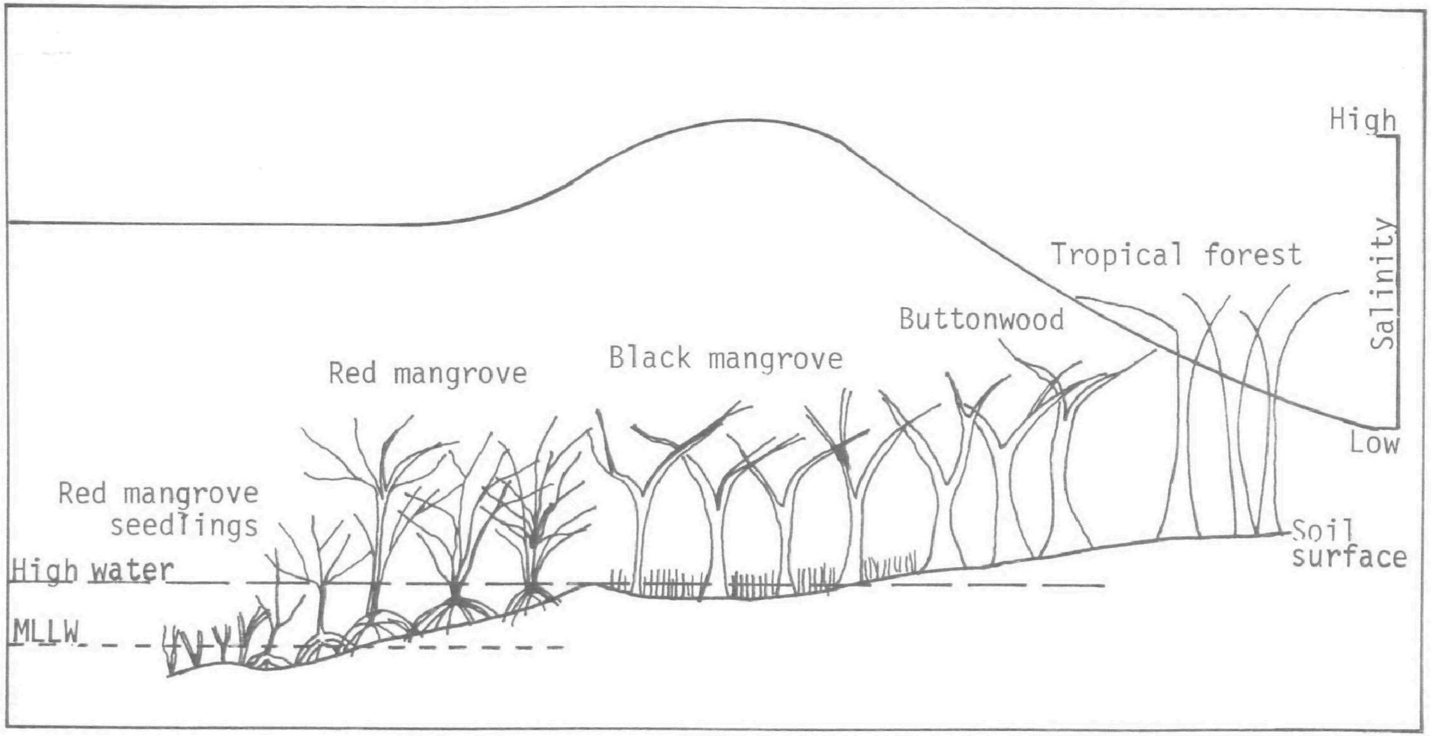

Figure 14. Schematic cross section of mangrove marsh. The graph shows zonation according to elevation and salinity.

like marshes are much more easily disturbed than the others, because they typically inhabit erosion-prone areas like river- and marsh-channel banks. Mangroves are least vulnerable to any soil-level changes that would be likely to result from oil spill response activities.

Exposure of green (photosynthetic) surfaces

All plants require their green tissues to be exposed to air and light so that they can produce food. Carbon dioxide in the atmosphere is the building block out of which plants make the food they need to survive, and sunlight is the power source for the food production process.

Anything that prevents air or light from reaching the plants' green tissues will have some detrimental effect. Heavy oils that coat leaves and stems will block out both air and light. Trampling of the plants into the wet soils may have a similar impact. Cutting and burning also reduce the availability of the photosynthetic tissues.

Most marsh plants are fairly tolerant of this type of disturbance, because they have food stored in their rhizomes or other tissue. They use this food to produce new photosynthetic structures. Recurrent destructive events may eventually deplete the food supply, and have a much more severe effect than a single event.

Reed-like marshes are most tolerant of activities that remove or block out light and air from green tissues. (For example, some types of spartina can be harvested for hay.) Few data are available on the tolerance of perennial succulent-like species although, except for such stresses as trampling, they may be nearly as resilient as reed-like species. Annual succulent-like species carry few if any food reserves. They are very unlikely to survive loss of green tissue. There is some conflict in the literature about the ability of mangroves to withstand leaf loss. Adult trees do not seem to be severely affected by a single event. Furthermore, their height makes it unlikely that they would be significantly affected by spilled oil or response activities. Seedlings, on the other hand, have minimal food reserves; they are much shorter and much more vulnerable.

Aeration

Carbon dioxide is not the only component of the atmosphere that plants require. They also need oxygen to breathe. The aerial parts of the plant are able to absorb oxygen directly from the air. The underground parts, however, cannot generally absorb oxygen directly, because marsh soils tend to be anaerobic. Instead, roots and rhizomes obtain oxygen that diffuses down specially adapted, air-filled tissues from aboveground portions of the plant. In Spartina, the grass leaves and stems act as air-intake structures for the underground parts. Red mangrove prop roots and black mangrove pneumatophores and leaves perform this function. Anything that prevents air from entering these structures will effectively strangle the roots of the plants, which will subsequently die. The sooner that air can once again enter the roots, the greater the chance that the plant will survive.

Succulent-like marsh plants also have air-filled tissues to bring oxygen to their roots. These plants grow closer to the soil, and may therefore be more vulnerable to complete coating by oil, and consequent suffocating than other species. However, succulents also sometimes inhabit less frequently waterlogged soil, which may not be anaerobic. In such a case, their roots are not likely to suffocate if the aerial portions of the plant are isolated from the air.

Sensitivity to physical disruption

To some extent, all plants can sustain physical injury from activities associated with protection and cleanup. The importance of maintaining intact photosynthetic tissues has been discussed above. The potential for erosion can also be increased by removal or decimation of the aerial portions of the plants which act as a cushion to disperse the energy of waves that impinge upon the marsh and bind sediments. It is important that stems remain intact, so that food and water can be transported within the plant. Rhizomes (roots) are also vitally important to plant survival. Rhizomes may extend for some distance underground. If the soil is soft, they may be broken by heavy foot traffic or other disturbance, but breakage is generally not harmful to the plant. In at least one reed, Phragmites communis, which grows in the higher or less saline areas of some salt marshes, rhizome breakage promotes sprouting.

The vegetation of Spartina marshes is very tolerant of physical disruption. The green parts of the dominant plants die back each year, and the rhizomes are very prone to sprout new shoots. Saltworts are less tolerant. Mangroves of both types are woody plants that could regenerate only over a long period of time if they were extensively injured (for example, by cutting). In an oil spill response, red mangroves are unlikely to suffer much physical damage. The pneumatophores of black mangroves may be exposed to breakage, which can result in invasion by water of the air-filled tissue and suffocation of the roots. Physical injury to plants can have secondary adverse effects, including increased vulnerability to toxic materials.

Sensitivity to toxic materials

All living organisms are subject to injury by toxic materials.* In the case of marsh plants, poisonous materials may either contact the

*As discussed earlier, Class A oils and cutter stocks in other classes of oil are considered as the most toxic. Marsh plants may also be subject to spills of hazardous or toxic materials (say, pesticides or chlorinated hydrocarbons) but such materials are not discussed in this manual.

plants directly or be buried in the soil by trampling or sedimentation, possibly damaging underground plant parts in the future. The aerial portions of most plants are protected to some extent by a waxy cuticle. Physical breakage opens this covering and may permit toxic substances to enter the liquid transport system so directly that poisons can be carried throughout the plant. The underground root hairs, which directly absorb water and nutrients from the soil, are not protected at all, and are therefore highly susceptible to toxins in the substrate.

Poisons in the marsh environment may do more than simply kill existing plants. They can prevent germination of seeds and growth of new sprouts, effectively sterilizing the soil and frustrating attempts at reclamation.

It is difficult to make a single statement about the effects that the many toxic substances would have on a given marsh, but the herbaceous Spartina and saltwort are likely to be more susceptible to most toxic substances.

Previous disturbance

Successive damaging incidents are likely to produce more long-term impact on a marsh than a single incident. Therefore, previous or chronic stress, whether physical or chemical, increases the sensitivity of all marsh types to most forms of disturbance. This relationship cannot be quantified in a general study, because it depends completely upon the form, frequency, and extent of previous damage to the affected area. For example, previous exposure to oil contamination or to pollutant stress generally lowers the tolerance of the marsh to further contamination. Studies near major marine terminals where chronic low-level oil contamination is a problem show that the greater the frequency of contamination, the greater the damage which results from new contamination. However, if previous contamination is not chronic, but rather a single large-scale contamination event, the tolerance of the marsh to new contamination is probably good.

Other biota

Throughout the above discussion, reference has been restricted to marsh vegetation because the vegetation and physical characteristics of the marsh determine animal habitat. It is assumed that animals will colonize suitable habitat areas, and that faunal populations are sensitive to various types of disturbance to the same degree that their habitats are sensitive. However, special features which make a marsh unique must be considered in determining that marsh's sensitivity to disturbance. Such special features include bird rookeries, important wintering grounds for waterfowl, rare species populations, and highly productive nursery areas. Local or regional experts should be relied upon to provide information about such highly sensitive marshes.

Season

The season of disturbance is particularly important in determining the potential threat to marsh biota. During migratory periods (primarily fall and winter), large concentrations of waterfowl may be temporarily present. Similarly, during nesting periods young birds may be exposed to impacts of disturbance.

Marshlands act as nursery grounds for a large number of fish as well as many commercially valuable invertebrate species. Nursery seasons can vary between the Gulf, West and East coasts but generally occur during the later winter and spring periods. Large scale damage to a marsh could have severe effects on future marine and estuarine communities contained therein.

The response of marsh vegetation is also frequently dependent upon the time of year. Mangroves of both types grow year-round, but reed-like and succulent-like plants have a distinct summer growing period and a winter season of dormancy. In winter, reed-like plants such as Spartina grass dies back to the soil level, so virtually anything can be done to the remains of the aerial portions without harming the plants. In general, succulent-like plants to not die back, alhough much of the green tissue may disappear. The aerial portions therefore remain sensitive, if inactive. In spring, the young sprouts of both reed-like and succulent-like plants are sensitive to toxic materials and physical disturbance. This sensitivity increases later in spring because the new stems have not yet produced enough food supply to replace the winter stores. Removal of green tissue does the most damage at this time of year, and decreases in severity as the season progresses.

Physical and toxic disturbance can interfere with the seasonal processes of flowering, seed-set, and germination. This is detrimental to both marsh plant types, but could completely eliminate a population of an annual succulent-like marsh which depends upon a new seed crop each year.

Physiography

One aspect of marsh physiography, the elevation or slope of the substrate, has been discussed above in terms of its relationship to tidal inundation and consequent effects on plants. Additionally, variations in elevation throughout the marsh determine where fluid substances like oil are likely to collect. The location of tidal channels likewise determines patterns of fluid flow. The sensitivity of a marsh in terms of accessibility by contaminants in the surrounding waters depends in part upon these patterns.

Physiography may provide clues to other aspects of marsh sensitivity. Wide mudflats adjacent to shallow bays are likely to be points of sediment accumulation. The erosion potential in such areas is low. However, toxic materials may become buried in the substrate. Conversely, the steep banks of rivers and tidal channels are not likely to accumulate sediment; toxic materials are not likely to become buried adjacent to them, but their potential for erosion is relatively high.

Tidal circulation

The importance of relative elevation of the marsh soil surface to average water level has been discussed above. However, the tidal patterns of ebb and flow are also very important to marsh life. The organisms in any given marsh are adapted to the local tidal cycle.

Interruption of this tidal cycling can be detrimental to marsh life. Marsh soil animals may become desiccated if tidal waters are prevented from re-entering the marsh. Continuous inundation, without tidal ebb, will cause salinity and temperature deviations and therefore, suffocation of structures like black mangrove pneumatophores that depend upon exposure to the atmosphere. In general, the longer the tidal cycle is interrupted, the greater is the potential that the marsh will be damaged. This form of disturbance is most serious where and when the tidal range is great, and less severe where tidal fluctuations are small.

Saltwort marshes are essentially exempt from this type of damage, because they do not require regular inundation. Mangrove plants of both the black and red types are probably able to sustain continued low water more successfully than reed-like plants, which has a strong requirement for regular inundation.

SPECIAL OR UNIQUE FEATURES

In addition to the potential danger to marsh plants from an oil spill, the special or unique features of threatened marshlands should be considered in evaluating sensitivity. Listed below are general categories of special or unique features:

1. Areas of threatened wildlife. These include the habitats of rare and endangered species, the nesting areas of either indigenous or migratory waterfowl, national and state parks, game reserves, and shellfish beds used for either seed stock or commercial harvesting.

2. Areas of prime recreational value. These include both public hunting reserves and private game clubs. Concern for these areas would be limited to the hunting seasons. Information concerning hunting season schedules can be identified by a call to the local game warden.

3. Areas of aesthetic value. Marshlands having unique aesthetic value are prevalent in the eastern and Gulf Coast states. These include special observation sites in parklands and viewsheds from major highways.

Special features will often be listed on charts or maps. Rapid identification of these features will require contacting local experts.

SECTION 4

PROTECTIVE MEASURES

APPROACH

Figure 1 presents the approach used to determine the protection strategy. The protection, as versus cleanup, strategy is used if the endangered marshlands have not been contaminated. The flow chart leads the user to first assess environmental conditions and predict the movement of the oil. If oil is expected to evaporate or sink, disperse or evaporate, no action is required. If the oil appears to be moving toward the marsh, monitoring meteorolgic and oceanographic conditions and oil movement predictions should continue until the oil either moves out to sea or contact with the marsh becomes imminent. If oil contact is possible with the marshlands, protection priorities are set and the protection strategy implemented.

A field inspection of the area potentially threatened should be conducted, normally following the OSC briefing and orientation. During this inspection it is desirable to obtain sufficient basic information, as contained in the list of field observations presented in Section 100, using a chart or map to note findings. The helicopter provides an ideal platform for rapid nearshore observations and documentary photography. In the marshland situation, however, total reliance on aerial observations should not be made, as oil penetrating into the marsh often will not be observable. Surface surveys should supplement helicopter observations in all cases.

Locations of oil slicks, shoreline contamination, and other relevant features should be recorded on a chart of the area. It may be convenient to compile data on clear plastic (mylar) overlays which can be sequentially superimposed over the charts thereby permitting a quick assessment of oil movements and other operations. A new set of mylar sheets can be compiled daily to give a chronological record of spill movement and damage. An example of such an overlay is given in Figure 15.

Threatened shorelines should be photographed during the initial overflight. Photographs will provide both a tool in the management of the response and a basis for determining the need for restoration. Oblique and vertical photography using hand-held 35 mm or medium-format

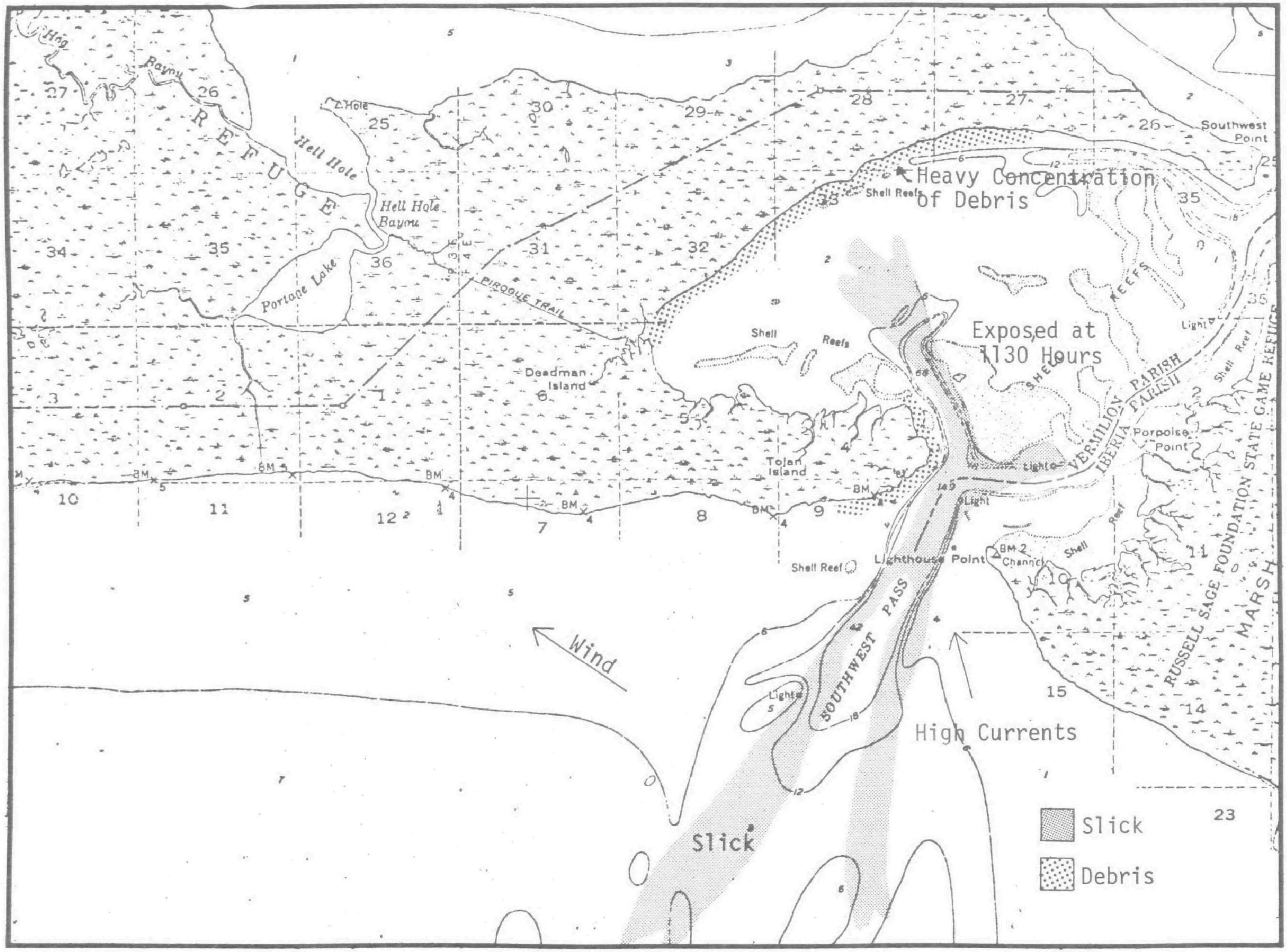

Figure 15. Use of overlay to plot slick movements and other features.

cameras is generally suitable for these purposes. Photographs should be taken in continuous sequences, beginning and ending with some recognizable landmark. A picture overlap of at least 20 percent is recommended. Camera altitude will vary with the situation and weather, with optimum balance between resolution and coverage found below 1,000 feet.

SPILL SIZE AND MOVEMENT PREDICTION

Early in the response, an estimation of spill volume will partially aid field personnel in determining the equipment and manpower needed to manage the spill containment, cleanup efforts, and disposal requirements. Since estimations of spill volume may be unavailable, field estimations are commonly necessary. Several methods can be used to provide working approximations. The most accurate method involves inspection of the source. Estimations for a tanker or barge can be based on the cargo capacity of the vessel and the number of holds involved. Spill volume from well blowouts or pipeline ruptures can be estimated in some cases from flow and production data.

Spill size approximations can also be based on the thickness of the oil slick and the area covered by the slick. Moderate- to high-altitude aerial photography coupled with sea-surface measurements are most useful since an assessment of the size of the entire slick at a single point in time is necessary. In the absence of photography, coverage may be carefully plotted on navigational charts. Spreading and rapid movement of floating slicks can, however, make accurate volume estimations difficult.

After estimating the area of contamination, the graph presented in Figure 16 can be used to provide spill volume based on slick appearance. For estimation of slicks of variable thickness it may be necessary to divide the slick into areas of similar appearance. Area measurements, especially of broken-up slicks, can be conveniently obtained, using a planimetric measuring device. Determination of extremely thick oil layers will probably require field measurement.

Slick Movement by Spreading

The initial spread of oil on the water is determined by gravity, surface tension of the water, and interface tension between the water and oil. After a day or two, the oil film thickness normally stabilizes between 0.002 to 0.003 cm. When no strong oceanographic or meteorological forces are influencing the spill movement, slick spreading may be approximated using the Blokker Equation (see Glossary). According to this equation, the film thickness and surface area will decrease rapidly. After an elapsed time of a few hours, the rate of spread and film thickness will decrease significantly.

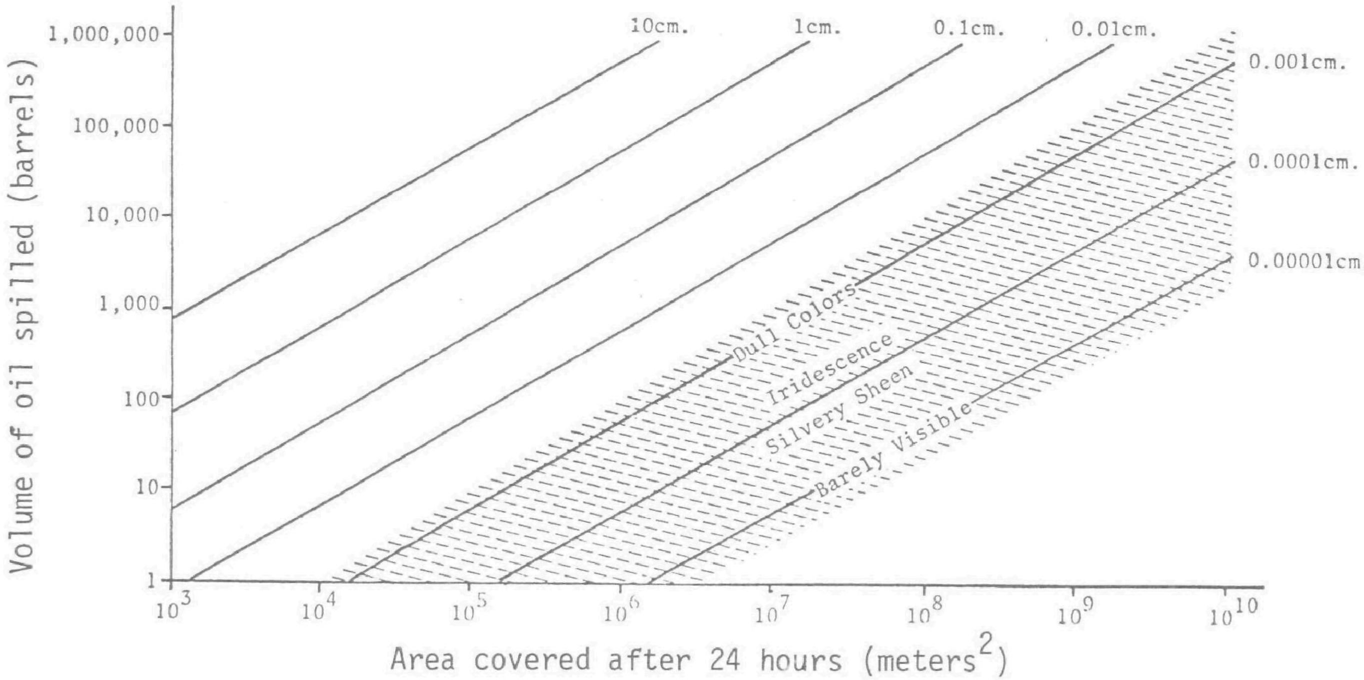

Figure 16. Volume, film thickness, appearance and area covered of oil spills.

Prediction of Slick Movements

Slick movement predictions can be as simple as observing oil movement and projecting continued movement of the slick at the same rate and direction. Generally, however, local current and weather variations must be considered driving forces which will modify the direction and extent of movement. Such information can be obtained from current charts, weather forecasts, etc.

Tide and current efforts can be rapidly deduced by simple vector addition, which assumes all driving forces to be additive. In making accurate predictions of slick movement, it is necessary to use the most current weather and tidal forecasts. New predictions or adjustments to the calculations are required whenever any of the driving forces change significantly. Shoreline recontamination is a possibility when such changes occur.

ENVIRONMENTAL CONDITIONS

In most coastal areas meteorologic and oceanographic processes comprise the dominant mechanisms influencing slick movement. Of these processes, wind, tide, and currents are the most important in dictating movement of oil on the surface of the water. Even within the salt marsh, oil remains highly subject to the influence of these processes. In addition temperature and precipitation influence oil movement in the marsh environment.

Field personnel must be aware of these environmental factors. Local sources of meteorological information should be contacted and weather predictions obtained. If such sources of information are unavailable, equipment for determining wind speed and direction should be utilized to keep the field team abreast of such changes.

General meteorological information and forecasts are available from U.S. Coast Guard stations, airport control towers or flight plan operation centers, U.S. Weather Bureau stations, or VHF-FM weather reports on 162.55 MHz. Area weather forecasts are made every 6 hours, forecasting the weather for the next 12-hour period.

Field personnel must also be aware of tides and currents. The major source of information on local currents and tides is that published by the U.S. Department of Commerce, National Ocean and Atmospheric Administration/ National Ocean Survey. Secondary sources of information are local tide tables and local personnel such as the U.S. Coast Guard harbor masters, etc.

Wind

Oil slicks can drift at speeds of 1 to 3 or 4 percent of wind speed, depending on oil type. If oil is floating immediately beneath the surface, it will move Iin response to wind) at the low end of the scale. Wind can also combine with high tides to force oil through the marsh fringes into the interior. After pushing the oil into the marsh, the wind tends to hold it in position until the wind changes direction. Changes in wind direction (commonly 180 degrees in coastal areas) can blow oil out of the marsh into open water which can cause recontamination. Mangrove marshes are particularly susceptible to oil remobilization by this process. When impending wind shifts can be predicted, containment procedures can often be implemented prior to the shift, thus limiting recontamination problems.

Wind shifts can also influence the cleanup operations. Oil held along one side of a tidal channel, for instance, can be blown to the other side as the wind shifts. Changes of this nature can require major redeployment of containment and cleanup equipment. If not foreseen, wind shifts can cause unnecessary spread of oil, additional contamination, and increased cleanup effort.

Winds can generate waves capable of interfering with the functioning of recovery equipment. While wind-generated waves are not normally a problem in salt marshes, their occurrence should be considered in the selection of oil recovery equipment.

Wind activity can influence the behavior of tides under certain conditions. Wind influence of tide is particularly common along the Gulf Coast, where strong consistent winds blowing from the Gulf can pile up water along the shoreline and produce extra or extended tides. A side effect of this condition includes the formation of unpredictable currents. Such local phenomena must be considered in planning and implementation.

Tides

In addition to generating tidal currents, tides can significantly influence the extent of contamination, and the type of response action necessary. The impact of the tide is of particular concern where variation between low and high water is significant or the marsh gradient is extremely flat. Under these conditions, potential for contamination is increased, both vertically and horizontally. As the area exposed to contamination increases, protection and cleanup requirements also increase. The anchoring of booms and other devices must accommodate the tidal rise and fall, and boom maintenance and monitoring requirements may increase.

Compared to east and west coast tidal fluctuations, the tides in the southern salt marshes are generally not of major concern when planning response operations. However, occasional spring and storm tides can be abnormally high in these areas. These occurrences can be determined by consulting tide tables and weather forecasts. In those southern salt marshes which have significant amounts of free standing water, oil spreading can occur regardless of tidal stage. More intensive protective actions are required in such cases.

Currents

Currents in the vicinity of a salt marsh are influenced by shoreline physiography, wind, tides, local runoff, and in some areas, oceanic circulation. In addition to moving the oil, strong currents can cause direct failure of many types of protective equipment, especially booms.

Velocity and direction predictions will be available only infrequently and only for navigable channels. When there are no formal predictions, general understanding of the nature of flooding and drainage of a marsh may be useful in implementing a protective response. Marshes tend to flood primarily through their system of channels and canals. As the water rises, the banks of these channels are overtopped and the interior low areas inundated. As the tide ebbs, water flows from the interior of the marsh to the fringe areas. Considering this pattern, protective booming of marsh channels and tidal inlets during the tidal flood stage can greatly reduce the extent of contamination of marsh interiors.

Temperature

Air and water temperature can influence the behavior of the oil and the nature of the control response. Temperature can significantly affects oil viscosity, evaporation rate, and burning characteristics. A response designed around the properties of oil and environmental conditions at a given temperature may not be effective if the temperature changes. The consequences of predictable changes should, therefore, be considered.

Temperature drops can increase the viscosity of the oil, potentially requiring use of a different type of recovery device (see Appendix C). Elevations in temperature can speed evaporation rate causing a reduction in the volume of a light oil or causing fluidity in heavy, nonsolid oils. Elevated temperatures can also lower viscosity, resulting in increased penetration into underlying soils. Further, oil which was adhering to marsh plants or stockpiles of collected debris can run off, leading to recontamination. Finally, extremes in temperature can affect the performance of the labor force. Crews will perform less efficiently when it is very hot or very cold and additional manpower may be needed in these extremes.

Precipitation

Rainfall can influence the response in a number of ways. Obviously direct rainfall can cause recontamination by washing oil from the marsh back into the water. Rainfall is particularly detrimental in leaching oil from debris stockpiles. Indirect effects include in river elevations and overland flow, reduction of marsh trafficability, and general deterioration of operating conditions.

GENERAL PROTECTION PRIORITIES

Time, weather, and logistical constraints seldom permit total protection of a threatened shoreline. Although it is desirable to attempt total protection, it is generally necessary to set priorities governing protection of special areas and features. Under emergency conditions the development of these priorities must be conducted rapidly in the field with minimal information. This section provides criteria for setting priorities using information developed in previous sections.

Emergency protection criteria are based on the following assumptions:

1. Regardless of oil type, quantity, and nature of the shoreline, some degree of environmental modification or damage will occur.

2. Once the oil has grounded, cleanup will generally be required -- or demanded. Effective protective actions will reduce cleanup and restoration costs and associated damage.

A logical sequence of priority considerations must be followed in planning an effective marshland protection response. Included are field examination and weighing of characteristics unique to the threatened area. Basic order-of-priority rules exist and form the foundation for developing response priorities.

Offshore spill control operations should be considered as the highest protection priority. Though beyond the scope of this manual, offshore containment can eliminate shoreline problems and should be given first consideration.

The following priority rules are stated in the order of decreasing importance and require field observations, interviews, and recording of the information obtained. It is recommended that pertinent data be plotted using a clear overlay on the chart, map, or preferably air photo(s) of the threatened area, as discussed in previous sections.

1. Protect Areas Where Public Safety is Threatened. Public, commercial, and industrial facilities are commonly found in or near many marshland areas necessitating consideration of the safety element. In all cases where human safety is potentially threatened, life-protection actions should receive highest priority. Typical facilities of concern include: harbors, piers and docks (especially those with enclosed and vapor confining configurations); water supply, cooling, or irrigation water intakes; and petroleum manufacturing or transfer facilities. Development of priority rankings within this category should reflect usage and number of people potentially impacted.

2. Protect Wetland Interiors. Driven primarily by winds, tides, and erratic wind tides, oil entering wetland interiors tends to spread widely, severely expanding and compounding damage and cleanup requirements. It is singularly important that every attempt be made to control oil at the entrance to the marsh's interior.

3. Habitat Protection. Once the areas of unique or special concern are identified (Section 300), priorities can be set. Available local experts should be consulted in this priority setting. As a guideline, priorities generally follow a progression of concern for direct impact to rare/endangered/unusual species and habitat protection downward to concern for arbitrarily set boundaries such as parks and refuges.

4. Protect Other Areas. To the degree possible, and to the extent practical, all other areas should be protected. Often action of this nature will delegate lower priority shorelines to containment, and subsequent pollution, in an effort to protect other areas.

PROTECTIVE DEVICES AND TECHNIQUES

A wide variety of devices and techniques have been developed for the control of oil spills. Although few are specifically designed for use in marshlands, most can be adapted for such use. The following section describes general categories of devices and techniques, and discusses relative advantages and constraints in their application to marshland protection. Implementation instructions are contained in Appendix B.

Protective devices and techniques can be categorized as follows:

1. Existing control features.
2. Skirt and fence booms.
3. Improvised booms.
4. Earth and rigid barriers.

5. Permeable barriers.
6. Sorbents (pads, rolls, pillows, snares, granular, etc.)
7. Wildlife deterrents.

Within the context of this manual, only inshore application is discussed. All actions described require subsequent removal of oil, and some require restoration. Additionally, most actions described can be used to contain an already oiled area preventing recontamination of adjacent areas.

Although legally permitted in certain cases of threat to human life, use of chemical treating agents in inshore marshland protection is not currently recommended. Consideration of chemical use in coastal protection should be restricted to offshore spills which threaten highly valuable coastlines. Application of chemical treating agents is the subject of a companion EPA Manual of Practice (Project Number 68-03-2621).

Existing Control Devices

Many coastal marshlands have controlled drainage in the form of weirs, tide gates, and so on. Before other protective measures are explored the threatened area should be examined for presence of such features. If such structures in threatened locations are simply closed or plugged, interior areas may be readily protected or existing contamination limited. In utilizing such control structures, it must be realized that restriction of natural tidal circulation for an extended period of time may result in environmental damage to the enclosed area. Limiting circulation to a few tidal cycles should not result in adverse effects; however, even short closure should be evaluated by qualified experts.

Skirt and Fence Booms

A wide variety of commercial booms are available. While varying in size and details of construction, all have certain common characteristics. All have a flexible or solid barrier (curtain or skirt) extending vertically into the water and supported by floats. Some (fence booms) also have a barrier projecting vertically above the water to control splash. Regardless of size or type, booms are hydrodynamically limited in their response to currents. Virtually all conventional booms fail (i.e., allow oil to pass under the boom) in currents exceeding 1.5 knots and normal, that is at 30°, to the boom. Depending on float configuration and skirt weighting or tensioning, many fail at considerably lower velocities. Performance in currents can be greatly improved by angling the boom to the direction of flow.

Other than availability, two primary factors govern the practiced application of booms in marshland situations. Perhaps the greatest limiting factor is ease of handling which is related to boom size and weight. Larger booms are heavy and extremely difficult to manipulate, requiring mechanical transport and much manpower. The manner in which the boom responds to depth and tidal variation is also critical. Booms are designed for maximum efficiency when free-floating. In inshore situations, tidal ebb exposes some or even all of the bottom. Thus, as water depth decreases, skirt booms tend to collapse on themselves, leaving a reasonably effective seal on the bottom but not necessarily on the side. Fence booms, on the other hand, tend to fall over with resulting oil loss. In general, smaller booms (with skirts of 12 inches or less) are more useful in marshes.

Sorbent Booms

Sorbent booms consist of loose sorbent materials encased in a mesh sleeve. Round in cross-section and low in density, sorbent booms generally ride high in the water and act as physical barriers only in still water. To work with maximum effectiveness they require considerable manipulation and adjustment. As with most sorbent devices, sorbent booms are most effective with light oils.

Improvised Booms

Virtually any floating object of more than a few feet in length can be used as an improvised boom in the absence of specialized equipment. Booms of this type are generally ineffective in the presence of light winds, waves, and currents, but can be effective in the still waters of marsh interiors.

Earth and Rigid Barriers

Temporary barriers of this type are particularly useful in preventing ingress of oil through narrow channels into low spots in the interior of the marsh. Such barriers must compensate for changes in tidal height. To prevent permanent changes in natural marsh circulation patterns, these barriers must be removed promptly after use. The prime advantage of these barriers is their relative ease of construction and continued effectiveness, with minimal maintenance, throughout the operation.

Permeable Barriers

Permeable barriers generally find application in small to moderate tidal channels within the marsh. Typically, in marsh usage, they consist of two layers of wire fence (chicken wire is excellent), firmly anchored at each side of the channel and extending to above (and below maximum tidal variations. The space between the two fences (4 to 8 inches) is filled with a sorbent material. When the fences are properly constructed, the sorbent floats on the water, responding to tidal changes and continually trapping oil. The distance between fences can be larger to prevent currents from sweeping oil under or sorbents blown into one area (also can use a couple of sorbent booms with sorbent between them).

Their prime advantage is that they do not restrict flow into interior areas. A major disadvantage is the requirement for frequent replacement of the enclosed sorbent material.

Sorbents

Two types of sorbents can be used in marshland protection: non-degrading synthetic materials and biodegradable natural materials such as seagrass or wood chips. Natural materials, when available, are preferred since they are simple to use and can, if unoiled, be left in place at completion of operations. However, noncohesive materials such as wood chips are to be avoided since retention and collection can be most difficult and, if lost when oiled, they can create recontamination problems.

Synthetic materials, which come in a variety of forms, must be gathered and disposed of at completion of operations, even if nonoiled. Granular sorbents should be used only in controlled situations and then with caution to prevent escape and loss. Some sorbent materials are constructed on plastic mesh to give them strength. After extended exposure, the sorbent may migrate leaving only the mesh which can ensnare small birds and animals. If such material is used, all such residual materials must be collected.

Sorbents can protect by serving as a physical barrier or, additionally, by trapping oil thereby preventing its further movement. Sorbents can be applied, for example, to immobilize a floating slick as it moves into a marsh. Sorbent rolls can be laid along near-level shorelines at low tide to protect the substrate against oil in the incoming tide. Granular sorbent can be used in fence booms to form a barrier as well as to trap oil. These sorbents have many applications in protection of marshlands but they must be used properly and then properly disposed of.

Wildlife Deterrents

Waterfowl may be present in many marshland situations. When present, they generally present an item of major concern. Birds will generally avoid areas of intense cleanup activity. Many species will instinctively avoid oily areas. A variety of devices and techniques can be used, with varying degrees of success, to keep birds away from oiled areas. In other cases firecrackers, shotgun blanks, or gas-powered cannons may be used to scare them away. Noise-generating devices may be limited severely by wind and the attenuation of sound over distance.

Recorded wildlife distress calls have been used with some success. They generally consist of sounds of wounded animals or local predators. In extreme cases personnel (preferably volunteers) can be stationed in critical areas to drive birds away.

IMPACTS ASSOCIATED WITH PROTECTION ACTIONS

Most protective techniques are unlikely to damage marsh ecosystems. For the most part, such techniques are used on open water and in tidal channels, and are consequently unlikely to affect marsh biota. Sometimes, areas of marsh must be traversed by foot or vehicular traffic in order to implement protective measures. Such traffic, even though small, can be damaging. The effects of traffic on the marsh are more fully discussed in Section 500.

Barriers (such as wiers or earthen dams) may be damaging to the marsh if they interrupt the tidal fluctuations. Exclusion of water from the marsh may be detrimental if it extends beyond a few tidal cycles, for the reasons discussed in Section 300. Construction of earth barriers can also be damaging to the substrate from which material is obtained.

Wildlife deterrents should be used with caution during the nesting season. They may cause birds in unaffected portions of marsh to abandon their nests. Local or regional experts should be consulted about this possibility before deterrents are employed.

As discussed in the previous section, nonbiodegradable remnants of sorbent materials can be injurious to marsh animals.

Table 4 summarizes the impacts associated with various types of protective action.

SELECTION OF PROTECTIVE TECHNIQUES

Once basic information about the marshland and spill is developed, appropriate protective techniques may be selected by answering a series of questions. The basic sequence of questions, actions, and references to supporting information matrices is presented in Table 5.

Selection Procedure

Using Table 6, actions and techniques compatible with the marsh type involved can be selected. Selection of the most ideally suited action from those specified as possible must be done on a case-by-case basis. The general description of action types may be useful in choosing an action(s). Commonly, cost and availability of equipment or materials may be limiting factors.

Not all actions are appropriate for all oil types. Using Table 7, the general compatibility of a device or technique with a given oil type can be identified. If the device or technique is not compatible, another option should be explored. Oil type definitions are presented in Section 200.

TABLE. 4. IMPACTS OF PROTECTION ACTION

Protective Action	Reed-like Marsh	Succulent-like Marsh	Red and Black Mangrove Marsh
Use of existing control features	Possible interruption of tidal cycle	No impact	Possible interruption of tidal cycle
Skirt and fence booms	No impact	No impact	No impact
Improvised booms	No impact	No impact	No impact
Earth and rigid barriers	Possible interruption of tidal cycle; substrate loss if marsh soil is used for barrier construction	Substrate loss if marsh soil is used for barrier construction	Possible interruption of tidal cycle; substrate loss if marsh soil is used for barrier construction
Permeable barriers	No impact	No impact	No impact
Sorbents	Possible injury to birds and other animals by nonbiodegradable remnants	Possible injury to birds and other animals by nonbiodegradable remnants	Possible injury to birds and other animals by nonbiodegradable remnants
Wildlife deterrents	Possible disturbance to nesting birds in nearby, unoiled areas	Possible disturbance to nesting birds in nearby, unoiled areas	Possible disturbance to nesting birds in nearby, unoiled areas

TABLE 5. PROTECTIVE TECHNIQUE SELECTION

	Question	Action
1.	What is threatened?	Predict movement. Identify marsh type and special features (Section 300)
2.	What should I be most concerned with?	Establish priorities (Section 700)
3.	What actions should I take?	Select candidate actions (Table 6)
4.	Is the action compatible with the oil type involved?	Determine oil/technique compatibility (Table 7)
5.	Is the action influenced by physical processes?	Determine response of action to physical processes (Table 8)
6.	Is the action environmentally acceptable?	Evaluate general impact of action (Table 4)
7.	Can the action be implemented in time?	If yes, go to 8. If no, select next best alternative.
8.	Implement Action.	Appendix B

TABLE 6. GENERAL COMPATIBILITY OF DEVICE/ TECHNIQUE WITH MARSH TYPE

Potential protection devices/techniques	Reed-like marsh	Succulent-like marsh	Mangroves Red	Mangroves Black	Man-made structures
Existing control devices	X	X	N.A.	N.A.	N.A.
Skirt & fence booms	X	X	X	X	X
Sorbent booms	X	X	X	X	X
Improvised booms	X	X	X	X	X
Earth and rigid barriers	X	X			
Permeable barriers	X	X	X	X	X (harbors, slips)
Sorbents - loose	X	X	X	X	
- other types	X	X	X		X
Wildlife deterents	X	X	X	X	

Key: X = Acceptable under normal conditions.
Blank = Not recommended.
N.A. = Not applicable.

TABLE 7. COMPATIBILITY OF PROTECTIVE DEVICE/ TECHNIQUE WITH OIL TYPE

Protective Device/ Technique	Reed-like Marsh	Succulent-like Marsh	Mangroves Red	Mangroves Black	Man-Made Structures
Existing control devices	all	all	NA	NA	NA
Skirt and fence booms	all	all	all	all	all
Sorbent booms	A	A	A	A	A
Improvised booms	all	all	NA	NA	all
Earth and rigid barriers	all	all	NA	NA	NA
Permeable barriers	all	all	NA	NA	all
Sorbents					
Granular	A	A	A	A	NA
Other types	A	A	A	A	A
	(-------------B limited effectiveness-------------)				
Wildlife deterents	NA	NA	NA	NA	NA

Key:
A = Oil Type A, light distillates and crudes.
B = Oil Type B, heavy distribution and residuals.
NA = Not applicable and/or recommended.

The limiting effect of major physical processes on the action or technique can be evaluated with Table 8. Currents, wind, tidal variation, and debris effects are considered. Weather forecasts should be consulted to determine possible impending changes in conditions.

Finally, before implementing an action, its environmental consequences must be weighed. Generally, impacts associated with protection actions are small or nonexistent. Table 4 in the previous section, summarizes the general impacts associated with the various protective techniques.

When a proposed action successfully passes the selection procedure outlined above it may be implemented. Appendix B provides details on the use and deployment of respective actions. In some cases no actions will be acceptable. In other cases, the acceptability of implementing a partially effective or slight damaging technique must be weighed against the alternative of no action and extensive contamination. In general, however, even a partially effective protective action is preferable to no action.

TERMINATION OF PROTECTION

The major goal of protection is to prevent or reduce oil spill contamination of a marshland. Marshland protection should be terminated when the danger of contamination ends or when all practical protection techniques prove ineffective. Some of the considerations that may justify terminating marshland protection include:

1. Meteorological and oceanographic conditions move the oil into open water where it will undergo natural dissipation.

2. The spread of the oil is physically halted by booms or barriers and removed before entering the marsh.

3. Oil is no longer subject to mobilization and additional contamination or recontamination of an area is impossible.

4. Weather or oceanographic conditions make protection ineffective or unsafe.

Protective action does not guarantee that marshlands will not be impacted. If oil enters the marsh protective devices should not be removed, but should be repositioned for the best protection action and augmented, if necessary, so that recontamination is prevented. For example, heavily contaminated shorelines and tidal inlets contaminated by spilled oil should be boomed.

A monitoring program can provide the On-scene Coordinator with valuable information in determining if marshland protection should be

TABLE 8. RESPONSE OF PROTECTION ACTION TO PHYSICAL PROCESSES

Protective device/ technique	Currents	Wind	Tidal variation	Debris
Existing control devices	Good	Good	Good	Good
Skirt and fence booms	May fail	May fail Skirt better	Good when floating. Fence may fail when stranded. Skirt better	Generally good, high debris loads may cause failure
Sorbent booms	Generally fail	Generally fail	Good	Variable
Earth and rigid barriers	Excessive currents may erode or destroy	Good	Barriers must be high enough	Good
Permeable barriers	Fair	Good	Fair to poor	Poor to fair
Sorbents				
Granular	May be scattered	May be scattered	Good	Good
Other types	May be scattered	May be scattered	Good	Poor to fair
Wildlife deterents	None	Range may be limited	None	None

terminated. Highly effective surveillance techniques include both continuing overflights and surface observations. Other useful information that should be incorporated is weather and oceanographic forecasts and status reports from field personnel. Biological experts should also be consulted in determining if the marshland is still endangered by the oil. It is the Onscene Coordinator, however, who has the final responsibility of determining when to terminate the protection phase.

SECTION 5

CLEANUP MEASURES

APPROACH

The cleanup process proceeds after the marsh is contaminated and involves the physical removal of oil from the marsh. The Flow Chart presented as Figure 1 suggests a procedural approach to a generalized cleanup strategy. Initially, location of oil slicks, shoreline contamination, and other relevant features should be recorded on a chart or map of the area. The determination of possible fire or safety hazard is then evaluated. If a hazard exists in populated areas, they should be evacuated; operations within the area will be restricted until the Onscene Coordinator considers it safe to begin cleanup operations. The sensitivity of the threatened marshland is then evaluated.

If the sensitivity/impact potential of the contaminated area is considered to be low or the possibility for adequate cleaning is good, no or minimal cleanup action may be considered and the natural cleaning alternative selected. If the possibility of recontamination is high requirements for protective actions should be considered. If cleanup action is considered necessary, cleanup equipment should be evaluated, access to the area determined, impacts assessed and cleanup priorities set. For implementation measures consult Appendix C.

PUBLIC/PERSONNEL SAFETY

Oil spills can pose direct and indirect threats to human life and safety. Some lighter oils may pose a fire threat in special situations. Oil can also contaminate public and industrial water supplies, forcing their shutdown.

Public safety is always the first concern. Thus, protection and cleanup activities may have to be directed at ensuring the safety of the general public. Of particular concern are built-up waterfront areas where structures, such as docks or piers can trap oil vapors and create a potential for explosion or fire. Evacuation of persons from such threatened areas may be required.

If the chance of explosion exists, an area restricted to trained personnel only should be established. Attention should also be given to any closed-in areas which may act as a trap for oil fumes. Personnel entering such hazardous areas should use only explosion-proof equipment; additionally, they may require self-contained breathing equipment. Fortunately, even in a short time, atmospheric dispersion will generally reduce flammability so operations can be conducted safely.

Marshes proper, even when adjacent to industrial facilities, usually have neither enclosed areas in which explosive vapors can accumulate nor ignition sources, aside from those brought in by cleanup workers. However, care must be taken to avoid accidental ignition.

Fire in a marshland during the dormant season or in marsh grasses coated with oil most probably burn uncontrollably.

Marshes may harbor a number of potential hazards which should be made known to the spill response team. Inherent dangers in marshes may include poisonous snakes, spiders, and insects. Field personnel should be able to identify and avoid such poisonous animals. Antivenom kits should also be readily available.

The topography of a marsh can also be dangerous to the unaware worker. Many marshlands are actually floating islands, whose surface can be broken through by foot traffic. Hip boots can be dangerous in these situations. Therefore, the clothes and equipment of the field team should be assessed for safety. Experienced workers should enter the marsh first and act as guides for inexperienced personnel.

MARSH SENSITIVITY

This section gives an analysis of marsh sensitivity and the kind of impact which can be expected from a spill. Section 300 proposes the basic criteria for determining marsh sensitivity.

General Impacts from an Oil Spill

The effects of an oil spill upon the biota of salt marshes are quite specific. Therefore, information given here cannot be indiscriminately applied to other environments. For simplification, three types of oil (light fuel oil, heavy fuel oil, and crude oil) three groups of marsh organisms (vegetation, burrowing and creeping organisms) and waterfowl are considered.

Characteristics of Different Oils

Light Fuel Oils (Class A oils - see Table 2) --
When light fuel oils are driven ashore, toxic effects are usually severe to both marsh plants and soil organisms. A high degree of

penetration into and contamination of soils is common. As a general rule, waterfowl will not be directly affected but may be poisoned by eating contaminated organisms buried in the mud along contaminated shorelines. Since light fuel oils are subject to rapid evaporation and weathering, short-term containment and protection measures may suffice to preclude oil from reaching the marsh.

Heavy Fuel Oils (Class B and C oils - see Table 2) --

Heavy fuel oils are less acutely toxic; rather, their effect upon organisms is exerted by suffocation, that is by plugging feeding or respiratory structures, and by simple physical interference with body parts of the organism, that is by stickiness. Plants and burrowers will not experience severe mortality unless the contamination is heavy. On the other hand, diving birds and mammals can be expected to experience widespread mortalities. Wading shorebirds are usually unaffected. Heavy fuel oils are not physically modified appreciably by evaporation or weathering, although chemical modification does occur during the period concerned with response and cleanup. They can come ashore floating as slicks, submerged in sheets, or mixed with water (emulsified). There is usually a very low degree of substrate penetration in all marsh types.

Crude Oils (Class D oils - see Table 2) --

Crude oils are an extremely variable group. Crude oil normally contains fractions of both heavy and light fuel oils. Thus, depending upon the extent of weathering of a slick, the oil can come ashore with a wide range of biologically influential physical properties. Even though significant evaporation of light fractions may occur from a floating crude slick, the residue can still exert considerable toxicity. Furthermore, it is generally of sufficient viscosity that it clings to plants and other organisms, limiting or preventing respiratory or feeding activities. Generally, experience with crude oil spills has shown that slicks that come ashore after an initial period of weathering exert their biological effects more through suffocation and occlusion than through toxicity. Penetration into the marsh substrate is highly variable depending upon the viscosity of the spilled oil.

Response of Marsh Organisms to Contamination

Vegetation --

Plants can be affected in several ways by contamination. Oil can coat the leaves and stems, inhibiting passage of air and gases through the plants' respiratory surfaces. If the oil is dark-colored, the sunlight's energy is absorbed in the oil film and photosynthesis is inhibited. If seedlings or young plants are emerging from the soil, the tips of the shoots may be damaged by physical and chemical properties of the oil. Light fractions are likely to kill green tissues which they contact and, if they penetrate into the substrate, can be taken up by the roots, poisoning the plant. Heavy oils are generally less toxic and can sometimes be removed to a sufficient degree to prevent widespread mortality. In numerous instances in which reasonable cleanup was achieved, either by natural means such as tidal flushing, or through an effective organized cleanup effort, damage to the marsh has been minimized and completed recovery has occurred.

Burrowing and Creeping Organisms --

This group includes clams, worms, snails, and crabs. They are found burrowing in the mud bottoms of canals or in the substrate, particularly in the rhizome matrix. Creeping forms emerge at night from hiding places among the roots or stems and feed by grazing on the surface of the substrate. Burrowing forms feed by sucking in water (or by ingesting sediment) and sieving out food particles by means of a filter-like apparatus.

Penetration of oils into the substrate can expose these organisms to damage by incorporation of toxic substances. Interference with feeding and respiratory structures may also occur when animals moving on the surface of the substrate contact oil deposits.

Recovery of burrowing animals can be expected within several years for spills of weathered crude and heavy oils; however, very long periods, perhaps 5 to 10 years, may be required following light oil spills.

Waterfowl --

Wading birds such as herons, egrets, sandpipers, snipe, and rails have no known natural response to avoid oil. They may wade in oil slicks or deposits; they may sit in oil if it contaminates the location of the nest or resting area; they may feed through oil deposits contaminating bills or heads. While this degree of contamination is not good for the bird, it is unlikely to cause death; this probably accounts for the frequent sighting of these birds in marsh oil spills in low numbers. Large numbers of ducks, murres, grebes, and diving birds, however, are found in marshes and can be completely incapacitated by oil contamination during marsh oil spill events. Once contaminated they are unable to fly, swim, or feed and the prognosis for their natural recovery is extremely poor. The long-term implications of oiling of a large number of such waterfowl are most negative. Since such birds produce a very few offspring per year, reduction of the breeding stock may reduce future populations for many years. Hence, readily available bird-rescue stations, which have been known to save 40 to 50 percent of birds treated, is most desirable.

Designation of Marsh Sensitivity

The sensitivity of the contaminated marshland should be known before the decision to cleanup can be made or cleanup priorities can be set. In many spill situations resources are limited so that cleanup of some areas may not be possible. In such cases, priorities must be set.

Figures 17 and 18 compare marsh classifications and type of biota with oil type. The figures present marsh plant and biotic sensitivity on a monthly schedule. These figures should be considered as gross generalities because no single figure is capable of simultaneously presenting information valid for marshes on the West, Gulf, and East coasts of the United States. Therefore, the user of this manual should have these figures validated by a marshland expert in the potential geographical area of use so that any corrections necessary can be made.

Five categories of oil type and degree of oiling were considered:

1. Light oil (Class A oils)
2 Heavy oil (Class B and C oils) light oiling of the marsh
3. Heavy oil (Class B and C oils) heavy oiling of the marsh
4. Crude oil (Class D oils) light oiling of the marsh
5. Crude oil (Class D oils) heavy oiling of the marsh

Because the sensitivity designation is arrived at by considering a worst case situation, the sensitivity of the marsh plants and biota is the same for light oils and heavy and crude oils under the conditions of a heavy oiling. Therefore, to avoid repetition, the previous categories are further divided into two groups for the purpose of determining sensitivity.

Group 1. Heavy oil/light oiling of the marsh
Crude oil/light oiling of the marsh
Group 2. Light oil
Heavy oil/heavy oiling of the marsh
Crude oil/heavy oiling of the marsh

To use Figures 17 and 18, the following steps are necessary:

1. Determine oil characteristics (Section 200).
2. Determine degree of oiling (Field Observation).
3. Determine if type and degree of oiling fall within Group 1 or Group 2.
4. Determine marsh type (Section 300).
5. Determine the presence of migratory and indigenous waterfowl and burrowing and creeping organisms (from information list in Section 100). The presence of larvae need not be determined.
6. A darkened space placed in the box for the month in which the spill occurs indicates a high or low sensitivity for marsh plants and biota.

Only high and low sensitivity designations are presented because the figures are designed for quick assessments yielding the user a "yes" or "no" answers. These figures should only be used as a guide and not a rule. If at all possible, a marsh expert should be contacted for final sensitivity designation.

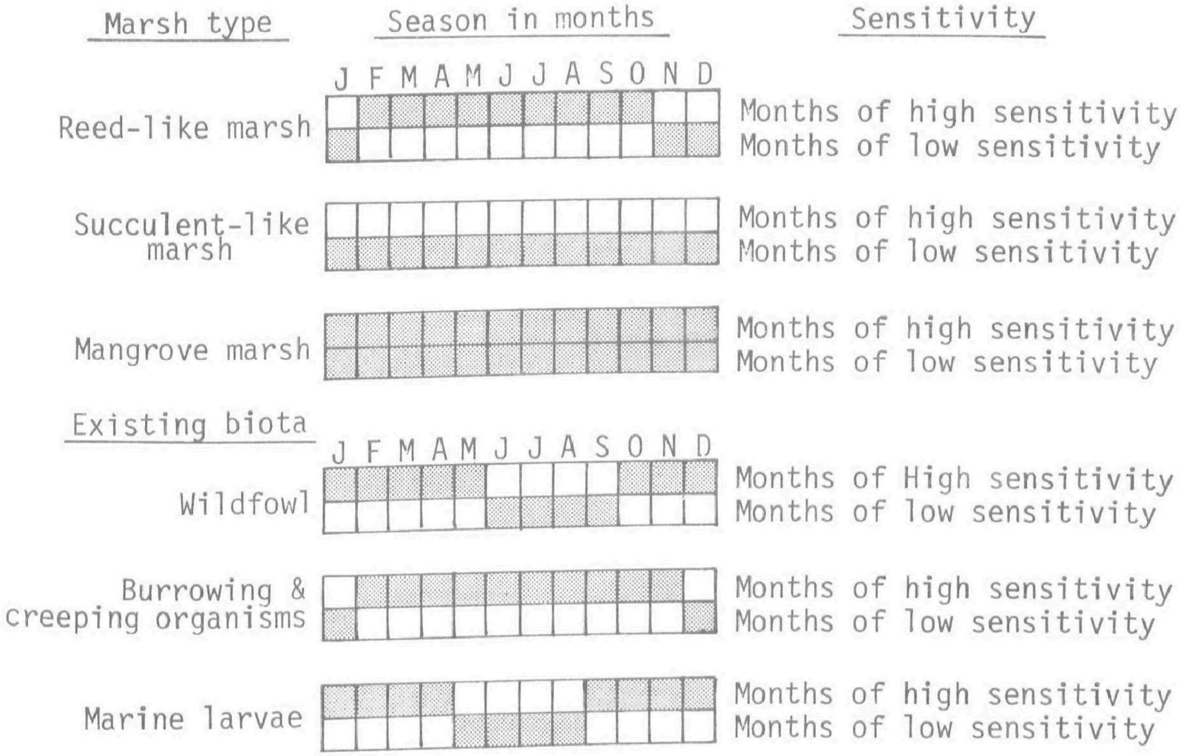

Figure 17. Marsh Sensitivity for Group 1 oils.

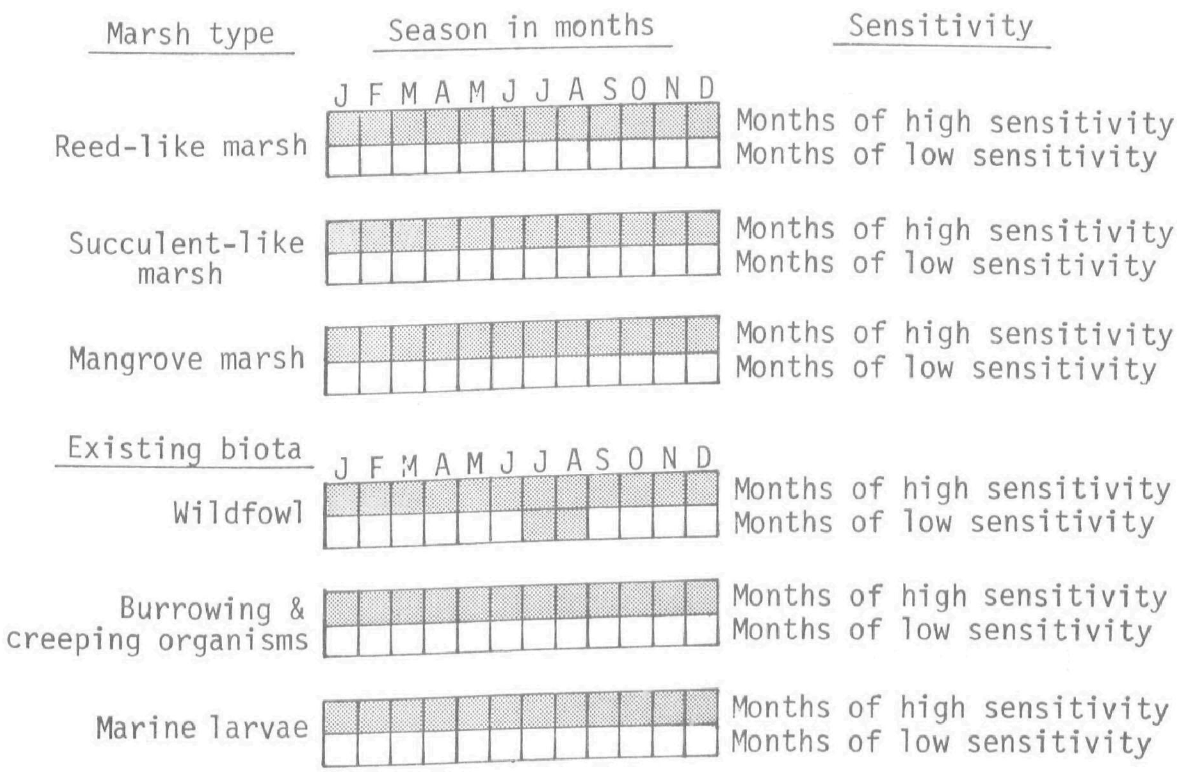

Figure 18. Marsh sensitivity for Group 2 oils.

Examples of the use of these figures are presented as follows:

Example #1

A heavy oil spill in December has lightly oiled (Group 1) a marsh in a reed-like marsh. Figure 17 aids the user in determining that there is a low sensitivity to marsh plants, burrowing and creeping organisms, and a high sensitivity to fowl. Because of the high sensitivity to fowl, protection priorities may be to block the oil from entering the marsh channels which may supply water to ponded feeding areas used by migratory fowl. The exposed marsh fringe can withstand some contamination during this period. A major priority would be to inhibit migratory fowl from landing in the area of contamination, possibly by use of propane zoom guns, etc.

Example #2

A light oil spill (Group 2) occurs in January (cold weather) in a succulent-like marsh. Figure 18 aids the user in determining that there may be a low sensitivity to the marsh plants and high sensitivity to the biota in this month. If protection efforts fail and oil enters the marsh, the cleanup strategy may be geared toward restricting entry of fowl into the marshland and using nonintensive cleanup methods such as flushing.

NATURAL CLEANING

Because of the potential for damage to the marsh from conventional cleanup procedures, natural cleansing should be evaluated as a non-damaging option. Factors that must be considered in selecting this option are discussed below. Table 9 presents criteria for evaluating this feasibility of natural cleaning. These criteria are <u>not</u> all of equal importance. Some, particularly mobility of oil and type of oil, are always of paramount importance. The importance of each factor in relation to the others varies on a case-by-case basis.

Tidal action and currents provide natural flushing mechanisms. The cleansing capability of these processes can be significant. Even without flushing, weathering causes physical and chemical degradation of the oil ultimately resulting in its disappearance.

The type of oil is an important factor in evaluating the rate of natural cleaning. The rate of weathering, and resulted decrease in toxicity, and the nature of the residual oil material dictate the degree of interference with biological processes (such as gas exchange, photosynthesis, and attachment by colonizing organisms).

Biological factors that should be considered include the presence of sensitive organisms such as waterfowl or endangered species, and the

TABLE 9. FACTORS FOR EVALUATING NATURAL CLEANING

Factor	Feasibility of Natural Cleaning*
1. Physical	
tidal and current energy	
high	+
low	-
<u>mobility of oil</u>	
high	-
low	+
degree of contamination	
high	-
low	+
degree of weathering	
high	+
low	-
2. Chemical	
<u>type of oil</u>	
high toxicity (light)	-
low toxicity (heavy)	+
3. Biological	
Waterfowl concentration present	-
Previously damaged	+

Note: Underlined factors are most important.

*+ = natural cleaning favored
 - = natural cleaning disfavored

overall health of the plant and animal community. A marsh may have considerable tolerance to a single spill and its cleanup, but may be damaged by repeated stress.

Bacterial degradation is a natural process that should not be overestimated when evaluating natural recovery. It may be a very slow process that takes place only at the oil/water interface. When the ratio of the contaminated surface-to-volume of oil is low, degradation is so slow as to be insignificant at mitigating potentially damaging effects of the oil. When the degree of contamination is low, the acceptability of natural cleansing is dictated by the efficiency of active methods. Sometimes natural cleaning is the only reasonable option, even when the degree of contamination is high.

RECONTAMINATION POTENTIAL

Remobilization of grounded oil may occur in response to a variety of factors and threaten recontamination. This can occur under the following conditions:

1. if the spill is not properly contained,
2. if the degree of clearing is inadequate,
3. if a drastic change occurs in environmental conditions which physically moves the oil from the contaminated site, or
4. if warming of oil or surfaces lowers viscosity to the point where the oil flows.

The degree of potential recontamination can vary from each of these causes. Criteria for evaluation of recontamination potential include a consideration of the following factors:

1. <u>Amount of Oil Remaining During and After the Cleanup Operation.</u> An oil budget is the means by which field personnel keep a running estimate of the amount of oil remaining in the spill area. An oil budget is estimated by calculating the total amount of oil spilled minus the estimated amount of oil lost to open waters, to evaporation, to the bottom and the amount of oil picked up through the cleanup operation. The development of a "budget" for light oils is extremely difficult, and unreliable, because light oils are not easily visable, once spilled. Since some light oils fluoresce, a method of locating light oil on the surface of sediments can be accomplished by a nighttime inspection of vegetation and soil using a battery-powered ultraviolet (UV) light source. The potential for recontamination may remain high if a significant amount of oil is unaccounted for.

2. <u>Type and Condition of Oil Remaining in the Contaminated Area.</u> Light oils do not adhere well to surfaces but may enter the

substrate. Heavy oils, on the other hand, can adhere to, but do not generally penetrate the substrate. Therefore, light oils can recontaminate recently cleaned or unaffected areas by means of a slow release from the substrate and heavy oils by warming of the oil on the surface, especially on sunny days, flowing into the nearby water for redistribution.

Both light and heavy oil can be trapped in cracks and interstices in the substrate. Unless removed, these pockets of oil may cause recontamination. It is very difficult to visually assess the amount of oil remaining in cracks, etc; however, the extent of substrate contamination may be determined by removal of a cross section of the sediment, either by a shovel or a core device, for examination. Heavy oils, if black and sticky, may be obvious; the presence of light oil may often be assessed using a UV light.

3. Environmental Conditions. The area subject to recontamination will be determined largely by the direction of currents and winds in respect to the site of the oil release. Knowledge of these factors will enable the field supervisor to plot which previously cleaned or uncontaminated marshlands could be threatened. In many cases, micro-environmental forces acting only within the confines of the marsh will determine the movement of free oil. Therefore, field investigations within the confines of the contaminated area is necessary.

4. Type of Shoreline Adjacent to Spill. A rapid inventory of shoreline types, including the location of marshlands, tidal inlets, and the mouths of rivers and creeks, should be performed at the time of the spill. The On-scene Coordinator and the cleanup contractors should be aware of valuable natural features outside of the immediate spill area which could be contaminated if the oil were mobilized.

CLEANUP TECHNIQUES

Section 500 provides a mechanism for identifying major types of equipment and candidate cleanup techniques for a variety of marsh and oil-type situations. In developing this mechanism, the state-of-the-art in marshland oil spill control has been divided into two groups: those techniques which treat the oil inplace; and those which remove both oil and oiled material (substrate and/or vegetation). The implementation strategy for these cleanup techniques is presented in Appendix C. The following paragraphs summarize relevant factors for techniques and equipment types within each group:

Inplace Cleaning

Low-pressure flushing --

The objective of this technique is to reverse the process which deposited the oil, that is, to generate a flood of water which loosens and floats oil out of the marsh. Water pressure must be kept low enough to prevent soil erosion; consequently all oil may not be removed. With portable pumps and hoses from shallow draft boats, flushing can be accomplished without disturbing the marsh surface. Appropriate containment and recovery equipment is required.

Sorbents (formed) --

Many types of surface oil can be recovered with sorbent materials. Commercial formed sorbents are available in a variety of shapes including pads, blankets, rolls, sweeps, pillows, booms, and snares. They are typically most effective on water or in open areas. In vegetated areas their use is limited because oil/sorbent contact is difficult to achieve.

Pads, snares, and rolls are most generally suited for marshland use. Some types are re-enforced with plastic mesh, however, and should be avoided as unrecovered mesh is believed to present a long-term entrapment hazard to wildlife. Snares (oleophilic strands) function best with heavier oils and can be worked in tight places. Pillows and booms are not generally effective in marshlands although they may find limited application in channels during light oil spills. Due to their high cost, sorbents should not be used on a large scale until other methods of concentration and collection have been explored.

Sorbents have proven effective in the final cleanup (or polishing) of many oil types. Care should be exercised in polishing operations to hold substrate disturbance to a minimum. Caution: Sorbent materials should never be used to wipe oiled mangroves!

Sorbents (loose) --

Recovery or immobilization of oil can be accomplished with loose sorbent material. Loose sorbents have the ability to penetrate around plant stems and respond to changes in water level. They can be removed by flushing and can be recovered with vacuum systems or nets. Recovery by raking should not be attempted. Loose sorbents are, unfortunately, highly responsive to winds and currents and should be used only when their control can be assured; as a significant percent of the material distributed is likely not recoverable, biodegradable types are preferred.

Endless Rope Skimmers --

Endless oleophilic rope skimmers (oil mops) can be used to collect surface and pooled oil in extremely shallow water. Advantages include: configurations of the rope can be varied to suit the geometry of the site; water recovery is typically low; and the rope is not affected by debris or surface irregularities. Smaller units are sufficiently portable to be used in marsh interiors.

Disc and other absorbent skimmers --

These skimmers squeeze or wipe oil from oleophilic discs or belts. Typically only the smaller units are applicable to marshland use. They are best used in a stationary deployment in conjunction with a system of booms to direct oil to them. Performance with debris is generally poor for disc skimmers and fair for belt skimmers.

Weir skimmers --

These skimmers which separate floating oil with a weir device must be used in conjunction with directing and concentrating systems. Their use in marshes is limited because of their extremely poor performance in debris and of their requirement for adequate water for floatation.

Vacuum systems --

Vacuum systems generally use septic tank pumping trucks; their use is limited to accessible areas. The use of skimmer heads will improve oil recovery efficiency, but these heads tend to clog with debris. If skimmer heads are not used, recovery is lower but clogging is lessened.

Manual recovery --

In some cases, particularly with Class D oils, manual recovery (pitch forks, dip nets, etc.) may be the only mechanism of recovery. Manual efforts result in extensive surface disruption and should be carefully controlled and limited.

Removal of Contaminated Material

Cutting --

Removal of oiled vegetation can be accomplished by either hand or mechanical cutting. Mechanical methods are preferred as they involve less surface disturbance.

Burning--

Efficient removal of some oils with minimum surface disturbance can be accomplished by burning. Not all oils will support combustion, and those that will may be difficult to control. Burning is normally practiced during the dormant or dieback stage. Effects of burning growing-state marshes are unknown. Buring should only be limited to reed-like marshes.

Soil removal --

Physical removal is the only known treatment for contaminated substrate. Equipment for large-scale removal includes hydraulic dredges, floating clamshells, drag lines, etc. If at all possible, soil removal should be restricted to small areas using manual methods (such as shoveling) to minimize the damage to the marsh.

Other --

Application of chemical and microbal agents in marshland situations is currently considered developmental and therefore not considered in this manual.

Bird-Cleaning Operations

There is a good potential for rescuing a significant number of oiled birds. However, no person should attempt to disperse birds from an area where they may be endangered, nor clean oiled birds, unless adequately experienced and with proper equipment and materials. Further, government regulations prohibit the capture and holding of wild birds without the necessary permits. A local bird-cleaning center should be established in the vicinity of the cleanup operation. Local veterinarians and game wardens can be contacted to manage the operation.

ACCESS/TRAFFICABILITY

Access

Access can constitute a major obstacle in mounting protection and cleanup operations in marshes since response actions cannot be conducted if equipment cannot be brought to the site. Access and associated traffic problems have been found to be detrimental to marshes.

To determine the most efficient equipment deployment strategy, charts and road maps should be consulted, local contractors contacted, and vehicles for equipment and personnel transport located. The weight and bulk of the protection and/or cleanup equipment should be estimated, so that the proper size transportation vehicles can be obtained. Land transport requires a knowledge of road conditions best obtained from persons familiar with the site. In inclement weather, landing mats, which may be available from local National Guard headquarters, can be used to improve trafficability on muddy roads or work areas.

If the spill site is far removed from road access, equipment transport may be limited to boat or helicopter. If water transportation is necessary, local launching sites should be plotted and local harbors contacted to check into the class of boats available. If strong winds or waves exist at the site, the use of small craft to transport bulky or heavy cargo should be avoided.

Helicopters are used for a number of purposes, including equipment transfer, so that a suitable landing site must be provided.

Trafficability

In planning the response to any marshland contamination situation, one basic rule should be followed: AVOID FOOT TRAFFIC AND VEHICLE

OPERATION ON MARSH SURFACES WHENEVER POSSIBLE, PARTICULARLY WHERE SURFACES ARE OILED.

There are two major reasons for restricting terrestrial marshland operations. First, operation on the low-bearing strength and irregular terrain of the typical marsh is, at best, difficult. Relatively few specialized pieces of equipment exist that can operate in this environment, and even these can become stuck. Even where possible, foot traffic is slow and hazardous, with the hazards often further compounded by the presence of poisonous or dangerous wildlife.

Second, damage to the marsh environment resulting from surface operations may far exceed that resulting from the oil itself. Damage of this type can destroy delicate root systems and burrowing organisms and may require long recovery periods. Disruption of the marsh surface can also result in the mixing of surface contamination with the upper sediment layers. Once contamination is mixed with soil numerous adverse effects occur: root systems and organisms not previously exposed are contaminated; the area of contamination is greatly increased; the oil is placed in a situation where degradation may be slow or halted; and general cleanup is greatly complicated.

Equipment capable of limited marshland operation is often available in many coastal areas. Among the best sources of information on available operational equipment are industries, such as those in petroleum exploration, which regularly must be concerned with marsh trafficability. Other sources of information are the Regional Contingency Plan, local regulatory agencies, and local contractors.

Equipment capable of limited-surface operation includes amphibious, tracked vehicles, specialized wheeled vehicles such as used for geophysical exploration, air boats, and air-cushion vehicles. With the exception of air boats and air-cushion vehicles, such types of equipment are generally damaging to the marsh surface, and should only be used if absolutely necessary. Repeated operation of equipment on the same surface will rapidly reduce soil-bearing capacity.

Vehicular trafficability can be increased by enlarging the vehicle's loadbearing surface area or by improving the bearing strength of the marsh soil. Loadbearing surface area of a vehicle can be increased by lowering the tire pressure, installing oversize tires or tracks, or adding tracks to the wheels.

The bearing strength of the marsh substrate can be increased by building temporary roads. One form of temporary road can be constructed by laying a dense material (rocks, gravel, etc.) on the marsh surface. Although effective, this type of roadway is difficult and expensive to remove after completion of the cleanup operation, and causes severe damage to the vegetation.

Temporary airport and beach landing mats can be used as convenient light-duty temporary roads. These mats consist of perforated, interlocking metal plates or fiberglass sheets and may be rapidly deployed as shown in Figure 19. The only preparation required is removal of rocks and brush from the planned alignment.

Construction of small bridges may be required to traverse the marshland drainage network. These bridges are usually small and can be readily constructed from locally available materials. Pipes should be installed when crossing any waterway to prevent restriction of local circulation.

IMPACTS ASSOCIATED WITH CLEANUP TECHNIQUES

The equipment used for several cleanup techniques considered in this manual do not impact on the marsh itself. For example, mechanical and weir skimmers are deployed in tidal channels and pools, not in the marsh proper. Vacuum skimming in itself produces no impact on the marsh, but it is frequently accompanied by substantial foot traffic. Foot and equipment traffic are considered secondary impacts and may, in themself, produce substantial adverse effects.

Major impacts of marsh cleaning activities are summarized in Table 10, and discussed in detail below.

Traffic

The most obvious type of disturbance caused by traffic in a marsh is physical breakage of plants. In both reed-like and succulent-like marshes, physical damage effectively reduces the amount of photosynthetic tissue and may expose the interior of the plants to toxic fractions of the oil. Plants are likely to recover from one such event, but recurrent trampling may clear a path that will persist for years. If the soil is soft, as it is in many marshes, roots and rhizomes will be broken thereby accelerating the erosive processes.

Foot traffic potentially accelerates erosion even where the substrate is firm and the rhizome mat remains essentially intact. Shorelines that consist of steep escarpments are particularly vulnerable. Cleanup activities that entail foot traffic should be used in such regions only after other methodologies have been considered and rejected.

Red mangroves are unlikely to be harmed to any significant extent by foot traffic. In contrast, black mangroves are subject to pneumatophore breakage, which can lead to root suffocation and death or severe stress of the tree. Furthermore, seedlings of both the red and black species are subject to injury.

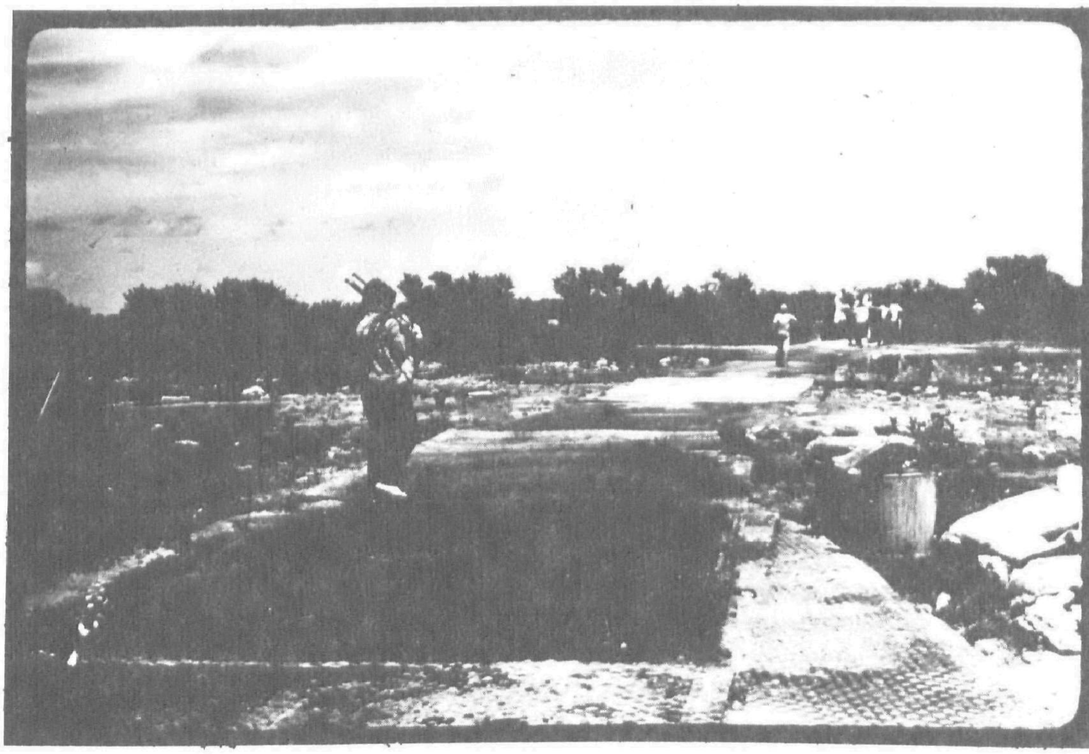

Figure 19. Application of fiberglass landing mats.

TABLE 10. MAJOR IMPACTS OF MARSH CLEANING ACTIVITIES

Cleanup Operation	Reed-like Marsh	Succulent-like Marsh	Red and Black Mangrove Marsh
Traffic	Rhizomes may be damages; erosion potential high	Rhizomes may be damages; little erosion potential	Red mangrove - tolerant to traffic Black mangrove - pneumatophores may be damaged
Cutting	Very tolerant	Tolerant	Intolerant
	--------------Frequently involves foot traffic------------------		
Flushing	Very tolerant	Very tolerant	Very tolerant
Burning	Very tolerant	Intolerant	Intolerant
Sorbents	Very tolerant	Very tolerant	Very tolerant
	--------------Frequently involves foot traffic------------------		
Soil Removal	Plant dominance may change, or marsh plant habitat may be eliminated	Plant dominance may change or marsh plant habitat may be eliminated	Plant dominance may change or marsh plant habitat may be eliminated

Sometimes it is necessary to transport heavy equipment to remote portions of marsh. The impacts of foot traffic described above apply even more strongly to vehicular traffic. The impenetrability and typically swamp-like character of red mangrove stands make it unlikely that cleanup crews would attempt to bring heavy equipment into a red mangrove marsh. Cutting trees to create paths is detrimental and not recommended unless this action is necessary to save the overall area.

Traffic on soft marsh soil may bury the stems and leaves of reed-like and succulent-like plants, consequently reducing their productivity until they resprout or grow back above the soil surface. Further, traffic under these conditions is likely to bury oil. In the anaerobic soils that characterize mangrove marshes, residual oil may persist for years. If the buried oil is toxic, it may inhibit the growth of anything in the contaminated zone until it eventually dissipates.

Flushing

Low-pressure flushing produces no adverse effects aside from foot traffic that may be required to deploy the flushing equipment. This method of cleanup, when properly conducted, essentially reverses the mechanism of contamination. It may additionally be effective in floating oil out of contaminated sediments.

High-pressure flushing may cause some erosion, local rearrangement of the substrate, and physical damage to the plants. These forms of damage are usually less severe than similar impacts caused by foot traffic, but this depends upon mode of deployment. Low pressure flushing seldom causes oil to be driven into the substrate. If steam or heated water are used, marsh animals in the spray pattern may be killed or stressed by thermal shock.

Sorbents

Sorbent pads, oil snare, and similar cleanup aids have two major drawbacks: first, they are usually used by a large group of personnel who heavily traffic the marsh and second, they must be recovered. Additionally, if cleanup teams are not trained in the use of these materials, there is a chance that oil may be mixed with a shallow layer of the substrate in the course of recovery.

If the oiled pneumatophores or prop roots of red or black mangroves are wiped with sorbent pads, the air pores in these structures may be plugged, resulting in root suffocation.

Because complete recovery of sorbent materials is seldom possible in a field cleanup exercise, remnants of sorbents may persist. Most remnants are merely unsightly, although some may ensnare birds and mammals. Large concentrations of undegraded materials could block the light from an appreciable portion of the marsh surface and consequently reduce the marsh's productivity in that region. Biodegradable sorbents avoid many of these problems.

Oiled sorbent materials (synthetic and biodegradable) should always be recovered from the marsh. Those that are not collected comprise a potential source of recontamination and a hazard to marsh animals.

Cutting

Cutting of oiled plants is a cleanup technique that entails direct physical destruction of plant tissues. As such, it severely reduces the amount of photosynthetic tissue and may expose the plant's interior to toxic substances in the oil as discussed in Section 500. Moreover, cutting operations are likely to require a great deal of foot traffic and the attendant adverse effects.

Cutting is probably most beneficial with certain species of reed-like plants which have been heavily contaminated with viscous oil and are not subject to natural cleansing. If the entire aerial portion of the plant is coated, the roots are likely to suffocate unless some passageway is opened to the plant's interior. Cutting accomplishes this, provided that free oil that might replug the cut stem has been removed from the surrounding marsh. However, if an oiled Spartina plant is not thoroughly coated with oil, air can still diffuse down the stem to the roots, so that cutting is unnecessary unless other threats are present.

Spartina marshes are very tolerant of occasional cutting, especially late in the growing season. Saltwort marshes are less tolerant, and mangroves are quite intolerant to cutting.

Burning

Burning is sometimes an effective method of removing oil and contaminated vegetation from a marsh without encouraging injurious foot traffic.

Spartina marshes can withstand occasional burning. In fall and winter they die back to a state of dormancy. During this period, the plants are dry and may support burning. In fact, fall burning of marshes is a commonly applied management tool in many areas. During the dieback period, burning can be achieved in reed-like marshes without damaging the buried portions of the plants and can stimulate their regrowth. In all other seasons, however, not only is Spartina difficult to burn, but the growing portions, shoots and buds are injured by burning. However, this damage does not necessarily permanently harm the marsh since the underground portions of the buried plants are likely to sprout and replace the destroyed portions soon after the fire. Saltwort marshes do not dieback seasonally; thus, burning is injurious at any time. Mangroves, which are large, woody plants that have a year-round growing period, should never be burned.

Soil Removal

Removal of soil entails elimination of marsh plant habitat. Nonetheless, if the substrate is heavily saturated with toxic oil and not predicted to recover naturally, this may be only available cleanup technique.

GENERAL CLEANUP PRIORITIES

Time, weather, and logistical constraints seldom permit total cleanup of spilled oil. Therefore, priorities which govern such factors as the overall magnitude of the cleanup response, equipment deployment and manpower allocations must be determined.

Because cleanup priorities must be modified to suit each geographical location, only general guidelines can be provided. These criteria previously discussed, are herein presented as topic headings with section references where applicable. Criteria are presented in decreasing order of importance.

1. Area of public and personnel hazard (Section 400)
2. Areas of commercial activity including fishing grounds, public hunting areas, marinas and docks
3. Areas of recreational value (Section 300)
4. Areas of special concern, e.g., rare and endangered species (Section 300)
5. Areas of high environmental sensitivity (Section 600)
6. Other areas.

SELECTION OF CLEANUP TECHNIQUES

Effectiveness of a given cleanup technique will vary with marsh and oil type. Table 11, 12, 13, and 14, may be used to identify generally acceptable treatments for the various combinations of conditions. These tables relate techniques to marsh type for each of the oil categories. Rankings of 1, 2, and 3 are given. Ranking 1 denotes a technique that will be generally productive. A ranking of 2 indicates a technique that may be suitable in some areas or provide an acceptable support function (e.g., a skimming system suitable for recovery of flushed oil). Techniques given a ranking of 3 will generally not perform acceptably in the marsh environment. No attempt is made to distinquish between multiple rankings for the same marsh type.

In situations for which no primary technique is recommended, selection of a secondary technique must suffice. Numbers following each technique in the tables refer to implementation instructions in Appendix C.

TABLE 11. CANDIDATE CLEANUP TECHNIQUES CLASS A OILS

		Low pressure flushing	Sorbents (formed)	Sorbents (loose)	Rope skimmers	Disc & other absorbent skimmers	Weir skimmers	Vacuum systems	Manual recovery	Cutting	Burning	Soil removal
Reed-like marsh	Outer fringe	1	2	2	1	2	3	1	NR	NR	NR	As required
	Interior	2	2	3*	2	2	3	3	NR	NR	1	
Succulent-like marsh	Outer fringe	1	2	3	2	2	3	1	NR	NR	NR	
	Interior	2	2	3	2	2	3	3	NR	NR	NR	
Mangrove	Red	1	2	2	2	3	3	2	NR	NR	NR	NR
	Black	1	3	2	2	3	3	2	NR	NR	NR	NR

1 - Primary Candidate Technique
2 - Technique may have limited application
3 - Technique will probably have poor effectiveness
NR - Not recommended

*May be useful in preventing substrate contamination.

TABLE 12. CANDIDATE CLEANUP TECHNIQUES
CLASS B OILS

		Low pressure flushing	Sorbents (formed)	Sorbents (loose)	Rope skimmers	Disc & other absorbent skimmers*	Weir skimmers*	Vacuum systems	Manual recovery	Cutting	Burning	Soil removal
Reed-like marsh	Outer fringe	2	2	2	2	2	3	2	2	2	NR	As required
	Interior	2	2	3	2	2	3	3	NR	NR	1	
Succulent-like marsh	Outer fringe	2	3	3	2	2	3	2	2	2	NR	
	Interior	2	3	3	2	2	3	3	NR	NR	NR	
Mangrove	Red	2	2	2	2	2	3	2	2	NR	NR	NR
	Black	2	3	2	3	3	3	3	2	NR	NR	NR

1 - Primary Candidate Technique
2 - Technique may have limited application
3 - Technique will probably have poor effectiveness
NR - Not recommended

*May foul with heavier oils.

TABLE 13. CANDIDATE CLEANUP TECHNIQUES CLASS C OILS

		Low pressure flushing	Sorbents (formed)	Sorbents (loose)	Rope skimmers	Disc & other absorbent skimmers	Weir skimmers	Vacuum systems	Manual recovery	Cutting	Burning	Soil removal
Reed-like marsh	Outer fringe	1	2	2	1	2	3	2	2	NR	NR	As required
	Interior	2	2	3	1	2	3	3	NR	NR	1	
Succulent-like marsh	Outer fringe	1	2	2	1	2	3	2	2	NR	NR	
	Interior	2	2	3	2	2	3	3	NR	NR	NR	
Mangrove	Red	1	1	1	1	1	2	1	1	NR	NR	NR
	Black	1	3	2	3	3	3	3	2	NR	NR	NR

1 - Primary Candidate Technique
2 - Technique may have limited application
3 - Technique will probably have poor effectiveness
NR - Not recommended

TABLE 14. CANDIDATE CLEANUP TECHNIQUES
CLASS D OILS

		Low pressure flushing	Sorbents (formed)	Sorbents (loose)	Rope skimmers	Disc & other absorbent skimmers	Weir skimmers	Vacuum systems	Manual recovery	Cutting	Burning	Soil removal
Reed-like marsh	Outer fringe	1	NR	NR	NR	NR	NR	2	2	NR	NR	Not expected to occur
	Interior	2	NR	NR	NR	NR	NR	3	NR	NR	NR	
Succulent-like marsh	Outer fringe	2	NR	NR	NR	NR	NR	2	2	NR	NR	
	Interior	2	NR	NR	NR	NR	NR	3	NR	NR	NR	
Mangrove	Red	1	NR	NR	NR	NR	NR	2	2	NR	NR	
	Black	2	NR	NR	NR	NR	NR	3	2	NR	NR	

1 - Primary Candidate Technique
2 - Technique may have limited application
3 - Technique will probably have poor effectiveness
NR - Not recommended

DEGREE OF CLEANUP

The determination of the degree of cleanup required is perhaps the most difficult question to respond to in this manual. The cut-off point of cleaning operations is ideally when the marsh is completely clean and realistically when the efficient use of manpower and equipment reaches a point of diminishing returns when related to the environmental damage resulting from the cleanup operation. Unfortunately a complex assortment of factors are involved in terminating the cleanup operation in the real world. In general, each oil spill will have a unique set of circumstances that must be evaluated before the decision to terminate is possible. The On-scene Coordinator normally evaluates these circumstances and upon consultation with experts and officials will decide if the cleanup should be terminated. The following are suggested criteria for termination:

1. Has the threat of fire or safety of local residents and visitors in the marshland been removed? The cleanup operation should not be terminated unless the contaminated area is free of oil-related fire hazard and people can visit the marshland without spill-related hazard. The fire hazard is normally ended when most of the light hydrocarbons have evaporated and when thick pockets of oil have been removed.

2. Has the cleanup operation removed the oil from sites that support commercial activities? Many marshlands are used by fishermen, trappers and hunters. Although the cleanup operation may seriously impair these commercial activities, the cleanup operation should not be terminated until the areas are cleaned sufficiently to prevent recontamination.

3. Has the cleanup operation removed oil from private property? The cleanup operation should not be terminated until privately owned docks, boats, erosion barriers, and other areas have been cleaned.

4. Are sensitive marsh areas (Section 300) cleaned to the point that any further effort would do more damage to the environment than would the presence of the oil? As a general rule, remove the oil that is visible and avoid heavy activity on the marsh except for areas with thick concentrations or pools of oil. Realistically, all of the oil cannot be removed. The cleanup operation should be terminated if it, in itself, can damage the marsh beyond its ability to recover naturally.

5. Has the recreational value of the marshland been restored? Most marshlands are used for a variety of recreational activities such as bird watching, aesthetic enjoyment and so forth. The contaminated area generally cannot be cleaned

sufficiently to allow all of these activities to return to pre-spill conditions. However, the cleanup operation should not be terminated until the area has been cleaned sufficiently enough to allow such areas as wildlife reserves, parks, wilderness areas, to recover naturally.

During and after an oil spill, pressure groups can place great demands upon those persons involved in the cleanup operation. The cleanup operation should not be terminated until the demands of these groups are considered within the realities of what can be accomplished by the cleanup. It will be up to the On-scene Coordinator to evaluate these demands and evaluate them on a case by case basis.

SECTION 6

RESTORATION

APPROACH

The restoration of a salt marsh must be considered whenever a marsh has been damaged beyond natural recovery by toxic effects of oil contamination or by cleanup procedures. Marsh restoration is not a fool-proof science. The techniques of marsh restoration have primarily evolved from the techniques of stabilizing dredge spoils, for example, as spoils islands or dumping areas. A large number of biological and physical factors determine the probability of a successful marsh restoration effort.

The approach to restoration is presented in Figure 1. First, the natural resources of the contaminated area are analysed to determine if natural recovery or restoration is the best course of action. If natural recovery is acceptable, a monitoring program is begun and the recovery program proceeds. If restoration is selected, field operations are begun followed by a monitoring program.

EVALUATION OF NATURAL RECOVERY OR NEED FOR RESTORATION

Given sufficient time and the proper natural conditions, most disturbed marshlands will recover. The time frame for recovery is, therefore, the first criterion to be considered. A disturbed marshland requiring assisted recovery and ineligible for the natural recovery process would be one:

1. noted as an area of threatened wildlife in which lack of cover for a season could endanger the biota. This includes habitat of rare and endangered species and selected areas heavily utilized by migratory fowl.

2. necessary for bank stabilization of such areas as channels affected by heavy routine shipping activity or beach frontage subject to heavy seasonal wave action. Priority should only be given to these areas if these losses could result in severe erosion or loss of shoreline.

3. used as a principal recreation area within a major recreational service area. This could include prime sport fishing or hunting areas, especially when lack of cover of food stocks would reduce occupation by migratory species.

The following factors are considerations if marsh restoration is required:

Need

Soil-binding properties -- transplanting will provide more soil-holding capability than will seeding.

Herbaceous growth -- transplanting will immediately provide some screening and forage vegetation, while growth of seedlings will provide denser growth, but not for several months.

Aesthetic improvement -- transplanting will provide immediate improvement.

Public relations -- transplanting produces an immediate visible improvement.

Time

If a stand of plants is required within 3 months, then transplanting should be considered. If a longer period can be permitted, then seeding may be the best alternative.

Area Size

Since transplanting proceeds one plant or clump of plants at a time, it is extremely expensive and tedious for large areas. Seeding can be accomplished either by hand or by aircraft. It is limited primarily by the amount of seed available.

Cost

Transplanting --

The cost for restoration by transplanting can be calculated by the number of plants required. Using an auger to prepare holes for planting gives a planting rate of 100 plants/hour/man. Using a shovel, an average rate is 30 plants/hour/man. Labor costs should be doubled to account for digging up the plants and then replanting them. The cost of plants, if purchased, must be included, but labor costs will be lower. In addition, a contingency for costs of transportation, soil testing, and miscellaneous items must be provided.

Seeding --

The cost for restoration by seeding is calculated on a per-acre basis as:

2/md*/acre x _____$/md + 300 lbs seed/acre x $____/lb seed = $/acre

If crop-dusting aircraft are used to spread seed, the cost is:

$200/hour x 0.5 hr/acre x 100 lbs seed/acre x $___/lb seed = $/acre.

Partial (selecting a portion of the total acreage for the restoration process) or complete restoration can be required by the necessity of maintaining the marsh's function or by state, federal, or local agencies. If it is determined that restoration of a salt marsh is required, one of the institutions listed at the end of this section can provide the necessary expertise. Each of these institutions has had experience in evaluating the feasibility of, and in actually conducting, the restoration and reconstruction of marshes.

If the loss of a significant number of marsh plants in a given marsh does not require immediate restoration action, the natural recovery process can proceed. It should be kept in mind that some areas of the disturbed marsh can still be designated for restoration even if a decision is reached to rely upon natural recovery for the marsh as a unit.

The condition of the remaining plants after the cessation of cleanup activities is of major importance in the natural recovery process. First, enough living vegetation must be present to recolonize the area. As an example, Spartina grows and expands into the marsh by means of extending rhizomes. New shoots are therefore established close to the fringe area of living plants and the clumps of plants expand to gradually recolonize an area. Spartina can also recolonize an area by seeding. Plant stocks must be available in the disturbed area to supply this seed, or be available in adjacent marshes so that seeds can be deposited in the disturbed area by currents and wave wash.

The marsh plant species composition which is recovering can be altered by the establishment of opportunistic plant species. If the plant composition is providing a specialized habitat for the biota (i.e., food, shelter or soil binding properties), a change in specie composition can be detrimental to the existing animal community. Many of the succulent-like or reed-like varieties can colonize areas which were previously inhabited by Spartina before the spill. If the marsh fringe undergoes erosion a short time after the spill, the elevational contours of the marsh fringe may be altered. Also, the soil characteristics may be modified by loss of fine sediments causing an increase in the percent of sand or gravel in an area. A change in these parameters can, for example, select against natural colonization by Spartina. Field personnel should continue to monitor these parameters during the recovery period.

*md = man-day.

RESTORATION TECHNIQUES

There are two general methods of restoration. One is by seeding; the second is by transplanting mature or seedling plants from an established marsh or nursery to the area to be restored. Seeding can be accomplished at relatively low cost and can cover extended areas. Generally, however, there is a fairly low percentage of germination and a time lag between seeding and the appearance of a vigorous marsh growth. Moreover, seeds may wash away. Transplanting gives immediate visual enhancement and physical stabilization. It is, however, both extremely labor-intensive and expensive. With the exception of a few specialized cases, only very small areas can be transplanted. It may be desirable to consider transplanting, however, when control of erosion is regarded to be a serious, immediate problem. The choice of restoration technique is also dependent on the type of marsh.

The reed-like marsh can be restored either by seeding or by transplantation. The succulent-like marsh can be restored only by transplanting at present; if seed stocks become available in the future, seeding will become a viable option. Black mangroves have been established by seeding; however, transplantation has been shown to be more successful. Red mangroves are viviparous (seeds sprout while still attached to the parent plant, see Figure 20). Either the embryos from these plants may be removed from parent stock and planted, or seedlings from established plant stocks can be transplanted to the disturbed area.

Transplanting

Plants for transplanting may or may not be available as nursery stock. Nursery plants should be furnished as seedlings in 4- to 5-inch peat pots. This greatly facilitates handling the plants. Nursery stock, when available, can be obtained from one of the sources listed. If nursery stock is not available, plants must be collected at the time of transplanting from adjoining marshes. Plants may be dug either as individuals, or they may be removed as blocks or mats (Figure 21).

Preparation of the substrate for transplanting is not required, unless oil contamination remains. In the latter case, oil and any contaminated substrate should be treated or removed and similar soil added to return the area to the original elevation.

After transport to the area to be restored, the plants are set in place as shown in Figure 22. To minimize the difficulty of working in soft substrate, one worker should remain on the bank. He can then pass the plants to another worker who digs the holes and places the plants as shown. The proper space between plants is critical to their successful establishment.

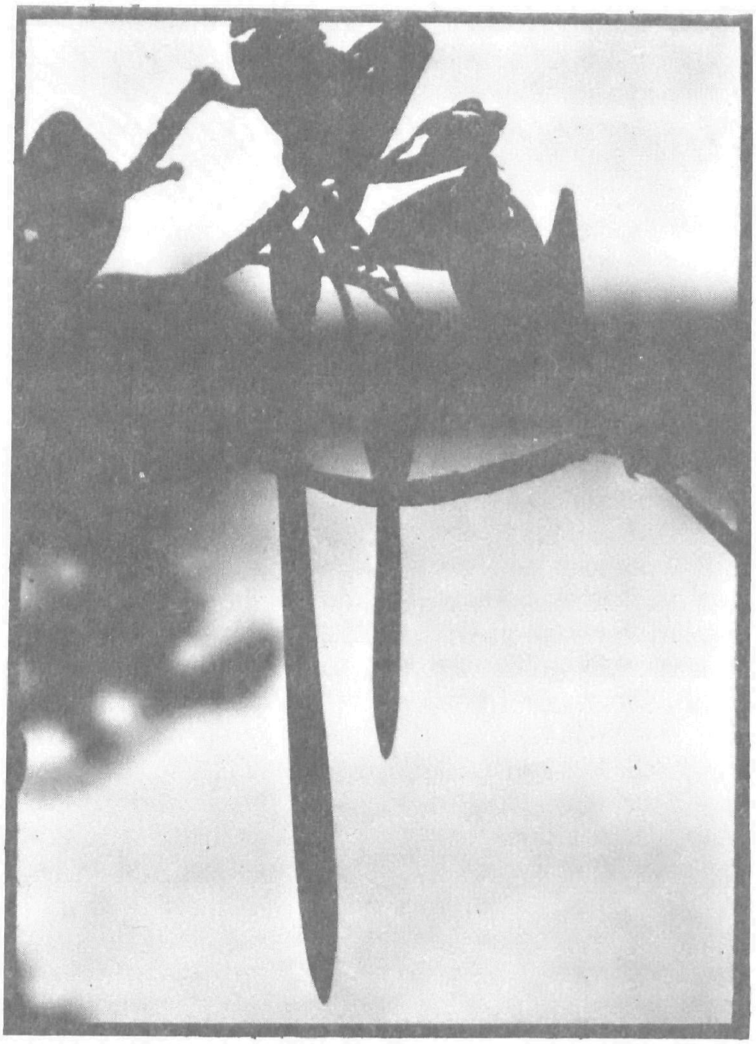

Figure 20. Red mangrove seeds.

Figure 21. Manual collection of mature Spartina plants.

Figure 22. Setting of Spartina stock.

Figure 23. Typical small scale replanting operation.

Several other variables will also influence the success of the transplants. These are depth of planting, tidal elevation, space between transplants, and seasonal timing. The sources listed can provide expert guidance in dealing with these variables and ensure full potential for success of the transplants.

Transplanting is highly labor-intensive and must be performed carefully to ensure establishment and thus reward the expense. Transplanting should only be used over small areas (Figure 23) and then concentrate on sites with the most severe damage.

Seeding

The seed (Figure 24) must be harvested (Figure 25) before its use, treated, and stored correctly to maintain viability. These procedures will have been completed with commercially supplied seeds. Spartina marsh seed has been successfully harvested and germinated and its use for reseeding is well proven in dredge spoils stabilization programs. Seed for succulent-like marsh plants is extremely scarce. Mangrove seeds are not stockpiled but can readily be collected during the fall.

Sites can be seeded at any time of year, although the rate of successful germination will vary seasonally. Wave and current action at a site may wash most of the seeds away before they can germinate and become established. Sometimes, this problem can be reduced or eliminated by using manual or standard agricultural techniques, i.e., discing, raking, harrowing, which bury the seed, as shown in Figure 26. Fertilizing has been practiced on some restored sites. Because of tidal flushing, however, it is difficult to keep the fertilizer on the seed and the results do not always justify the effort. Migrating waterfowl, particularly geese, may invade newly sown and germinated areas and cause very severe damage by grazing. Some means of waterfowl exclusion, such as alarm signals, may be necessary.

Seeding of very large areas can be accomplished in some limited cases through the use of crop-dusting aircraft. When the site is accessible to small aircraft, weather conditions permit, and seed stocks are available, use of the crop duster is most useful and economical alternative.

Sources

The private and public institutions listed below have the special capabilities required to check transplant stock for disease, match soil type of the area to be restored and the source of transplant stock, investigate soil nutrient balance at the restoration site, and evaluate the need for fertilization. Furthermore, these institutions then can furnish the materials, trained manpower, and equipment necessary to undertake this procedure.

Figure 24. Spartina seed.

Figure 25. Manual harvesting of Spartina seed.

Figure 26. Hand sowing of Spartina seed.

1. Agricultural Experiment Station, North Carolina State University, Raleigh, North Carolina.

2. Environmental Concern Incorporated, West Chew Avenue, P.O. Box P, Saint Michaels, Maryland.

3. Marine Research Center, Inc., Richmond, California.

4. Florida Department of Natural Resources, Marine Research Laboratory, St. Petersburg, Florida.

MARSH RECOVERY MONITORING PROGRAM

If either natural recovery or restoration is selected, a marsh recovery monitoring program should be established. The program will aid decision-makers in determining the success of the project. Because natural recovery is not always successful, the monitoring program should be designed to determine if a restoration project is necessary after the natural recovery project is selected.

This type program can range from visual observation combined with photographic documentation, to an intensive scientific investigation. In any case, the program should adhere to some set plan including a monitoring schedule, specific sites of study, and a standard methodology which is followed during each site visit. At a minimum, the program should:

A. Determine The Study Areas

Stake out or plot study areas in the disturbed marsh. The plots can be physically marked by flags or tall stakes on easily readable charts. The plots should be located to ensure accessibility during all seasons of the year. Because stakes can be lost, each location, based on a reading from a pocket transit (or better a sextant), should be noted on a large-scale map.

B. Determine The Monitoring Frequency

During the first month after the natural recovery or restoration program has begun, the study plots should be monitored once a week. During the second and third month, the plots should be inspected every other week; and during the fourth through the eighth month, inspection should occur once a month. If the plants appear to be establishing a good hold in the disturbed marsh and the ground cover is spreading, the plots should be inspected at intervals of 6 weeks until the disturbed surface is once again covered by plants.

If a new growing season begins during the first 8-month period, monitoring should resume at the once-a-week inspection intervals.

C. What to Look For

A photographic record of the study plot is a helpful tool to make an accurate assessment of the success of the project over time. An object of known dimensions should be placed in the study plot being photographed so that plant growth can be gauged over time. The following points should be considered during each site visit:

1. Do the plants look healthy?
2. If plants were used for the restoration, look for an increase in height; if sprigs were used, look for new shoots appearing around the sprig; if seeds were planted, look for sprouts. If natural recovery was the method chosen, look for new shoots around the existing clusters of plants.
3. Are animals eating the plant shoots or birds eating the seeds?
4. Is the amount of ground bared by the disturbance decreasing in area?
5. Is the bared area eroding? Is the soil's composition changing from silt or silty-sand to one with a higher percentage of sand? If so, measures may have to be taken to dissipate wave energy such that erosion is slowed until new plant growth can stabilize the area.

Notes should be kept throughout the monitoring program and local experts contacted for confirmation of marsh reestablishment.

SECTION 7

WASTE HANDLING

Materials generated during a wetland oil spill can be massive, often containing such diverse elements as oil, oil-water mixtures, emulsions, oil-contaminated debris of all types, plant material, oily soil, and oil recovery and response debris such as spent sorbents, paper, and plastic products.

Method of offsite handling and ultimate disposal of these waste materials is beyond the scope of this manual. Detailed information regarding disposal may be found in a recently prepared EPA companion document: Oil Spill: Decisions for Debris Disposal, EPA Contract Number 68-03-2200. It is recommended that this document be used in conjunction with the recommended wetland procedures included here.

Onsite handling of debris, however, is of primary concern to wetland cleanup. Improper handling techniques can result in a greatly expanded spill area and contamination, thereby magnifying environmental effects and cleanup/ restoration costs. Since waste handling efforts are visible to public scrutiny, improper handling can damage the public's reception of an otherwise successful operation.

Methods of waste handling in wetlands:

A. Minimize the number of transfer operations by minimizing distances between operation areas and points of vehicle/vessel access. Only one operation should be required.

B. Minimize waste material storage time at transfer points to avoid oil loss and subsequent recontamination from stockpiled materials. Losses can result from: (1) oil flowing from elevated sites, (2) elevated temperatures decreasing the viscosity of the oil allowing it to flow, and (3) oil flushing by rainfall. Provisions should be made for immediate removal of stockpiled material from onsite to ultimate disposal site. The basic restriction against nighttime operations can be waived for stockpile removal.

C. Areas for stockpile sites should be selected to avoid recontamination. Areas should not be chosen where leaching oil can flow into water. Permeable soils should be avoided or modified as necessary through site preparation including emplacement of clay or plastic liners, berms, etc. No stockpiling within the wetland itself should be permitted.

D. Field cleanup crews should be instructed on the importance of proper waste handling, both from an environmental and public relations standpoint.

APPENDICES

APPENDIX A. PHYSICAL PROPERTIES OF OIL

Introduction

Crude oils and refined products are not homogeneous fluids; rather they are mixtures of organic and other miscellaneous compounds with varying physical properties and, often, designations. For simplicity these materials can be classified into three types. The types, shown in Table A-1, are light distillates (characterized by low boiling points and specific gravities), heavy distillates (characterized by high boiling points and specific gravities), and crude oil (raw oil with a wide range of boiling points and specific gravities). Table A-2 groups are common designations of the more refined products.

Light Distillates --

Light distillates are fractions of refined crude oil with boiling point ranges from 35° C to 300° C and specific gravities from 0.76 to 0.97. The four main classifications of these distillates are motor gasoline, jet fuel, kerosene, and naphtha. These four distillates are not intended to represent all products with boiling points below 300° C but are included rather to depict the range of physical properties. Specific properties of these four light distillates are shown in Table A-3.

The rate of evaporation of light distillates is fairly high. The evaporation rate by weight of gasoline and kerosene is shown in Figure A-1. Factors that accelerate the evaporation rate of oil include surface winds and elevated air temperatures, and to a minor extent, water temperature. With reasonable air circulation and moderate temperatures, almost all light distillates can be expected to evaporate within a week. However, the volatile nature of these materials can pose an extreme fire hazard. Extreme care should be exercised in using equipment that may ignite the oil or vapors.

Many light-distillate constituents dissolve, elute, or separate out of the oil and into the water column. A general rule is that the lighter the molecular weight of the oil, the more soluble it will be in water. Many light organics (such as benzene and toluene) are quickly dissolved in water, but later are lost to the atmosphere due to evaporation

TABLE A-1. GENERAL OIL CLASSIFICATIONS

Light Distillates (Boiling Point--BP--Range from 35° C to 300° C)	
A. Motor Gasoline (BP Range 69° C to 198° C)	
B. Jet Fuel (BP Range 177° to 288° C)	
C. Kerosene (BP Range 189° C to 300° C)	
D. Naphtha (BP Range 35° C to 300° C)	
Heavy Distillates (Boiling Point Range over 188° C)	
A. Diesel Fuel Oil (BP Range 204° C to 382° C)	
B. Number 1 Fuel Oil (BP Range 188° C to 329° C)	
C. Number 2 Fuel Oil (BP Range 221° C to 334° C)	
D. Number 4 Fuel Oil (BP Range 257° C to 427° C)	
E. Bunker Fuel Oil (BP Range over 316° C)	
F. Number 6 Fuel Oil (BP Range 283° C to 683° C)	
Crude Oil (Major Sources)	
A. Libya	G. Venezuela
B. Nigeria	H. United States
C. Iran	I. Canada
D. Iraq	J. Algeria
E. Kuwait	K. Etc.
F. Saudi Arabia	

TABLE A-2. COMMON DESIGNATIONS OF REFINED PRODUCTS

Group	Common Designations
Gasoline	Gasoline
Aircraft Tubine Fuel	JP-1, JP-3, JP-4, JP-5, JP-6, Type A, B, C
Kerosene	Kerosene, No. 1 fuel oil, range oil, Type A, C, JP-5, Aircraft Turbine Fuel
Diesel Fuel Oil	No-1D, No-2D, No-4D, Marine Diesel (Type I: No-1D, Type II: No-2D, Type III: heavy distillate or marine diesel, Type IV: residual and distillate - includes Bunker C)
Distillate Heating Oils	No. 1 grade No. 2 grade
Residual Fuel Oils	No. 4, No. 5, No. 6, Navy Special, Navy Heavy, Bunker C

TABLE A-3. PHYSICAL PROPERTIES OF SOME LIGHT DISTILLATES

Properties	Motor Gasoline	Jet Fuel	Kerosene	Naphtha*
Distillation Range, ^{o} C				
10%	69^{o}	177^{o}	189^{o}	$\sim 35^{o}$
50%	105^{o}	218^{o}	214^{o}	$\sim 177^{o}$
90%	125^{o}	260^{o}	249^{o}	$\sim 191^{o}$
Final Boiling Point, ^{o} C	193^{o}	288^{o}	300^{o}	$\sim 300^{o}$
Distillation Residue, %	3	3	1.5	Variable
Vapor Pressure, cm Hg	47 to 67	10 to 36	5 to 31	Variable
Maximum Sulfur Content, %	0.25	0.4	0.13	$\sim$ 5%
Freezing Point, ^{o} C	-60^{o}	-60^{o}	-46^{o}	Variable
Flash Point, ^{o} C	--	43^{o}	58^{o}	$\sim 38^{o}$
Gravity				
API	60	50	43	34 to 16
Specific Gravity	0.76	0.78	0.81	0.85 to 0.97

*Many organic compounds are included in the general category of naphtha products. Some of these are: Mineral spirits (both light and heavy), solvents, benzene, naphtha (both light and heavy), toluene, and xylene.

Source of much of the information came from: Guthrie, Virgil B., editor, 1960. Petroleum Products Handbook, New York: McGraw-Hill Book Company.

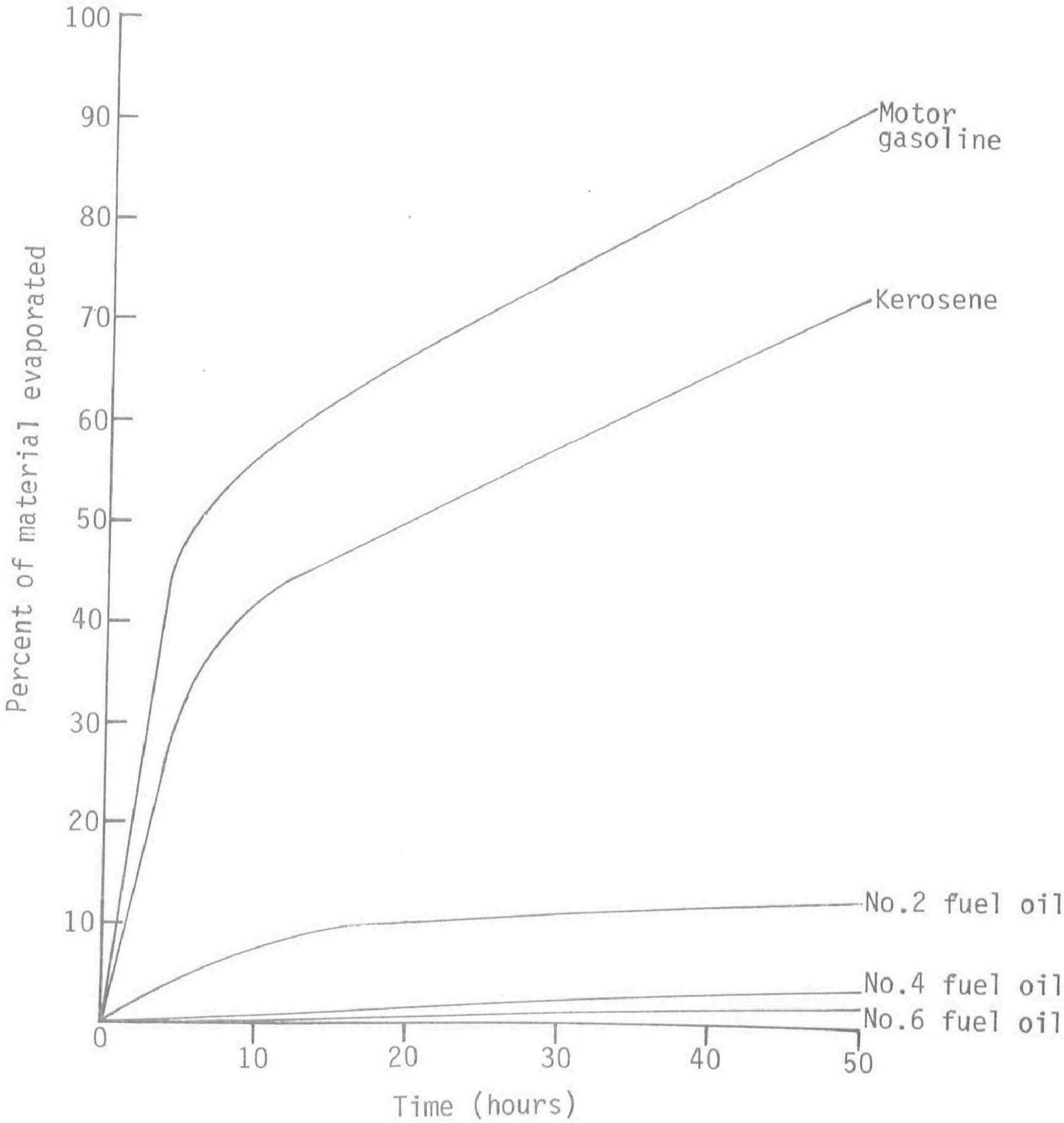

Figure A-1. Theoretical evaporation rates of several selected distillates.

(normally within 24 hours). The quantity of free-floating light distillates may quickly be reduced due to their solubility in seawater.

Light distillates commonly penetrate and contaminate marsh substrates following spills. Factors that determine penetration of oil into sediments are temperature, exposure time, and porosity and water content of the sediment. Light distillates have been found to penetrate marsh sediments faster and deeper (up to 60 cm) than other oil types. Once the oil has penetrated the sediment, it tends to persist rather than evaporate into the atmosphere or dissolve in the water column.

Heavy Distillates --

Heavy distillates are composed of refined products with a boiling point over 175° C and a specific gravity over 0.81. There is some overlap between the boiling point of heavy distillates and light distillates with heavy distillates having the majority of their fractions distilled at temperatures over 300° C. The oils that will be classified as heavy distillates are fuel oils, diesel oils, and bunker oils. Selected physical properties of several heavy distillates are shown in Table A-4.

Several physical changes occur when heavy distillates are exposed to the environment. The first, and most predominant, is the evaporation of the most volatile oil fractions (that is, with a boiling point below 370° C). Experimental and field tests have shown that up to 90 percent of the light hydrocarbons (C_{17} and C_{18}) and 50 percent of the medium hydrocarbons (C_{19} to C_{21}) are lost in a few months. Little change in heavy hydrocarbons (above C_{21}) is generally observable. Figure A-1 shows percent losses for several types of heavy distillates.

Light and heavy fuel oils, as shown in Table A-5, will tend to form oil/ water emulsions. Emulsion formation is rapid at first but stabilizes within 5 days. Emulsification has been found to be accelerated by wave action, high surface currents, and high winds, because of the increased mixing action between water and oil. Formation of emulsions having a water content of up to 70 percent is not uncommon.

Low temperatures will affect the behavior of oils heavier than No. 4 fuel oil. As temperatures drop, the viscosity of these heavy oils will increase significantly.

As discussed previously, lighter distillates will penetrate deeper and faster than heavy distillates. Given enough time, however, heavy distillates can penetrate some marsh sediments, though the fine-grained nature of typical marsh soils resists penetration by heavier oils.

Crude Oil --

Crude oils are mixtures of simple and complex organic compounds and inorganic elements. Physical properties of crude oil vary from country

TABLE A-4. PHYSICAL PROPERTIES OF SOME HEAVY DISTILLATE OILS

Properties	Diesel Fuel Oil	Number 2 Fuel Oil	Number 4 Fuel Oil	Number 6 Fuel Oil	Bunker C
Distillation Range, °C					
10%	∿ 204°	∿ 221°	∿ 257°	∿ 283°	--
50%	∿ 296°	∿ 261°	∿ 310°	∿ 493°	--
90%	∿ 357°	∿ 288°	∿ 388°	∿ 593°	--
Initial Boiling Point, °C	∿ 177°	∿ 184°	∿ 216°	∿ 256°	∿ 316°
Final Boiling Point, °C	∿ 382°	∿ 334°	∿ 427°	∿ 683°	--
Gravity					
API	∿ 36	∿ 30	13 to 33	0.3 to 20	∿ 8
Specific Gravity	∿ 0.84	∿ 0.87	∿ 0.89	∿ 0.96	∿ 0.98
Viscosity @ 38° C	33 to 50	2.6	43 to 119	45 to 342	∿300 @ 50° C
Flash Point, °C	38°	43°	∿ 65°	> 65°	> 65°
Cloud Point, °C	-46°	-29°	-12° to 2°	∿ 2°	∿ 2°
Pour Point, °C	-57°	-43°	-43° to 7°	-18° to 24°	∿ 18°
Average Sulfur Content, %	0.1	0.3	0.83	1.4	2.0

Source of most of the information was: Guthrie, Virgil B., editor, 1960. Petroleum Products Handbook, New York: McGraw-Hill Book Company.

TABLE A-5. OIL/WATER EMULSIONS AND SOLUBILITY OF DISTILLATES

Types of Oil	Formation of Emulsion	Water % in Emulsion After 5 Days	Solubility of Oil in Water
Light Distillates			
Gasoline	None	--	Fairly Soluble in Water but Evaporates Easily
Kerosene	None	--	
Naphtha	Partially Stable	5 to 10	
Heavy Distillates			
Diesel	None	--	Soluble in Water
No. 2 Fuel Oil	None	--	
No. 4 Fuel Oil	Partially Stable	5 to 10	Little Solubility in Water
Bunker Oil	Significant	70	
Crude Oil	Significant	70 to 85	Variable Solubility in Water

to country and from well to well. Considering the variability of the physical properties of crude oil (Table A-6), it is impossible to categorize them easily. The determination of the rate of evaporation, dissolution, emusification, microbial degradation, oxidation, etc., for a specific crude oil will be difficult. However, several physical properties of crude oil may provide enought information to facilitate cleanup operations.

Normally, a crude oil with a low specific gravity will have many light fractions with low boiling points, thereby increasing the weathering loss to atmospheric evaporation and seawater solubility. Conversely, if an oil has a high specific gravity, the short-term weathering losses will be smaller. The rapid weathering of the lighter and more soluble compounds will also increase the specific gravity and viscosity. Therefore, a cleanup crew may start the cleanup operations removing oil with the consistency of a No. 2 oil but finish cleanup operations cleaning up crude oil that behaves as a Bunker C oil, depending upon the nature of the oil and time. After weathering, the specific gravity of some crude oils may exceed 1.0 and they can sink. Since the specific gravity of many crudes is near that of water, they are also susceptible to sinking by emulsification, weathering, or incorporation of sediment.

Most crude oils are capable of forming water and oil emulsions or "mousse." The content, depending upon the character of the crude, will normally range between 70 and 85 percent water.

All factors being equal, soil penetration is generally deeper and faster for a crude oil with a low overall specific gravity than a crude oil with a high specific gravity.

The salinity of the water affects crude oils with a low specific gravity more than crude oils with high specific gravity because the solubility of light fractions is increased in low-salinity water.

APPENDIX B. IMPLEMENTATION OF PROTECTIVE MEASURES

This section of the Manual provides procedural information on the use of equipment and methods for the protection of marshes threatened by oil contamination. Divisions within this section are provided for easy access to the marsh protection technique desired. The breakdown of these techniques are shown as follows:

1. Fence and Skirt Booms
2. Sorbent Booms
3. Improvised Booms
4. Rigid Wall, Permeable, and Earth Barriers
5. Pneumatic Barriers
6. Sorbents
7. Wildlife Deterrents

TABLE A-6. GENERALIZED PHYSICAL PROPERTIES OF CRUDE OIL

Properties	Range
Gravity	
API	13 to 57
Specific Gravity	0.73 to 0.98
Sulfur Content, %	Nil to 4.0
Asphaltene Content, %	Nil to 5.8
Wax Content, %	Nil to 27
Pour Point, ^{o} C	-57^{o} to 21^{o}
Viscosity @ 38^{o} C	1.6 to 739
Distillation Rate, %	
to 149^{o} C	3 to 54
to 232^{o} C	7 to 84
to 343^{o} C	23 to 100
to 371^{o} C	27 to 100

It should be understood that each application of a technique will be unique. As such, precise instructions are impossible. Procedures given are designed to provide a basis for general application.

Fence and Skirt Booms

Fence Booms --

Most fence booms are difficult to transport and deploy without heavy equipment due to their physical size and weight. Normally, they are assembled at a nearby dock, barge, or shoreline and towed to the site. However, if good terrestrial access is available, they can be brought directly to the site by trucks.

For effective control of oil, all types of booms must be used in conjunction with some type of oil-recovery system. Oil which is trapped and accumulates behind the boom must be removed, periodically or continuously, depending upon the rate of accumulation. Failure to do so will lead to escape of oil around the ends or from the pocket of the boom.

Planning prior to installation should consider possible stranding at low tide, current reversals, and vessel traffic. In the following paragraphs a variety of deployment configurations are described.

Open Shore Deployment -- Shown in Figure B-1 are three types of configurations that can be used to block the path of the oil.

The first configuration shows a fence boom diverting the oil slick to a recovery system. Normally, both ends of the boom are secured to the sea floor by anchors; other locations along the boom can be anchored if the boom is long or currents and winds are strong. This configuration requires that one or two boats be available as support for transfer of oil from the recovery system to shore and for boom repositioning.

The second configuration shows an application where oil is funneled into a recovery system. The booms can be anchored or workboats put at the ends of the boom, and the system towed.

The third configuration is similar to the first except that shore-based recovery equipment is used. Although this configuration reduces the workboat requirements, good marsh accessibility is needed to move the equipment to the marsh and recover the oil. Skirt booms or some other shallow water barrier may be necessary to prevent the loss of oil in the shallow water where the fence boom no longer works.

Channel Deployment -- Figure B-2 shows two different channel deployment configurations.

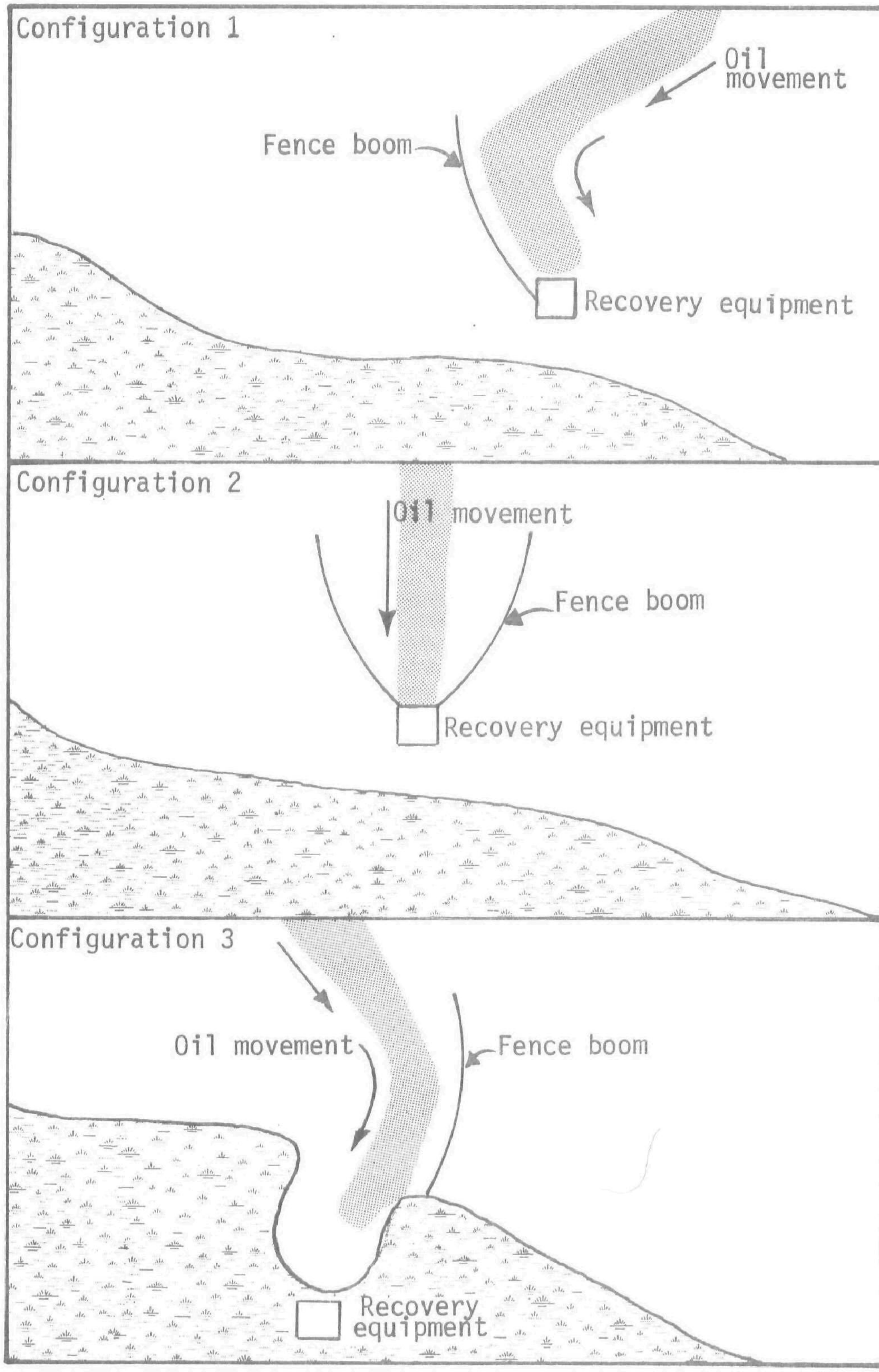

Figure B-1. Open shoreline boom deployment.

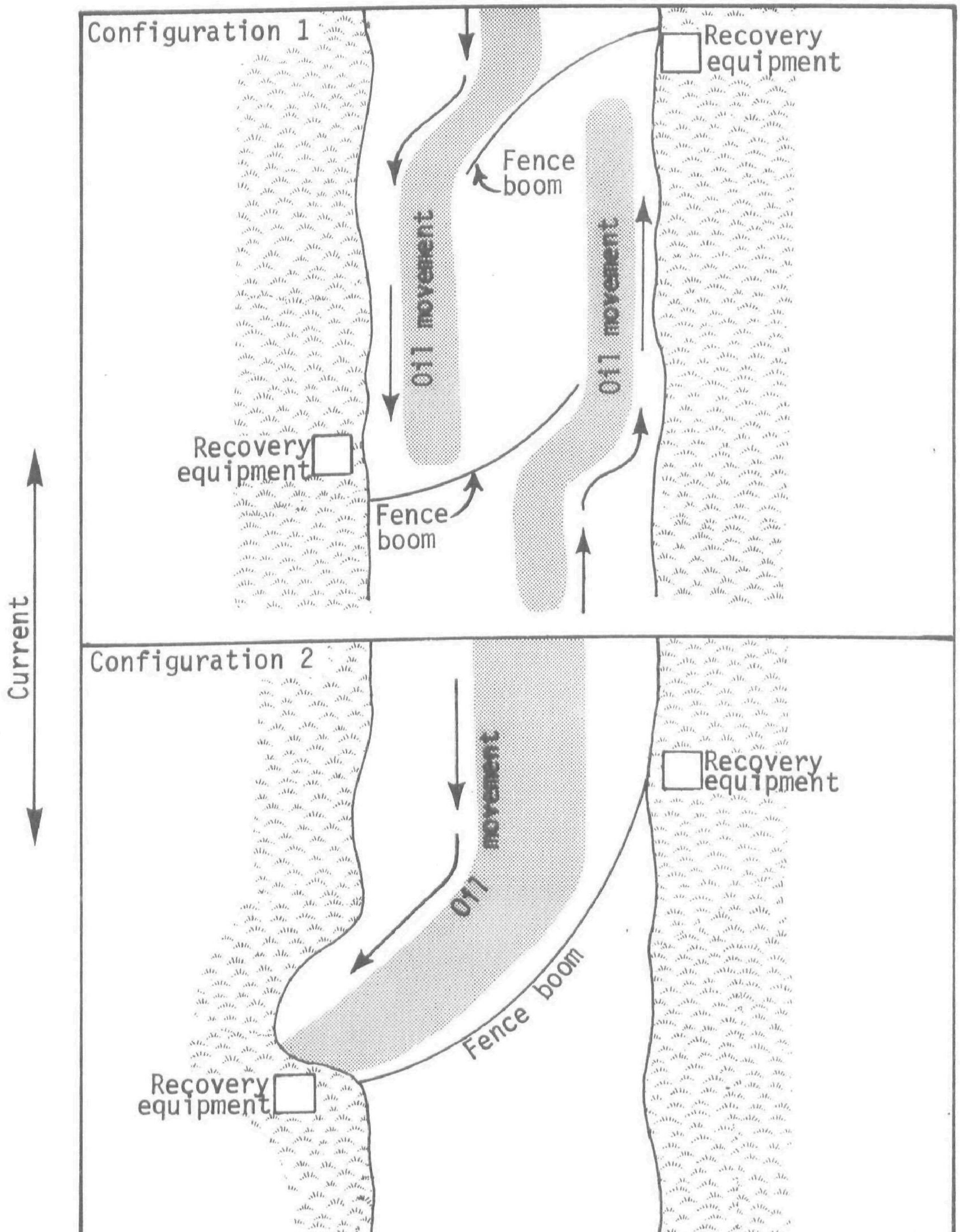

Figure B-2. Channel deployment.

The first shows a double boom deployment, permitting boat traffic to move along the channel. This configuration responds particularly well to tidal current reversals.

The second configuration can be used when disruption of boat traffic is not a problem. As in the previous situation, this deployment also responds well to tidal current reversals.

Skirt Boom --

The light weight and high flexibility of skirt booms permit a variety of methods of deployment. These booms can be deployed from the shore by small boat or barge (as shown in Fig. B-3), or by helicopter (using a break-away connection) as shown in Figure B-4. Like fence booms, skirt booms are containment devices only. They must be used with oil-recovery equipment, or oil and debris will build up and boom failure will occur.

Booms may be fixed in place by a variety of methods. They are generally held in place in the water by terminal and intermediate anchors. Anchors should be suited to bottom type and must be self-setting in situations where tidal current changes are present. The landward end of the boom may be fastened to any convenient feature (tree, etc.) or attached to a pipe anchor as shown in Figure B-5. Note that in this case there is a gap between the boom and the shoreline. Sand bags or sorbent materials placed in the gaps will greatly reduce escape of oil through such spaces. In situations where the appropriate equipment is available, piles have been effectively used to anchor booms. An installation of this type is shown in Figure B-6. Although booms fixed by this mechanism still require oil and debris removal, maintenance required in response to tidal reversals is low. In any marshland application the possible stranding of the boom at low tide should be considered.

In most cases it will be neither possible nor desirable to protect entire shorelines with booms. Instead, the primary objectives should be exclusion of oil from particularly sensitive areas, prevention of penetration into the marsh interior, and containment of existing contamination.

<u>Minor Channel Deployment</u> -- Normally, skirt booms are positioned across these channels to restrict oil from flowing into backwaters or the marsh interior. This is illustrated in Figures B-7 and B-8. These booms should be checked as often as possible to make sure they remain correctly deployed or have not failed. Where the possibility of boom overloading exists, double booming such as shown in Figure B-9 may increase the efficiency of blockage.

<u>Coastal or Seaward Exposure</u> -- Normally, skirt booms are not deployed in open areas unless the sea is calm and current velocity is low. Figure B-10 shows typical protective booming in an open shoreline

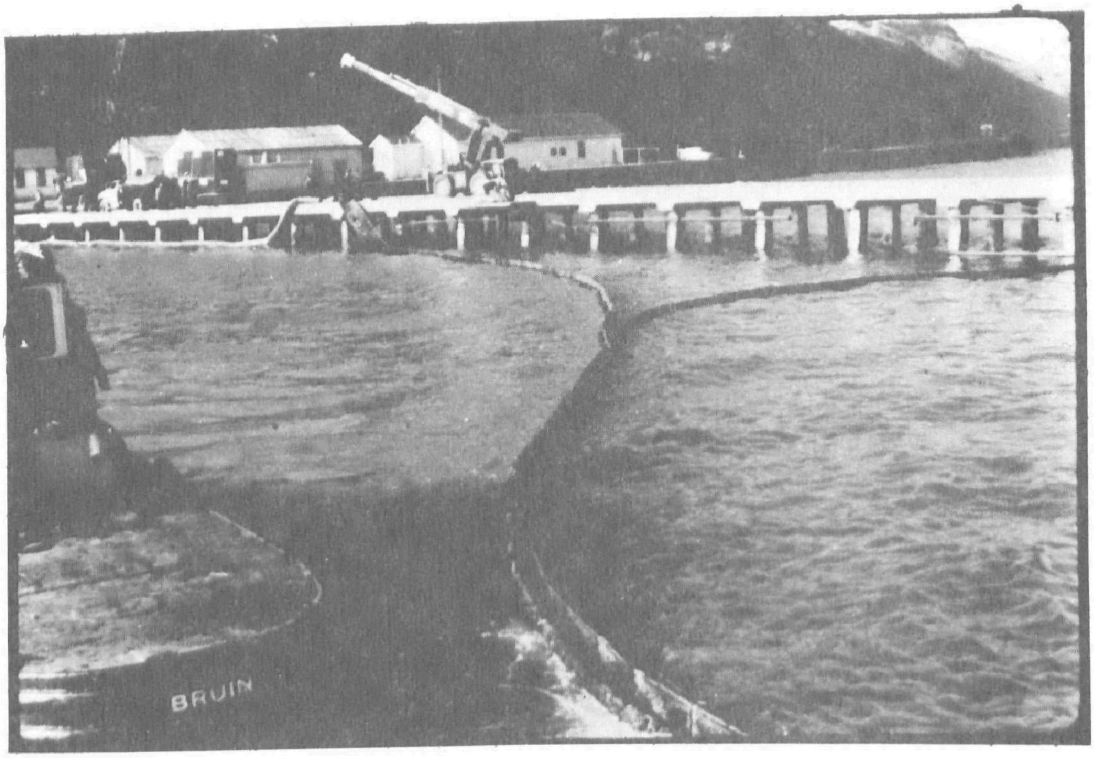

Figure B-3. Deployment of boom from barge.

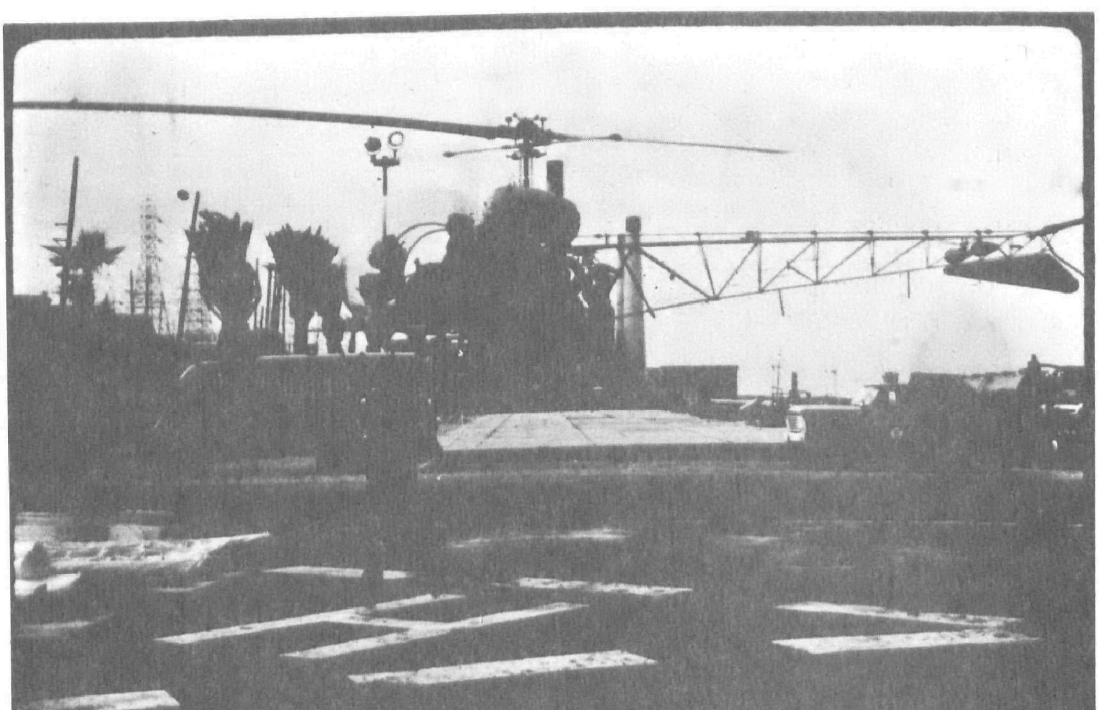

Figure B-4. Helicopter deployment of skirt boom.

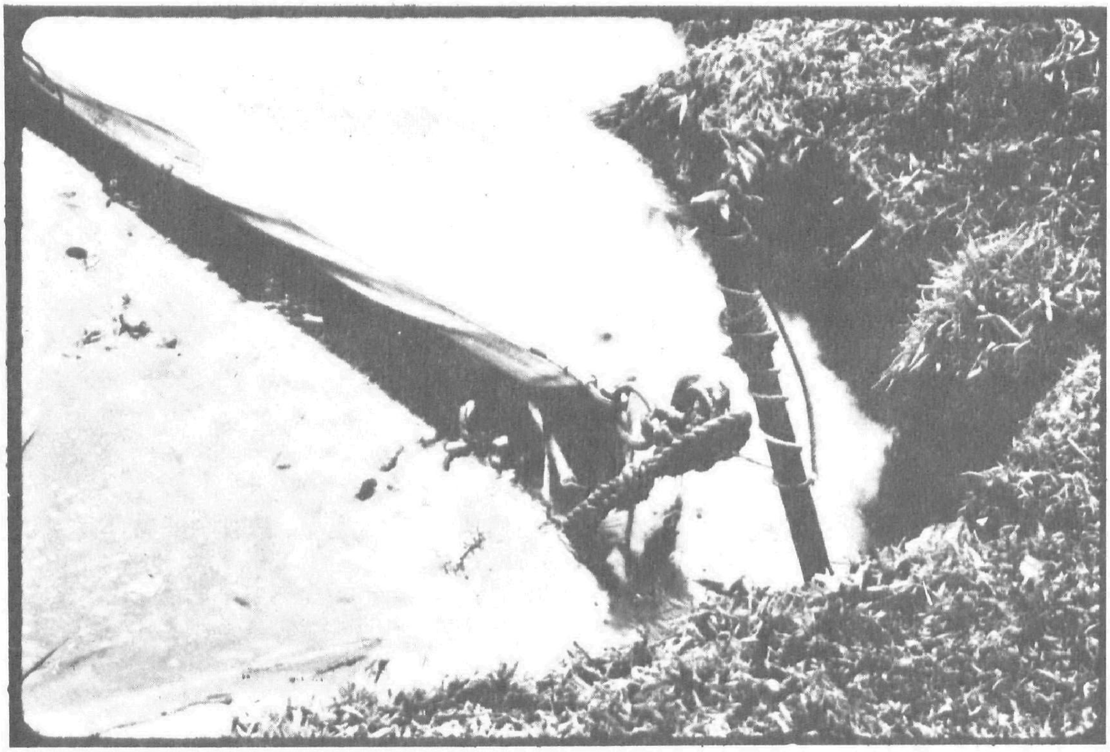

Figure B-5. Shoreline termination of boom.

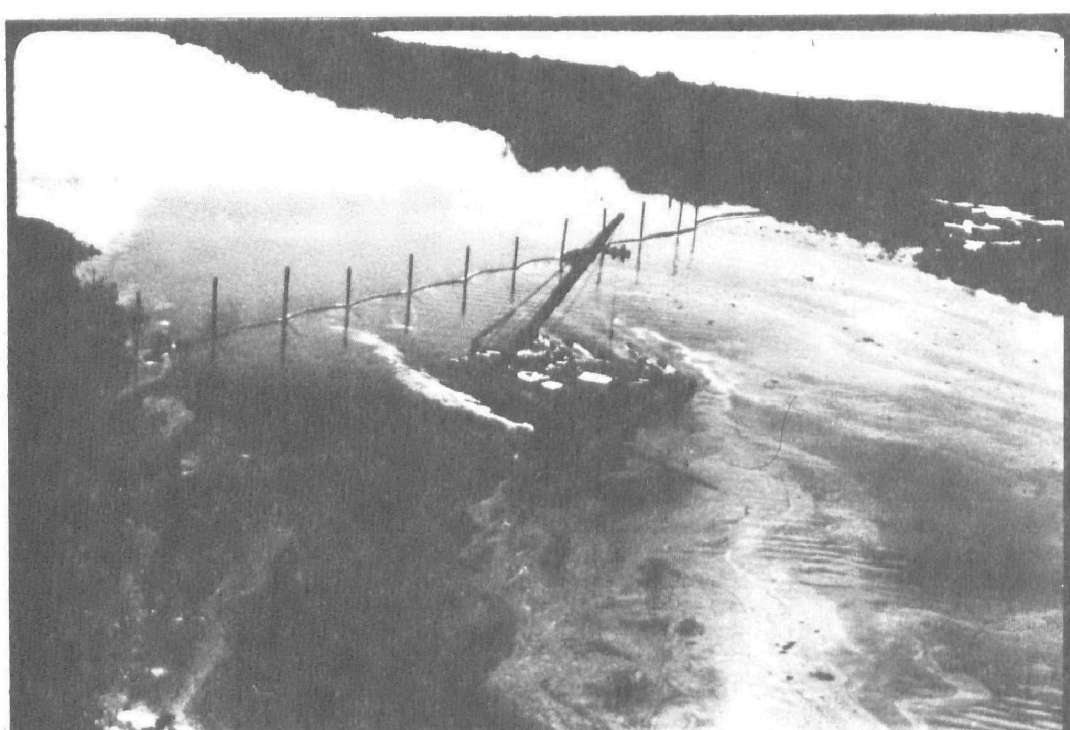

Figure B-6. Anchoring of boom with piles.

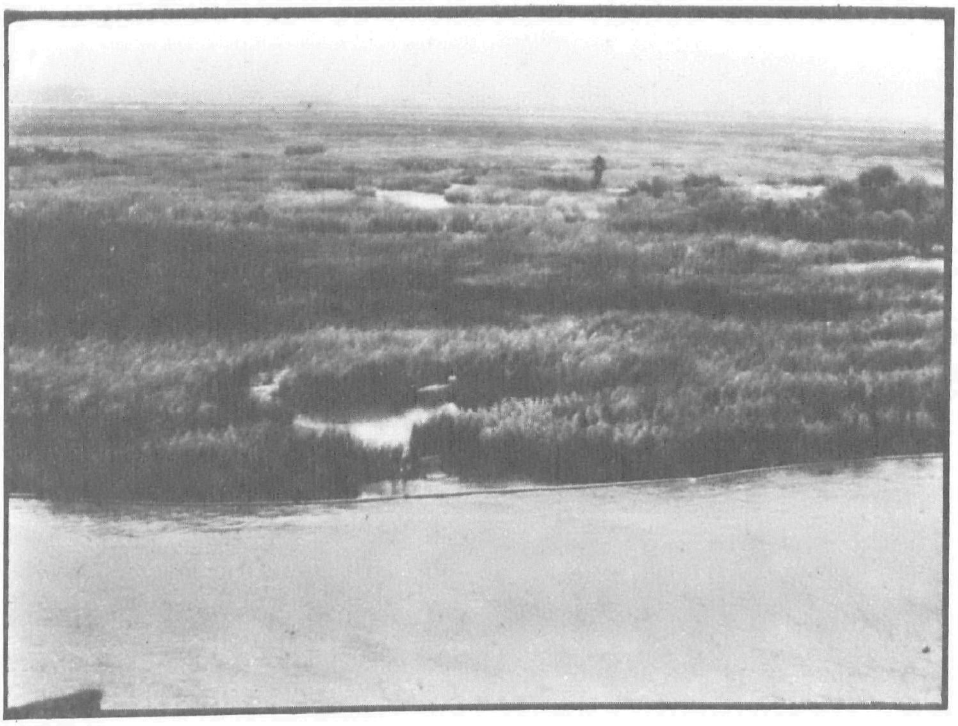

Figure B-7. Small channel booming.

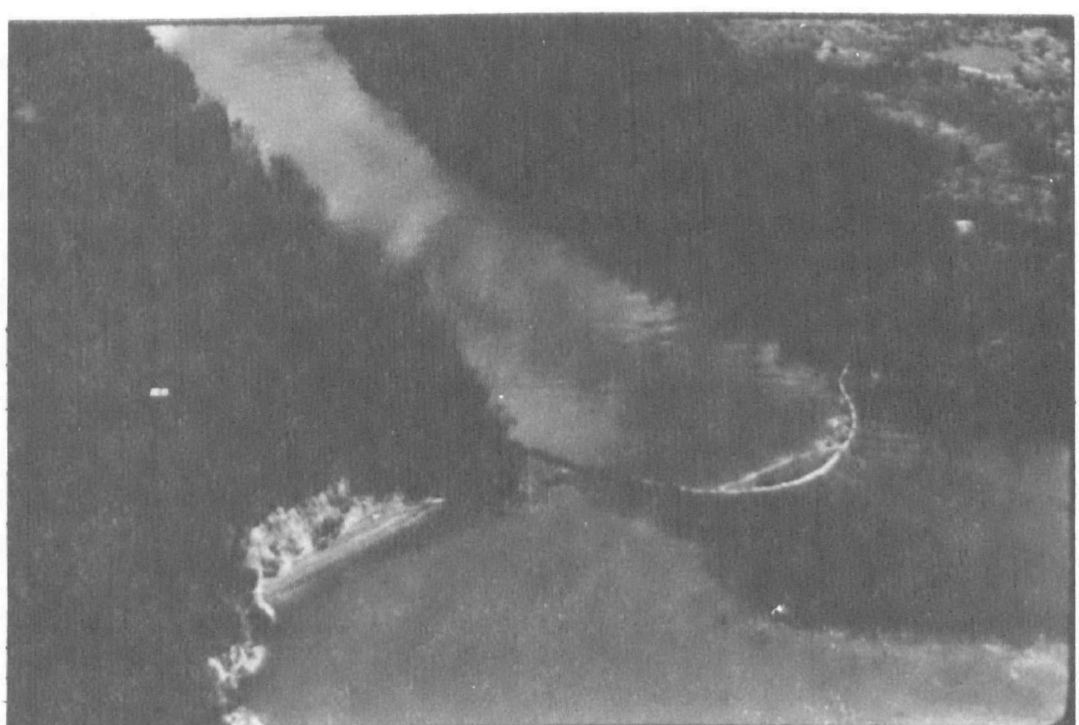

Figure B-8. Small channel booming.

Figure B-9. Double booming.

Figure B-10. Skirt boom positioned for open shoreline protection.

situation. Grounding of the boom at low tide is particularly a problem in coastal areas. When stranded, skirt booms serve little useful function, as shown in Figure B-11. If it is not possible to anchor booms so that they will not be stranded, continual repositioning may be necessary.

High-Flow Channel Deployment -- The successful use of skirt booms is inversely related to the strength of currents in the channel. If currents are not excessive, skirt booms may be deployed in the same configurations as discussed for fence booms.

Harbors and Marinas -- Many coastal marshalands often border commercial and recreational boat harbors. If a harbor area is threatened, it may be desirable to protect it with skirt booms. Generally, currents and wind exposure in harbor areas are low enough to permit simple closure of the entrance as shown in Figure B-12.

Sorbent Booms

The use of sorbent booms as protective devices is generally limited by their low retention capacity and poor performance in even low currents. Perhaps their best applications are in the containment of existing shoreline contamination where they serve to recover oil coming out of the marsh, and in situations where the water is extremely shallow.

Due to their light weight and flexibility, sorbent booms are easily deployed, even by small work crews. Physical arrangement and anchoring are similar to that for skirt booms. Sorbent booms should not be used for diverting flow or blocking channels.

Improvised Booms

The type of improvised boom used will determine the equipment and manpower for its deployment. Likewise, the deployment location will determine the configuration requirements of the boom. For typical configurations, see the fence and skirt boom sections. Table B-1 lists some types of improvised booms.

Rigid Wall, Permeable, and Earth Barriers

Rigid Wall Barriers --

Most of these devices can be constructed from new or used building materials available in virtually all localities. The equipment needed to construct these barriers consists of simple hand tools. Construction of rigid barriers is relatively labor-intense.

Rigid wall barriers should not be constructed across deep channels or long expanses because they require strong vertical supports.

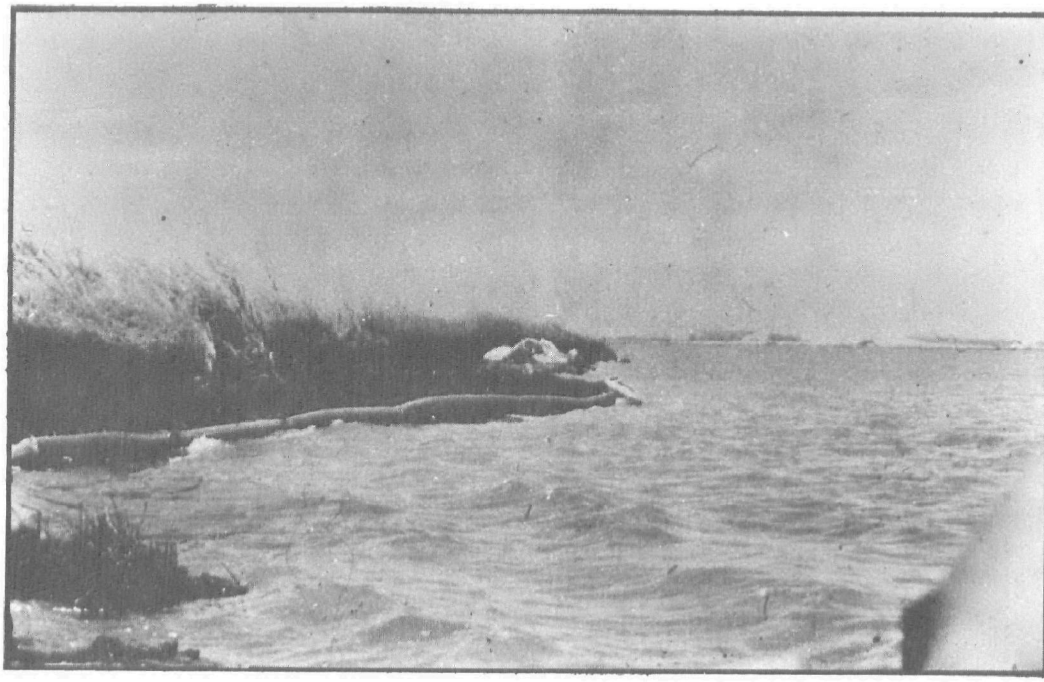

Figure B-11. Skirt boom stranded by falling tide.

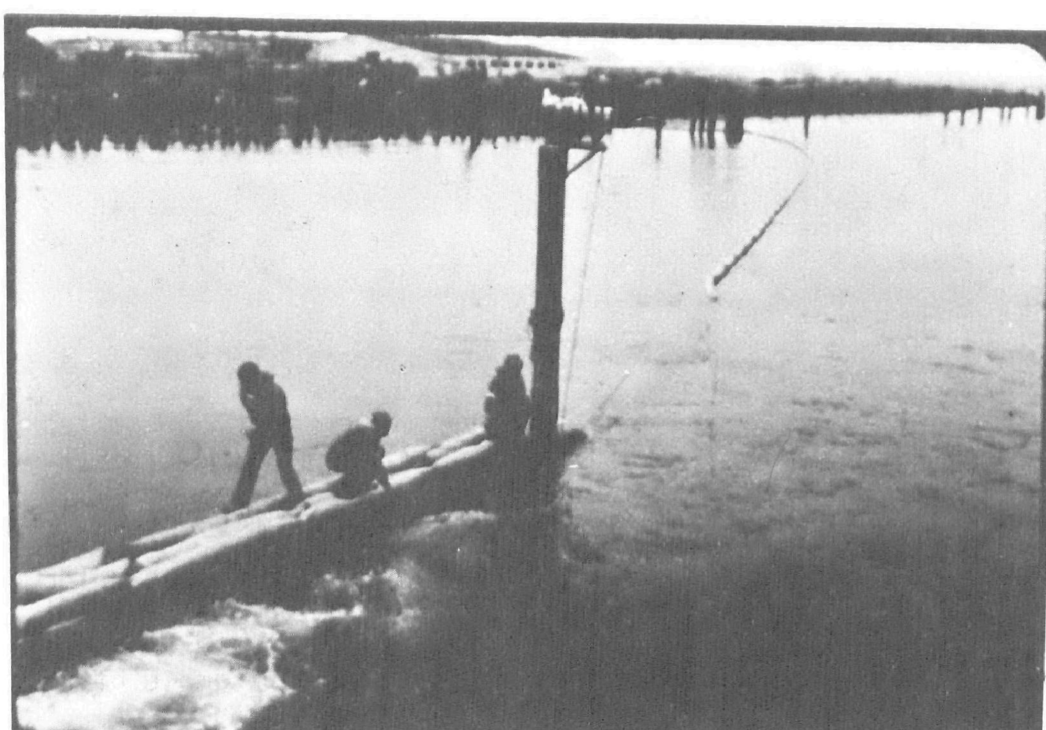

Figure B-12. Harbor protection using skirt booms.

TABLE B-1. TYPES OF IMPROVISED BOOMS

Type of Boom	Construction Material
Wooden Boom	Timber, railroad ties, railroad poles, etc.
Plastic or Metal Pipe Boom	Watertight plastic water pipe, aluminum pipe, thin gauge steel pipe, etc.
Fire Hose Boom	Blown up and capped fire hose
Rubber Tire Boom	Connected rubber tires
Float Booms	Cork, synthetic foats, rubber bladders, etc.
Puerto Rican or U.S. Navy Boom	55-gallon barrels strapped to marine plywood

The best time to start construction is during low tide. In most cases, the support posts are driven into the ground (using sledge hammers) or held in place by heavy shoes, such as concrete or sand bags. Panels are then connected between these posts. All cracks should be sealed with plastic, or other materials to prevent unnecessary leaks. Typical rigid wall barriers are shown in Figures B-13 and B-14.

It is neither time- nor cost-effective to build barriers strong enough to withstand waves and currents. Instead, their use should be limited to low-flow situations, such as drainage pipes and narrow channels.

Rigid wall barriers must be removed after the cleanup operations have been terminated or the danger of oil pollution has alleviated.

Permeable Barriers --
The construction of permeable barriers can be done with materials found on site and with common hand tools.

The one-sided type of permeable barrier is used along or in channels that have continual water flow in one direction. A single line of posts is driven into the bottom. Screen is then secured to the upstream side of the post by nails or staples. An elaborate example of this type of barrier is shown in Figure B-15. Notice that sorbent is placed only

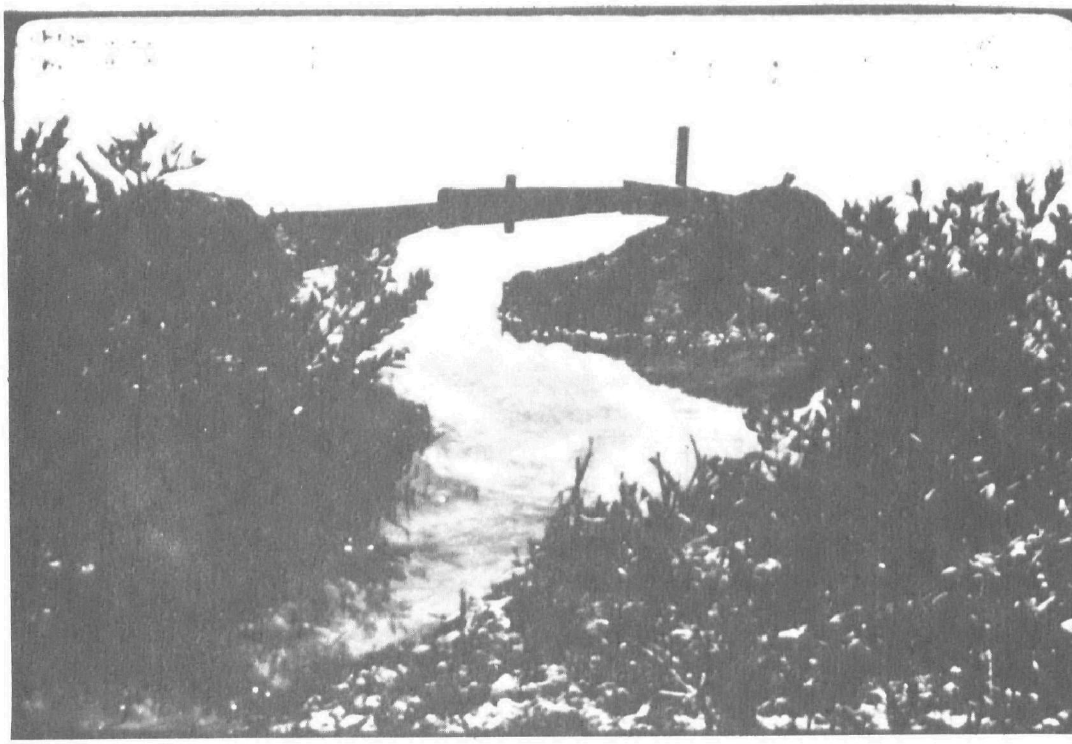

Figure B-13. Typical rigid barrier.

Figure B-14. Rigid barrier using logs and sandbags.

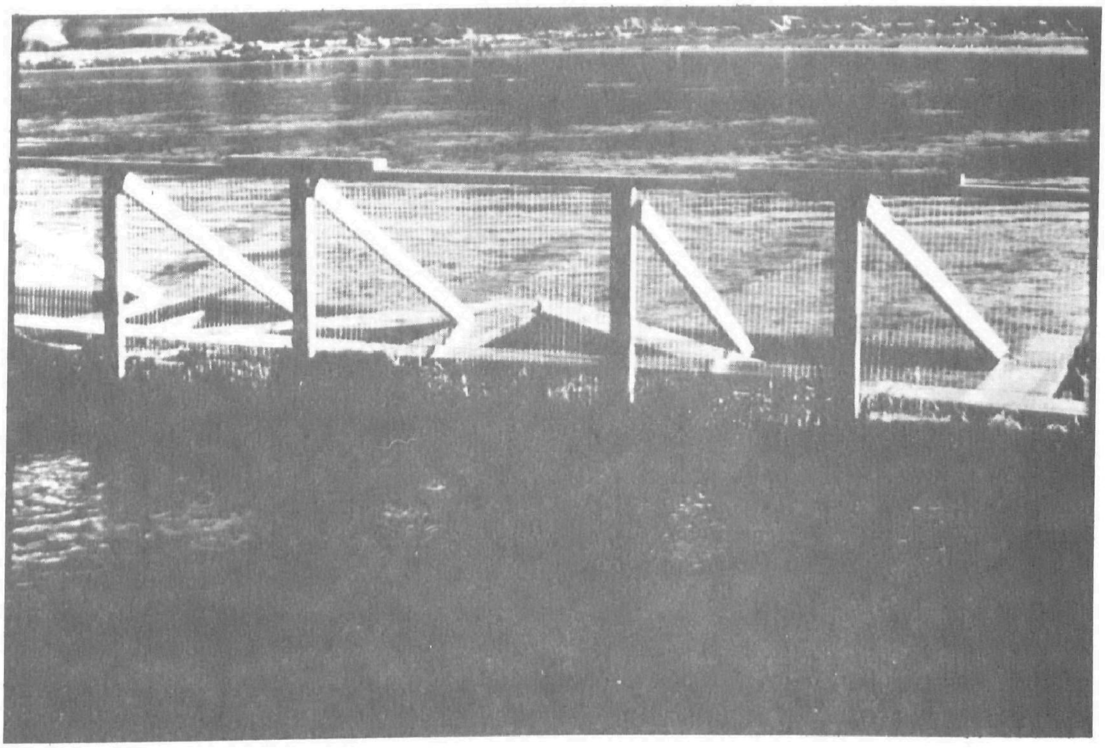

Figure B-15. Permeable barrier -- single direction of flow.

Figure B-16. Permeable barrier -- for flow-reversing situations.

on the upstream side of the barrier, thus preventing it from being washed away.

The second type of barrier must be used when tidal action is sufficient to change the direction of the current. This type consists of two parallel wire fences with the sorbent material placed between. This is illustrated in Figure B-16. These barriers are normally used across low-flow channels and in some coastal areas.

The screen height must be sufficient to prevent the sorbent from going over the top at high tide and under the bottom at low tide. The permeable barrier's main advantage is that it does not obstruct the flow of water out of or into an area. Of course, permeable barriers should not be deployed across channels having significant boat traffic. Where possible, the barriers should be placed to take advantage of shoreline configuration such as the small islands shown in Figure B-17.

Earth Berms --

The deployment instructions for earth berms are dependent upon the size and depth of the site to be blocked. The simplest and probably the majority of cases will involve the construction of a shallow barrier across a small inlet. A work crew of three to five men should be able to quickly construct such a barrier using simple hand tools such as shovels and hoes. This type of berm can also be constructed across shallow coastal areas, or shallow tidal lakes. A typical berm is shown in Figure B-18.

If larger berms are required, heavy equipment and trained operators will be necessary. Marsh accessibility and soil-bearing strength must be good if conventional equipment is to be utilized. Floating or self-propelled dredges of a dragline or clam-shell type are well suited for marsh application. Typical of this type of equipment is the amphibious dredge shown in Figure B-19.

The thickness and height of these berms are relative to the tidal or wave action against them. If the tidal and wave action is significant, the berm should be thick and high, allowing for wave erosion.

Time needed for berm construction and the availability of local resources (equipment and labor) are other factors requiring consideration.

After the cleanup operation has been terminated, the earth berms must be removed.

Pneumatic Barriers

Generally, the pneumatic barriers are effective when surface currents do not exceed 1 to 2 knots, or winds 20 knots. A typical deployment profile is shown in Figure B-20.

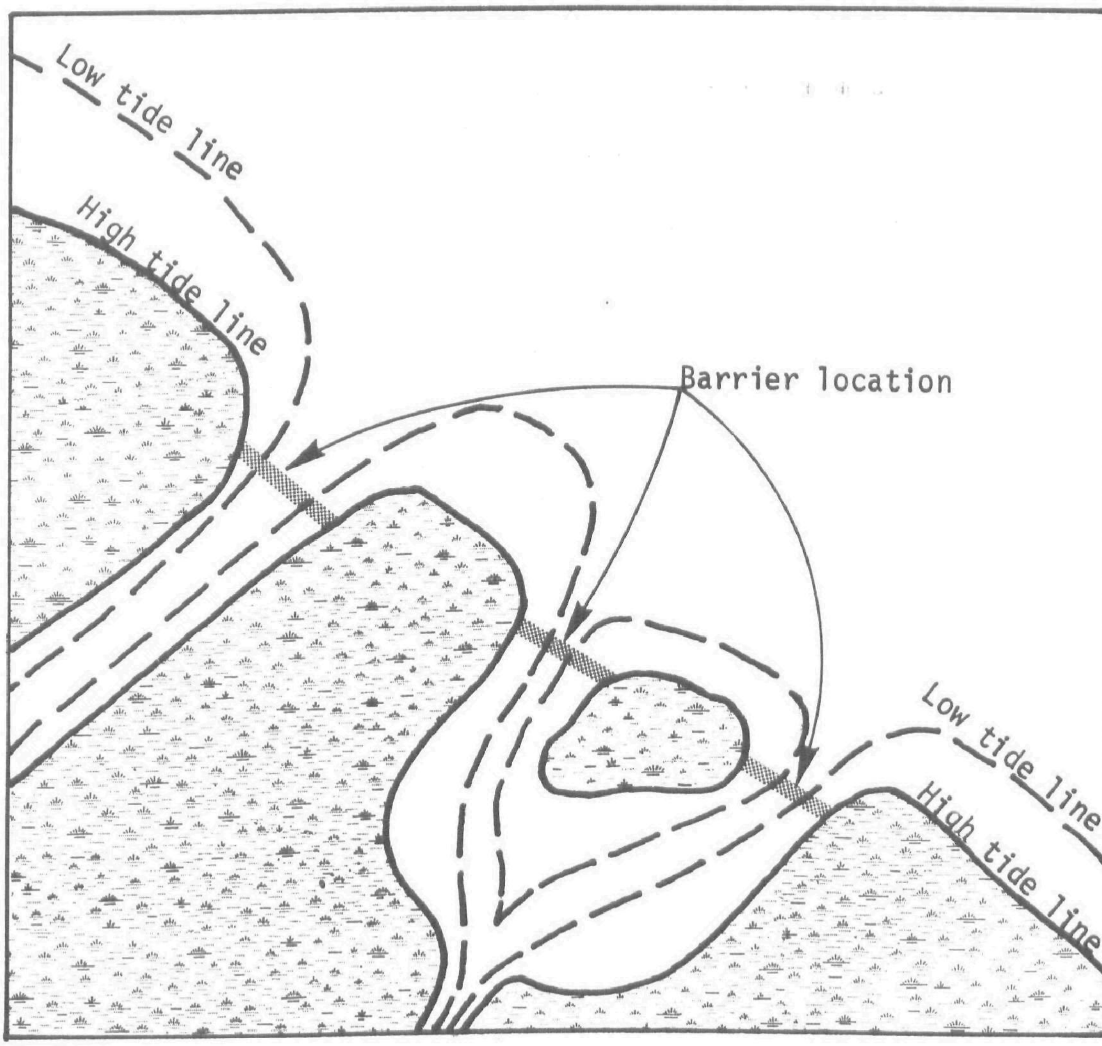

Figure B-17. Utilization of shoreline geometry in placement of permeable barriers.

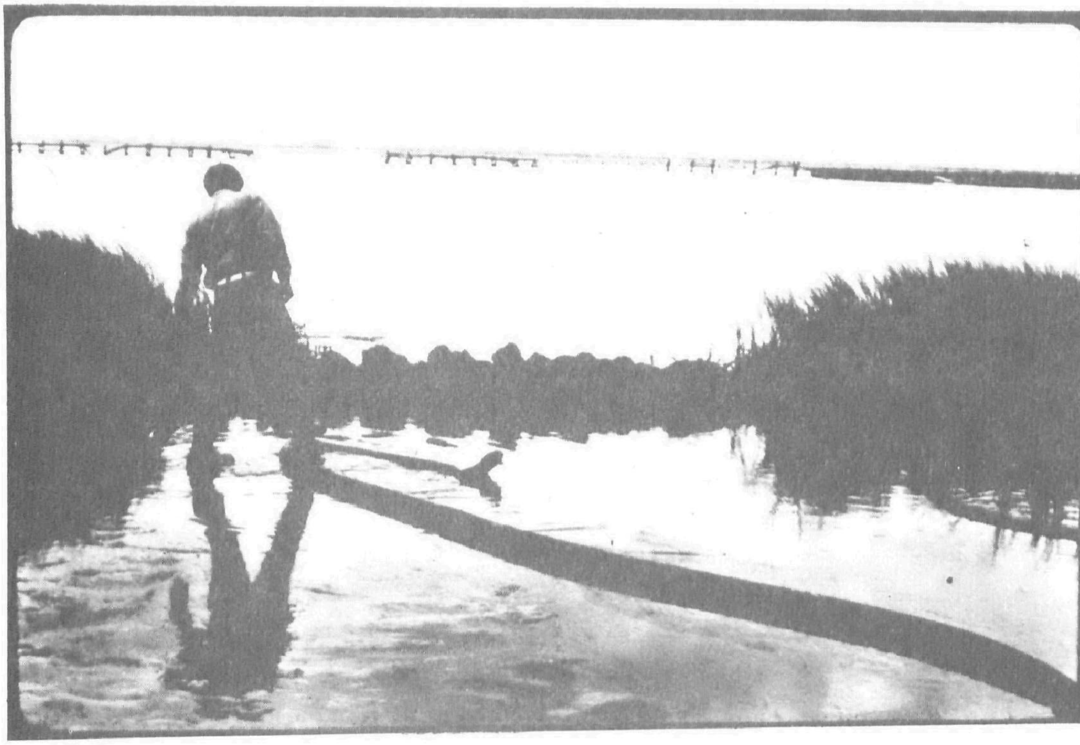

Figure B-18. Blockage of small channel with earth barrier.

Figure B-19. Construction of large earth barrier with amphibious dredge.

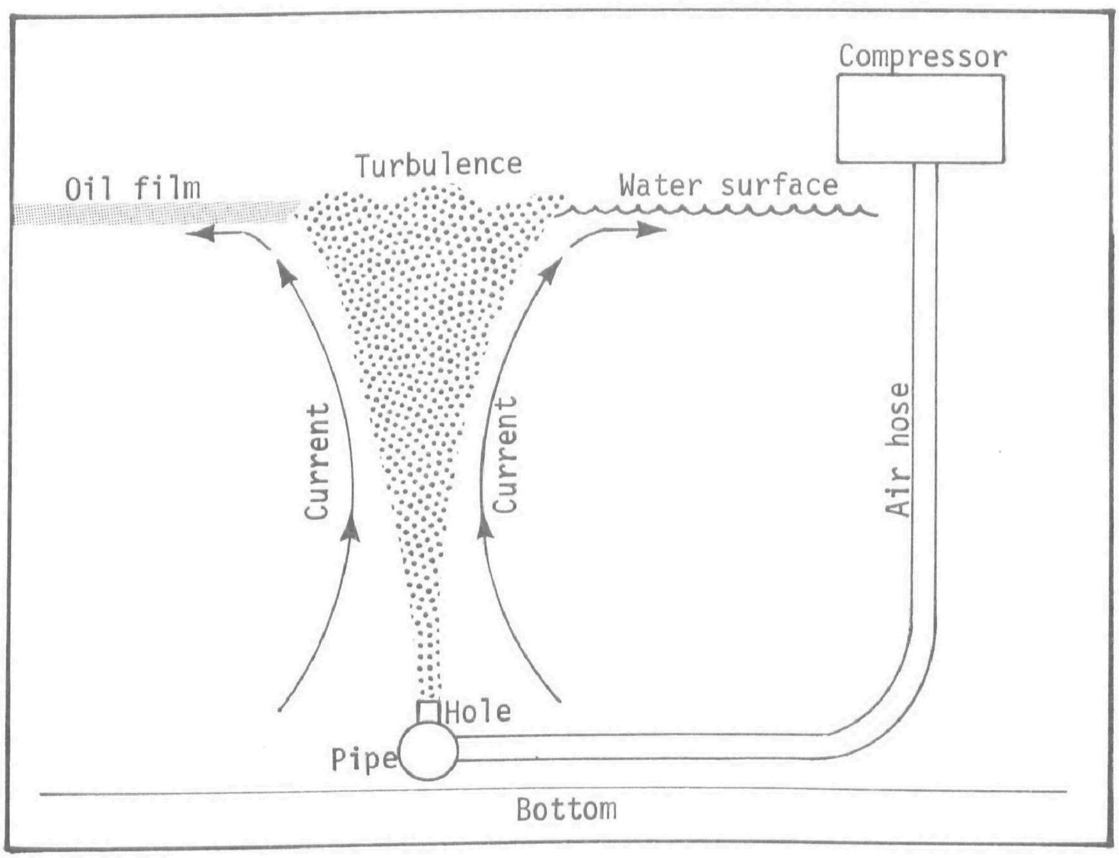

Figure B-20. Pneumatic barrier.

Effective operation of the pneumatic barrier requires water depths of at least several meters. This fact alone limits application to deep low-flow channels and harbor areas. In the latter case, pneumatic barriers are particularly applicable as they do not disrupt vessel traffic.

The physical requirements for constructing a pneumatic barrier are given by the formula:

$$C = 13{,}825\ hdl,$$

where
- C = compressor capacity in m^3/min (cubic meters/minute)
- h = hold size in m (meter)
- d = pipe i.d. in m
- l = pipe length in m

Materials which can be used to construct pneumatic barriers (if commercial ones are unavailable) include pastic, steel, or aluminum pipe. Most of these materials can be found locally.

Pneumatic systems normally require at least one day to construct and deploy properly. The installation of one of these systems will probably require a crew of five or more people, and of at least one workboat. Once deployed, continual monitoring of the compressor and pipe will be required. Weights may be required to prevent the pipe from floating.

If the pneumatic pipe is directly on the bottom, the small outlet holes may get plugged by debris during start-up or shut-down. To avoid this situation the pipe should be mounted somewhat above the bottom. When a pneumatic barrier is deployed to impound oil, cleanup equipment must be provided to remove the oil that accumulates behind the barrier.

Sorbents

Sorbents are produced in a variety of sizes and shapes, including granular, pads or pillows, or rolled strips. (Only granular and roll sorbents are recommended for protective use.)

Granular Sorbents --

Granular sorbents are composed of small pieces of plant, mineral, animal, or synthetic materials. Table B-2 lists many types of sorbents and their general properties.

Granular sorbents can be deployed from shore, by boat, or in some cases by air, either by hand or mechanically assisted with mulchers or blowers. To act as a protective mechanism, granular sorbents can be applied in one of two ways.

TABLE B-2. TYPES OF FLOATING SORBENT MATERIALS

Materials	Near-Site Availability	Water to Oil Ratio	Buoyancy After 6 Hours	Application (Hand, Equip., or both)	Weight	Possible Toxicity*	Oil Type†	Material Only Cost
Plant Material								
Straw/Hay	Generally	3-5	Sinks	Both	Moderate	None	H	Low
Seagrass	Generally	1	Sinks	Both	Moderate	None	H	Low
Sawdust	Generally	5	Sinks	Both	Light	None	H	Low
Bark	Limited	3	Floats	Hand	Light	None	H	Low
Peat	Limited	1	Sinks	Both	Moderate	None	H	Low
Cotton Waste	Limited	3	Sinks	Both	Moderate	None	H	Low
Cork	Seldom	5	Floats	Both	Light	None	H	Moderate
Corn Cobs	Limited	5	Sinks	Both	Light	None	H	Low
Waste Paper	Generally	2	Sinks	Hand	Light	None	H	Low
Reeds	Generally	1	Floats	Both	Moderate	None	H	Low
Mineral Material								
Asbestos	Seldom	4	Sinks	Hand	Moderate	Yes	H	Moderate
Talc	Seldom	2	Sinks	Hand	Very	None	H	Moderate
Fuller's Earth	Generally	2	Sinks	Hand	Very	None	H	Low
Volcanic Ash (Pumice)	Seldom	3	Floats	Hand	Moderate	None	H	Moderate
Perlite	Generally	3	Floats	Hand	Moderate	None	H	Moderate
Vermiculite	Generally	2	Sinks	Hand	Very	None	H	Low
Activated Carbon	Seldom	2	Sinks	Hand	Moderate	None	H	Moderate
Animal Material								
Wool	Seldom	4	Sinks	Both	Light	None	H	Moderate
Chrome Leather	Seldom	10	Sinks	Both	Moderate	None	H	Moderate
Polymers or Synthetics								
Rubber	Seldom	4	Sinks	Both	Moderate	None	H	Moderate
Polyether (Foam)	Limited	6	Floats	Both	Light	None	H	Moderate
Polystyrene (Foam)	Limited	5	Floats	Both	Light	None	H	Moderate
Polyurethane (Foam)	Generally	15-18	Floats	Both	Light	None	H	Moderate
Polyester Plastics	Seldom	3-16	Floats	Both	Moderate	None	H	Moderate
Nylon Fibers	Limited	6-15	Floats	Both	Light	None	H	Moderate
Cellulose	Limited	3-15	Floats	Both	Light	None	H	Moderate
Imbiber	Limited	27	Floats	Both	Moderate	None	H	Moderate
Polypropylene	Generally	10-20	Floats	Hand	Light	None	H	Moderate
Polymeric Fiber	Generally	10-24	Floats	Hand	Light	None	H	Moderate
Polyethylene	Limited	10	Floats	Both	Light	None	H	Moderate

*Many synthetics give off toxic fumes when burned.
†H, heavy oils and most crudes.

First, the sorbent can be applied ahead of an advancing slick, using wind and currents to drive it ashore. The resulting configuration will be similar to that shown in Figure B-21, conforming well to the shoreline and responding to tidal variations reasonably well. Barriers of this type may not perform satisfactorily with light fuel oils.

While virtually any size shoreline can be treated by this method in theory, actual application should be limited to areas where effective control of the materials can be maintained and effective recovery conducted.

Where coves are used for containment, granular sorbents can be effectively used for shoreline protection. In such cases, diverting booms present as part of the containment system insure the control of the sorbent.

Second, granular sorbents may be applied directly to an advancing slick. Used in this manner, they serve a protective function by immobilizing the oil rather than keeping it off the marsh. Although applications of this nature can be made under any circumstances, it is recommended that application be limited to slicks immediately threatening unprotected shorelines. The recovery of all sorbent materials will probably be impossible; therefore, if possible, granular sorbents should be restricted to biodegradable materials.

Any benefits gained by use of granular sorbents for protection must be balanced against costs and potential environmental damage associated with their recovery and disposal.

Once applied, the sorbent should be left in place to minimize environmental damage until the threat of contamination is over or impending weather shifts indicate the possibility of wide dispersion.

Respiratory protective devices should be worn by all personnel involved in deployment of granular sorbents to avoid ingestion of sorbent dust. Eye protection is also recommended.

Roll Sorbents --

These sorbents are almost exclusively manufactured from synthetic or treated materials. They also come in a variety of lengths, thicknesses, and shapes.

Roll-type sorbents are best suited for specialized protective applications. Generally, quiescent conditions are required for their successful use. Deployed in sheltered shallow water (Figure B-22), the form an effective, easily deployed, and low-maintenance barrier for restricting movement of oil through a marsh interior. When the absorbing power of such a barrier is exhausted, a new layer of sorbent will restore its function. Sequential removal of exhausted sorbent is not recommended

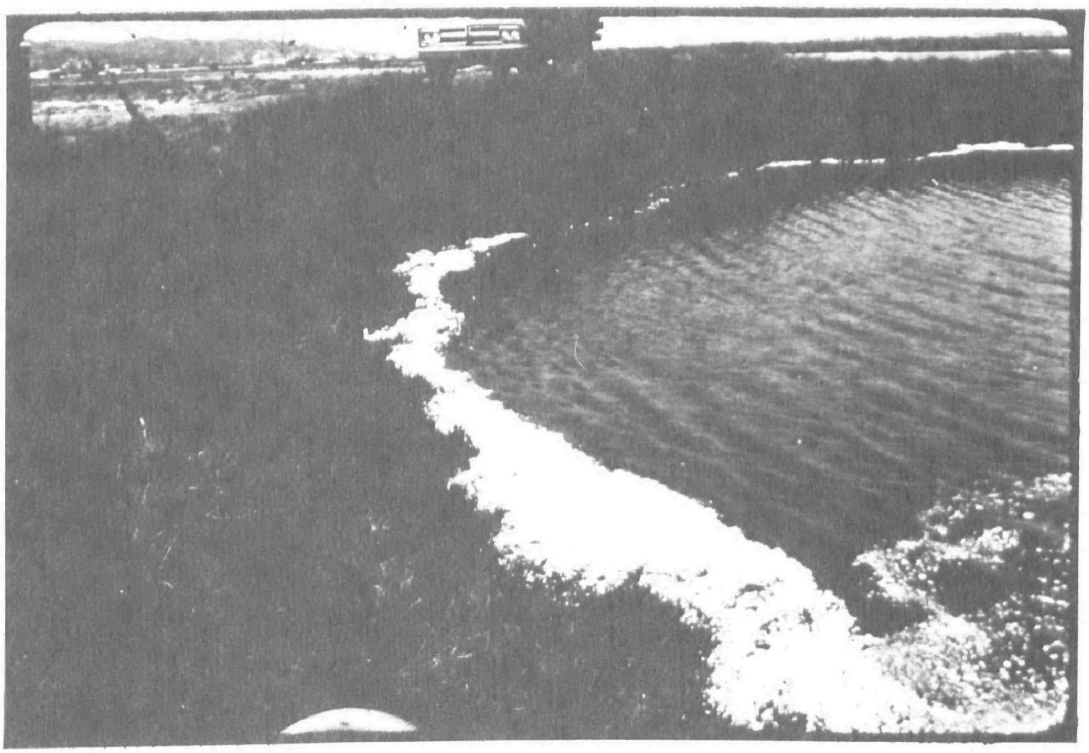

Figure B-21. Use of granular sorbent as a protective barrier.

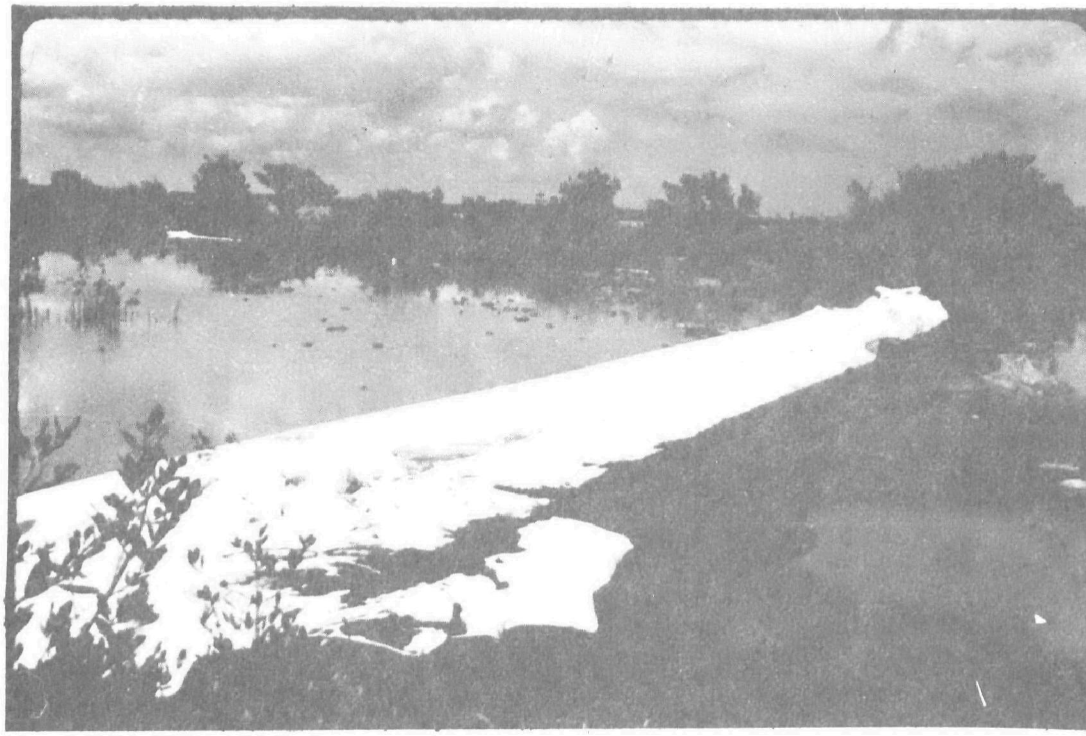

Figure B-22. Use of roll sorbent as a marsh interior barrier.

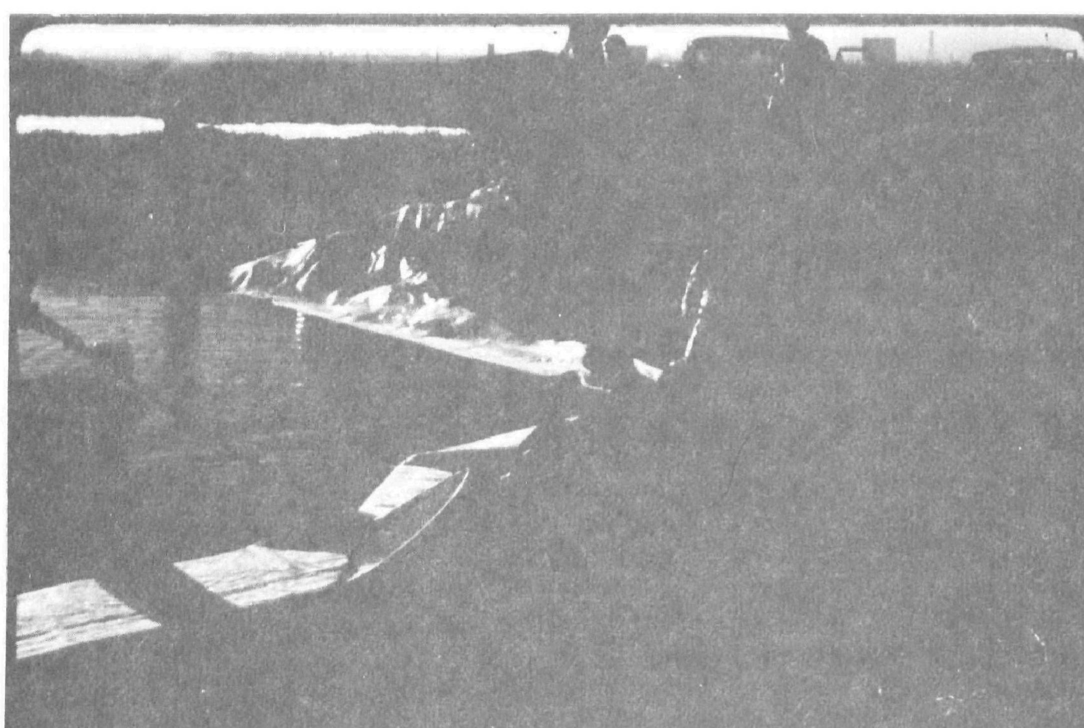

Figure B-23. Use of roll sorbent for shoreline protection in a containment area.

unless soil contamination is taking place. Less damage to the marsh will generally result from a single period of sorbent recovery.

Figure B-23 demonstrates the use of a roll sorbent to protect the edges of a small cove being used for oil containment and recovery. In this case, minor position adjustments as necessitated by tidal variation are conveniently made by the cleanup crew. Unattended shoreline application of this type sorbent is not recommended.

Wildlife Deterrents

Wildlife deterrents are normally classified as either a loud-noise type or the animal distress and predator call type. The loud-noise type chase animals away from one area to another by creating a sharp noise similar to a gun blast, and the animal distress and predator call type operates on the principle that wildlife will flee when they hear a danger signal such as an animal in trouble or a prey animal in the area. Although these devices are used mostly for birds, they can be used to scare mammals.

The loud-noise type can be manually operated, although newer models are designed to use signals or timers. A propane fueled device is commonly used. Animal distress and predator call types, however, are operated using tape recordings.

Both types of devices must be positioned sufficiently close together to allow overlap of the effective noise envelopes. During rain or windy conditions, these devices must be spaced closer together. Since birds and animals become conditioned to these devices, their use may have to be rotated. Still, such systems can become ineffective for many species of animals in the area.

Commercial devices can frequently be found at major airports (where bird ingestion into jet engines presents a problem) or ordered from commercial outlets. Local fish and wildlife services may prove to be excellent sources for locating these devices on short notice.

Almost all of these devices can be operated from land or boat, depending on the terrain of the contaminated area. Many marsh locations either have thick undergrowth or are inundated with water, making land deployment of the device impractical. Whenever practical, however, land deployment of the device is preferred.

APPENDIX C. CLEANUP EQUIPMENT AND PROCEDURES

This Appendix provides procedural information (or implementation instructions) for the cleanup techniques and equipment identified in Section 600. As the number of marsh configurations and cleanup requirements is potentially limitless in any given incident, the section is, of necessity, general. For simplification, however, techniques and equipment may be divided into three general categories, and several subcategories:

Removal and Collection of Oil

1. Low-pressure water flushing
2. Sorbents (formed products)
3. Sorbents (loose)
4. Rope skimmers
5. Disc and other absorbent skimmers
6. Weir skimmers
7. Vacuum systems

Handling of Contaminated Materials

1. Cutting
2. Burning
3. Soil Removal

Bird Cleaning

The successful application of any technique depends on adhering to certain common rules which include the following:

1. The marsh is a fragile environment. All physical actions should be restricted to only those absolutely necessary. This requires careful supervision of field crews.

2. Physical conditions in a marsh change rapidly and often unpredictable. Thus, close monitoring of cleanup techniques and readjustment of equipment deployment is required.

3. Many cleanup techniques, such as booming, require removal of accumulated contamination at regular intervals. Thus, regular attention of equipment is essential.

Removal and Collection of Oil

Low-Pressure Water Flushing --

Low-pressure water flushing provides one of the easiest and most effective methods of removing the bulk of most oils on substrate and plant surfaces without extensive damage to plants or erosion of the substrate. Once the oil is driven into open water, a water spray unit can also be used to direct the oil to a recovery point.

The equipment required for most flushing operations are booms, portable pumps, inlet and outlet hoses, and an oil-recovery system. A typical deployment of the low-pressure flushing system is shown in Figure C-1.

Figure C-1. Typical deployment of low pressure flushing system.

The boom used in the flushing operation should be compatible with the terrain and the deployment capabilities of the obscene personnel. In gradually sloping, shallow-water locations, a small light skirt boom (e.g., 8-inch float with 12-inch skirt) will meet the requirements. Cleanup crews must be supplied with equipment to deploy and redeploy the boom as wind and current situations change. The selection of the anchor to stabilize the boom should be compatible with the bottom sediments. In a marsh most equipment may be accessible from the water at high tide but not at low tide. As a result, movement of equipment may be limited to a few hours of daylight each day.

Small portable gasoline-powered centrifugal or diaphragm pumps have been found to be the most flexible method of flushing. (Larger pumps can also be used if marsh access is good and if the outlet pressure can be reduced). Self-priming type pumps are preferable because they are the easiest to operate. Although maintenance requirements are minimal, pumps should be equipped with extra gasoline and oil and an extra spark plug with a wrench. It is recommended that a number of spare pumps be stockpiled for immediate replacement of any "down" units.

Each pump must be equipped with an inlet hose (suction line) and outlet hose (spray line). Intake hoses must have a rigid wall to prevent collapse. Consequently, they should be as short as possible to facilitate handling and maneuvering. The water intake should also be equipped with a screen to preclude debris. Outlet hose length is dependent on the distance to a continuous water supply and the length and horizontal depth of the area to be flushed. The outlet hose should be flexible and easy to handle. Garden hoses, fire hoses, and small diameter are suitable. Several hoses can be operated from one pump, by equipping the pump discharge with a multi-outlet nipple ("T's," crosses, etc.).

The oil-recovery unit can vary from a skimmer equipped with a vacuum system to a sorbent system, depending on the oil concentration and type and the terrain of the site. Some recovery units are more effective on light density oils than heavy and vice versa. Regardless of the type used, operation of the recovery unit must be continuous while flushing the oil from the shoreline.

Organic debris and drift material will be washed out with the oil during the flushing operation. This debris will clog or foul most recovery systems. Therefore, the cleanup crew must be provided with equipment for removing and safely storing debris. Some devices that have proven effective in removing debris from water are dip nets, seines, leaf rakes, and pitch or clam forks.

Before commencing flushing operations, physical conditions along the shoreline must be assessed. If wind and currents are not in an appropriate direction to hold the oil along the shoreline once flushed from the substrate, containment booming will be necessary.

Flushing should proceed from the highest elevation of contamination and work downslope toward the shoreline. Also, flushing should proceed from the upstream area and work downstream to take advantage of natural currents. Although flushing may be conducted from land, boat operations are preferable since they result in less physical disruption of the marsh. The water spray should be concentrated on removing as much oil as possible from the leaves and stems of plants and from rocks. Generally, oil on the substrate surface will float off with the water flow. Direct application of the water stream to the substrate should be avoided since it will usually result in soil erosion and damage of buried organisms and plant roots. Lighter oils will be easier to flush. Even after flushing, a coating will normally remain but this coating, usually innocuous, will be scoured off in time by tidal and wave action or else will disappear during the seasonal marsh dieback.

In many marsh situations, access is provided by roads on dikes and berms. In these locations flushing from onshore may be desirable unless traffic extends into the marsh itself.

Once driven into the water, the oil can be herded toward a collecting point with water jets. Attempts should be made to utilize shoreline characteristics and work with currents and tides. Figure C-2 illustrates the general sequence of flushing using natural processes.

Provision for protection of cleaned areas is an important and often overlooked aspect of cleanup operations. Protection is critical where tidal reversals prevail since an area capable of withstanding one period of cleanup can be destroyed by repeated operations. Figure C-3 illustrates one procedure for prevention of recontamination of clean areas, using a skirt boom. As each area is flushed, the boom is repositioned to prevent recontamination due to currents or winds. In cases of extremely heavy or ongoing oil contamination, total booming of cleaned areas may be required.

A sump (natural or dug) can act as an oil/water separator to ensure an uncontaminated water supply. The inlet hose is placed at the bottom of the sump, allowing oil to accumulate above it. Collected oil must be removed regularly. This system can be used within depressions or other inland areas where water naturally collects.

Sorbents --

The use of sorbents must consider application recovery, and disposal. In general, the use of sorbents involves more manpower and disposal requirements than other procedures. Additionally, the physical acts of deployment and, in particular, recovery, can severely disrupt and damage the marsh surface. In general, then, <u>use of sorbents is not recommended if other options exist</u>.

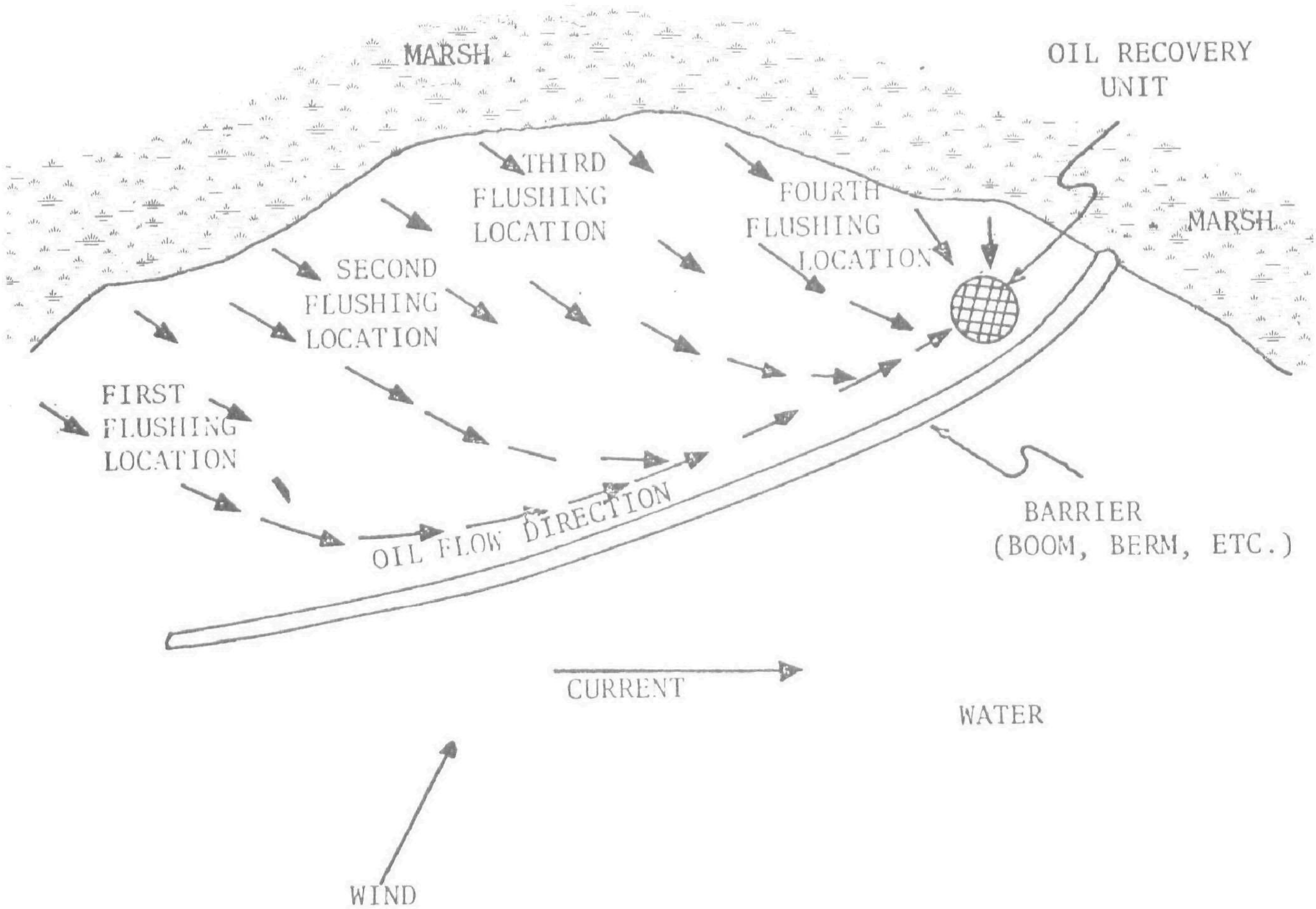

Figure C-2. General flushing tactics.

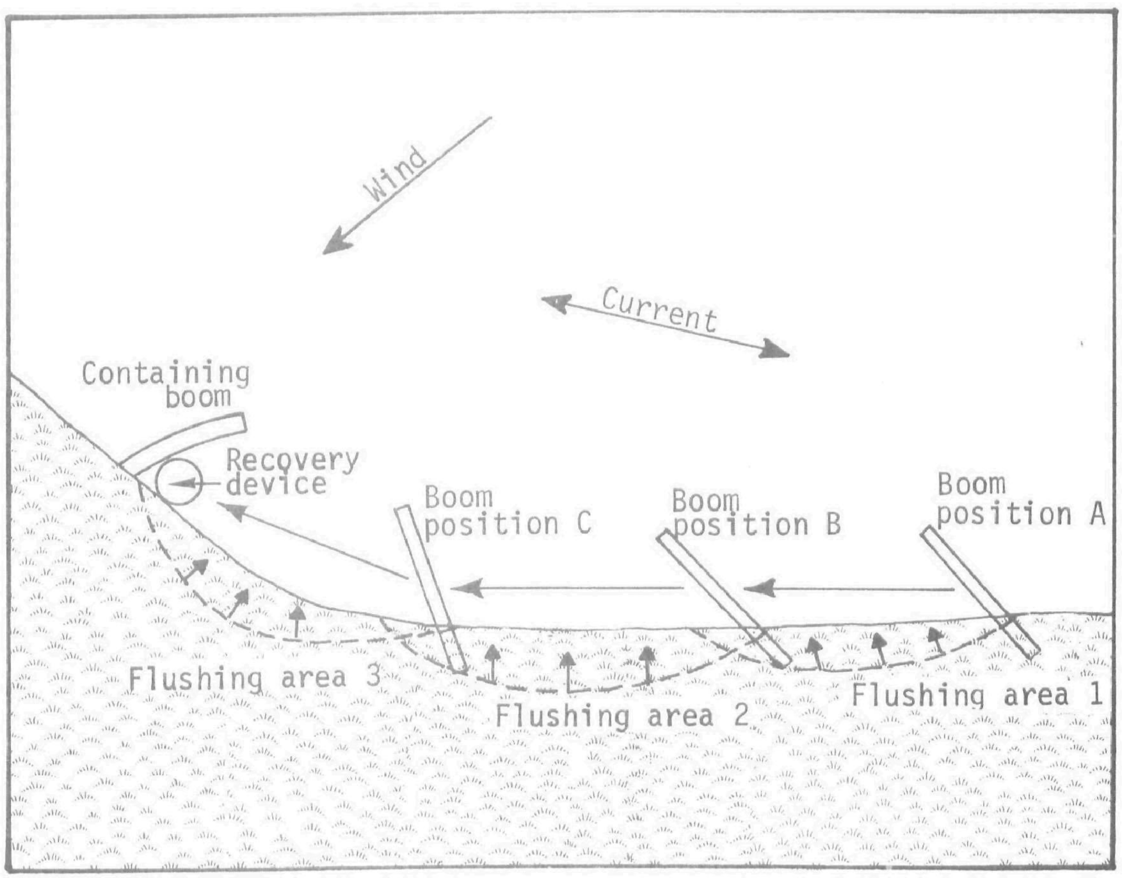

Figure C-3. Booming to prevent recontamination of cleaned areas.

If granular-type sorbents are used, preference should be given to biodegradable types, such as bark because one-hundred percent recovery of any granular sorbent is virtually impossible. Thus, biodegradable sorbents not oiled may be left in the marsh without environmental consequence, whereas persistent types should be removed, whether oiled or not. When using sorbents for cleanup, it is wise to restrict application to small areas and to mandate the use of containment booms. If tidal changes in the marshes are large and rapid, sorbent control and recovery may be impractical. In such cases, sorbent use should not be attempted.

Granular sorbents may be applied mechanically or by hand as shown in Figure C-4. After distribution of the sorbent, a contact period consistent with the nature of the material must be allowed. Too little contact time will not permit full effectiveness of the sorbent, while too much time may result in waterlogging and possible loss by sinking. The status of the sorbent can normally be evaluated visually (i.e,, degree oiled, and floating or not). In many cases it may be desirable to agitate the sorbent to improve its penetration around the plant stems and contact with the oil. Light spraying with water is usually effective for this purpose.

Sorbent removal from or transport through a marsh can generally be done by water flushing as shown in Figure C-5. Care must be taken to minimize the amount of foot traffic when operations in the marsh itself are required. In vegetated areas raking can physically damage plants. In areas devoid of vegetation, raking will work the oil and sorbent into the soil, spreading the contamination rather than reducing it.

Sorbent recovery may be accomplished by a variety of means, including flushing into seines (Figure C-6). In this case the sorbents are encircled and physically removed with the net. Tarps or plastic sheets should be available to control spreading of contamination where the net is emptied.

Granular sorbents may be herded into position for recovery by small portable vacuum boat-mounted units. (Figure C-7). Run from gasoline generators, these vacuum units may be used in conjunction with modified 50-gallon drums, greatly increasing holding capacity. Where road access is available, commercial vacuum trucks may be brought directly to the site. Advantages in the use of vacuum trucks are their large capacity and ability to recover small solids.

Shallow-draft, improvised floating conveyor systems or commercial aquatic weed cutters (Figure C-8) can be used for granular sorbent recovery operation along shorelines. Commercial units require only minor modification to control leakage of oil through the mesh belts and holding bins. They are particularly useful where driftwood and other floating debris are abundant. A mechanized recovery system of this type will require a shoreline crew to flush or physically herd oil and sorbents

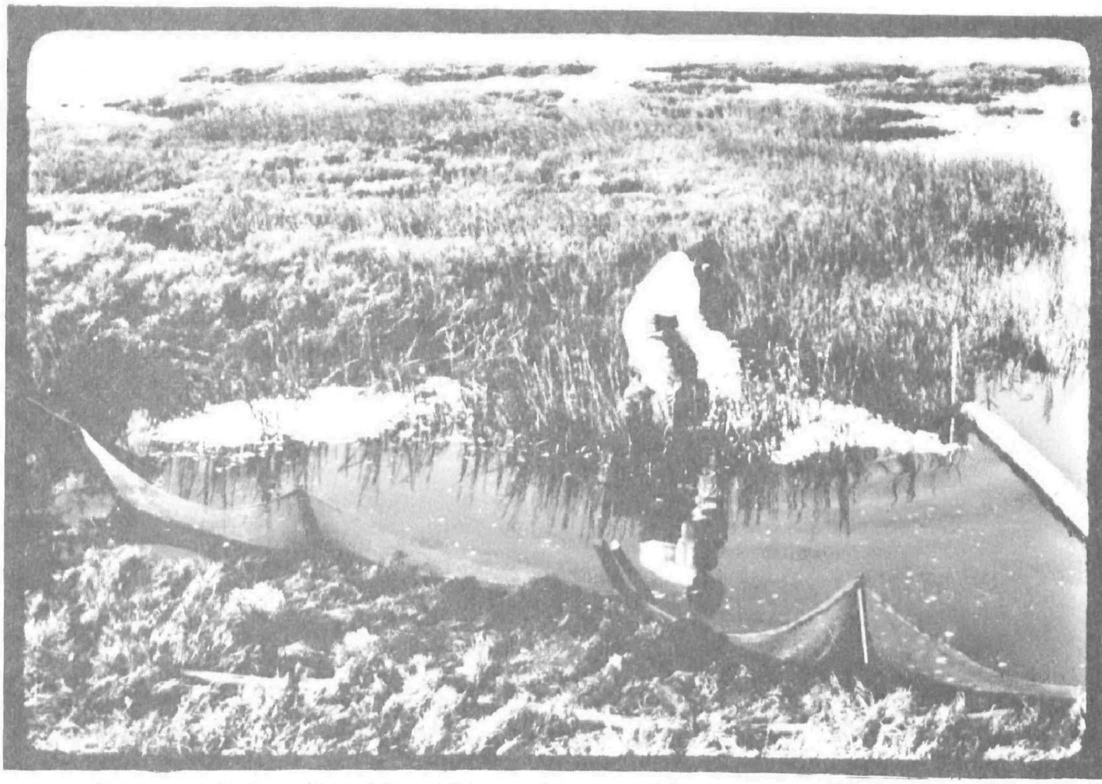

Figure C-4. Application of granular sorbents by hand.

Figure C-5. Removal of granular sorbents by flushing.

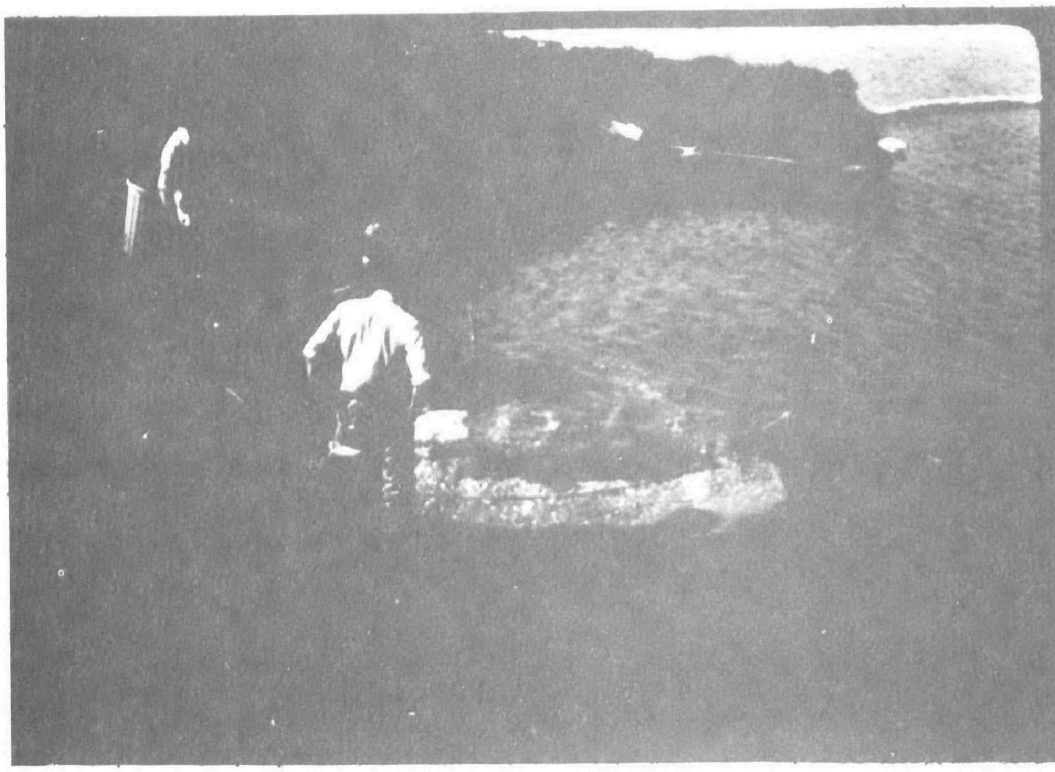

Figure C-6. Recovery of granular sorbents with seines.

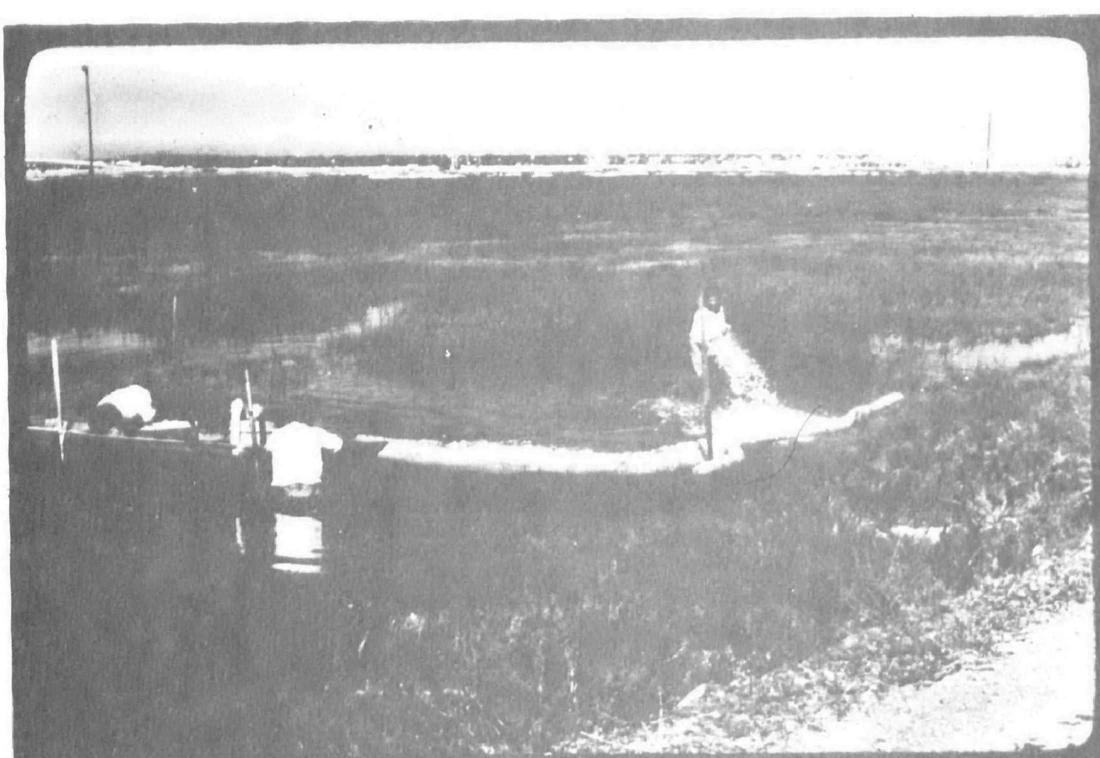

Figure C-7. Portable vacuum system for recovery of sorbents.

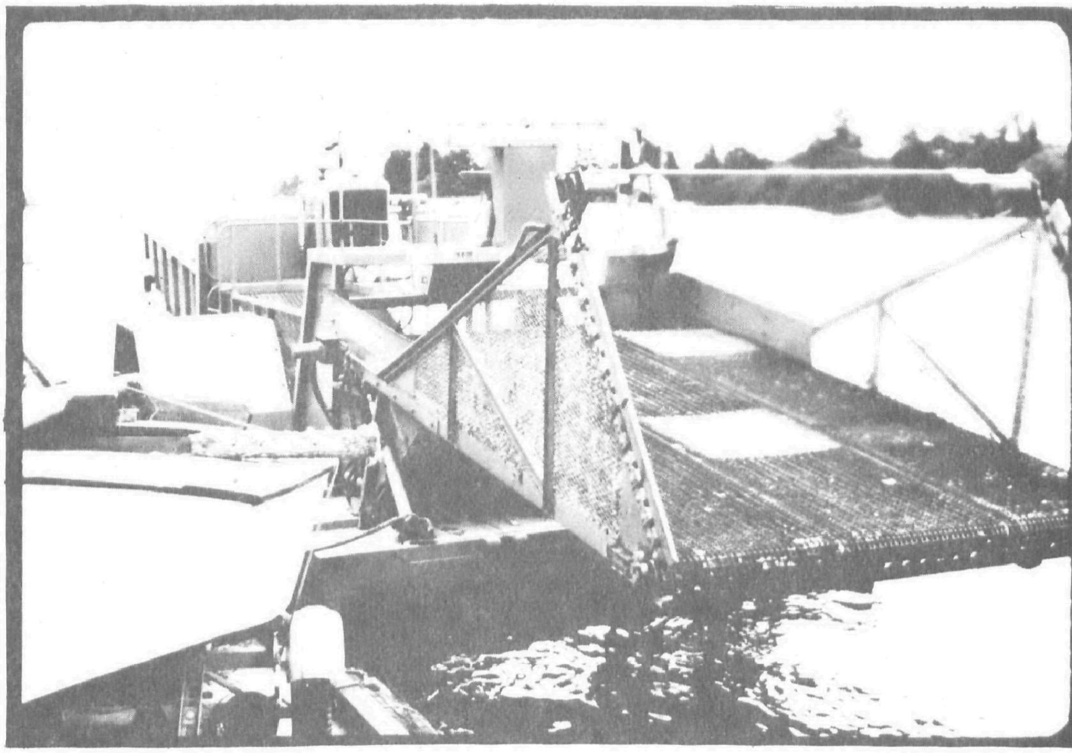

Figure C-8. Conveyor system for weed cutter.

Figure C-9. Typical deployment of endless rope skimmer in a containment area.

to the device, and a number of tarp-lined boats to receive the contaminated discharge.

Pad and roll sorbents have limited application for marsh cleanup. Generally, their use is restricted to zones devoid of vegetation, such as salt pans, or for the recovery of floating oil along shorelines lined with debris. As their application and recovery involve considerable surface activity, and they are difficult to handle when oiled, use should be limited to those situations where no better means of cleanup exists.

Roll sorbents can provide a secondary function in cleanup operations, not involving recovery of oil. Laid on the ground, they can increase bearing characteristics to the point that foot traffic is often possible in areas previously inaccessible. At the same time, the sorbent roll prevents oil from boats or whatever being forced into the substrate.

Sorbent "snares" consist of spaghetti-like masses of oleophilic material. Although expensive and labor-intensive to use, "snares" may find application in marshland situations as filler for permeable barriers, and leak-proofing of boom connections and shoreline terminations. Sorbent mops -- essentially "snare" material fixed to the end of a stick or pole -- are convenient for small-scale cleanup of small pockets of oil in difficult-to-reach areas. They may prove extremely convenient for final cleanup in mangrove areas.

Rotating Drum, Endless Belt, and Rope Skimmers --

This type of skimming device removes oil from the surface of the water by adherence of the oil to a rotating drum, conveyor belt, or rope covered with, or constructed from, an oleophilic material. The oil that adheres to the surfaces is subsequently squeezed into a holding tank or scraped off by a blade or squeegee. Skimmers of this type recover very little water and are less sensitive to debris-fouling than other types of recovery equipment.

Rotating Drum and Conveyor-Belt Skimmers -- The application of rotating drum and conveyor-belt skimmers in marshlands is generally limited. When mounted on a workboat or barge, they may be maneuvered for cleanup of floating slicks in larger channels and nearshore areas where depth permits. They may also be anchored in positions where the oil may be directed to them.

Endless Rope Skimmers -- Endless-rope skimmers are among the most effective saltmarsh oil-recovery devices. They exhibit infinite flexibility in deployment configuration, are not easily fouled by debris, are little affected by water depth, and are completely portable. They require an oleophilic rope, two or three anchored pulleys (water resistant and designed to float), a wringer, collection and containment, and a power drive.

The usual application of the endless-rope skimmer is in recovery of oil from a natural or artificial containment. A typical deployment in a containment area is indicated in Figure C-9. Note the use of plastic sheets to protect the marsh surface crossed by the rope before reaching the wringer. Water-jet herding, either from land or water, as shown in Figure C-10, is particularly effective when used with endless-rope skimmers due to their large effective recovery surface.

The size of these units ranges from configurations designed to fit on top of 50-gallon drums to larger, trailer-mounted units. While the smaller units are ideal for small boat or remote location use, even the larger versions are small enough to be carried into remote areas by helicopter. Most types are equipped with small holding tanks and, requiring frequent emptying.

While it is theoretically possible to use ropes of extremely long lengths and many pulleys, it is seldom practical to exceed 100 meters and more than two pulleys. The threat of snagging and the maintenance required is greatly increased for large, elaborate systems.

Anchoring of the pulleys is relatively simple. As the pulleys float, it is a simple matter of using ropes to attach them to fixed objects or posts set in the shoreline. In shallow water, pulleys may be fixed to piles set in the bottom. It is difficult to fix the pulleys with anchors as they pull at an angle and tend to foul. If it is necessary to use an anchor to fix a pulley offshore, placing a buoy between the anchor and the pulley will reduce the risk of fouling.

Endless-rope skimmers respond poorly to currents. Even relatively low currents tend to cause submergence of the rope and place tremendous forces on the anchors.

Other possible applications of this type of skimmer are numerous, responding to the configuration and requirements of the individual situation. In Figure C-11, a rope skimmer is shown in use along a marsh shoreline. Completely contained by booms, this configuration is ideally suited for shoreline flushing and recovery.

Weir Skimmers --

Shallow depths and high-debris concentrations, characteristics common to salt marshes, greatly influence the application and usefulness of weir skimmers. In order to maintain the proper relationship of the weir to the water surface, weir skimmers are designed to float (where water depths are insufficient, weir skimmers can only be operated by placing them in excavated sumps). Floating debris will interfere with operation by forming an impenetrable barrier along the weir as material is drawn toward the intake. Further, debris passing over the weir will usually clog the intake orifices. Attempts to prevent clogging by using wire-mesh barriers to exclude debris are only marginally successful as they merely move the site of clogging; oil flow to the skimmer is still impeded.

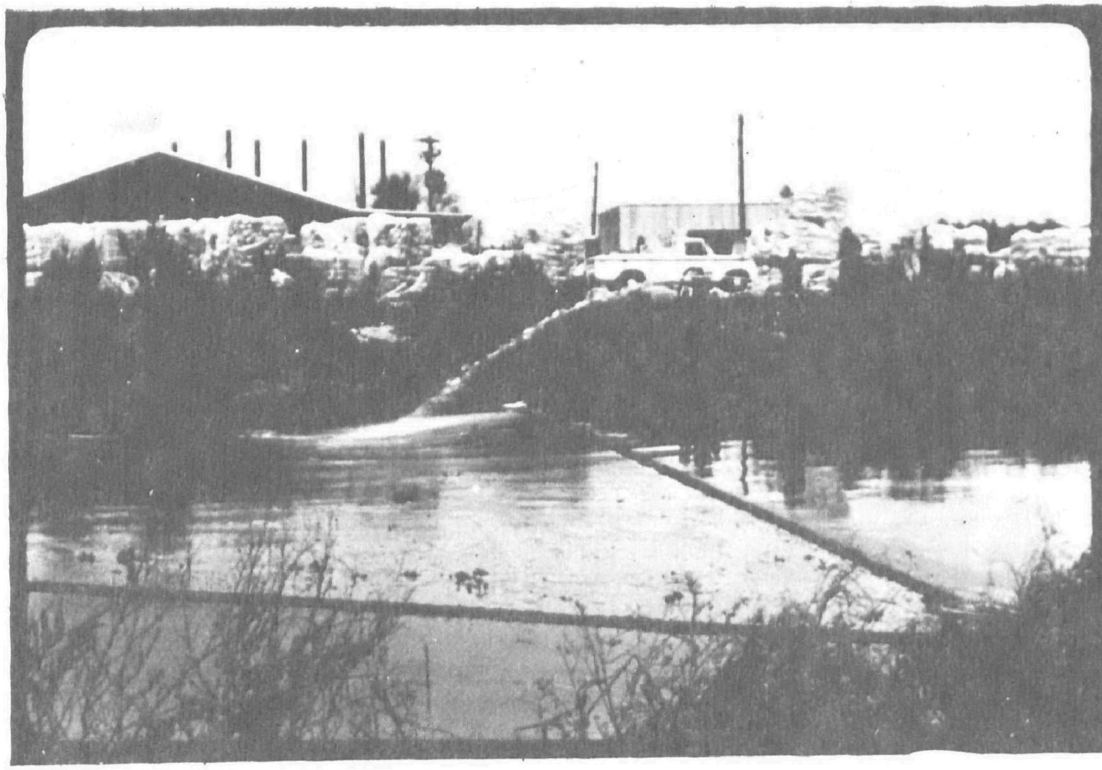

Figure C-10. Water jet herding used with endless rope skimmer.

Figure C-11. Shoreline application of endless rope skimmer.

Generally, use of weir skimmers is limited to cases where there are extremely high concentrations of oil, adequate depth for operation, access for large-scale removal of collected fluid, and little or no debris. Advantages of most weir skimmers are their small size and ease of deployment.

Where conditions dictate their application, weir skimmers should be deployed in conjunction with herding, diverting, and collecting devices. Placement of the skimmer should be as near to the "apex" of the collecting mechanism as possible. Typical applications utilizing shoreline configuration and booms are shown in Figure C-12. In designing any collection system of this nature, care must be taken to locate the "apex" point so that it is accessible to maintenance and recovery equipment.

Vacuum Systems --

Deployment tactics are essentially the same as described for all other types of stationary recovery devices. Shoreline configuration and booms can be used to allow natural processes to move the oil to the skimmer. Water-jet herding provides a convenient substitute in the absence of wind and current. Once near the suction head, the current caused by the device itself will entrain nearby oil.

Vacuum recovery systems are most effectively operated from the shoreline. Conventional vacuum trucks (normally used for cleaning out residential septic tanks or transferring industrial wastes) can be used for recovery, transport, and disposal operations. By proper scheduling of the proper number and size of trucks, near continuous operations can be maintained.

Vacuum skimming is best applied where heavy concentrations of oil are present. It is also effective in recovering small debris, including granular sorbents. For light concentrations of oil, the high concentrations of water recovered make application of vacuum skimming impractical. Depending on the nature of the suction head, debris of varying sizes will cause clogging. Debris exclusion measures generally will solve the clogging problem, but in doing so, will reduce the flow of oil to the device. Constant cleaning of the suction head (Figure C-13) is the only currently available solution to the clogging problem.

Maximum efficiency of the vacuum-skimming operation also requires careful positioning and adjustment of the suction head. In some marsh areas the adjustment required will be continuous. A method for positioning the suction head in shallow water with wedges is shown in Figure C-14.

For dealing with small concentrations of oil in isolated areas, such as found in mangrove swamps, small improvised vacuum systems may be useful. The limited holding capacity of such small systems can be somewhat offset by having several crews exchanging empty for filled 50-gallon drums.

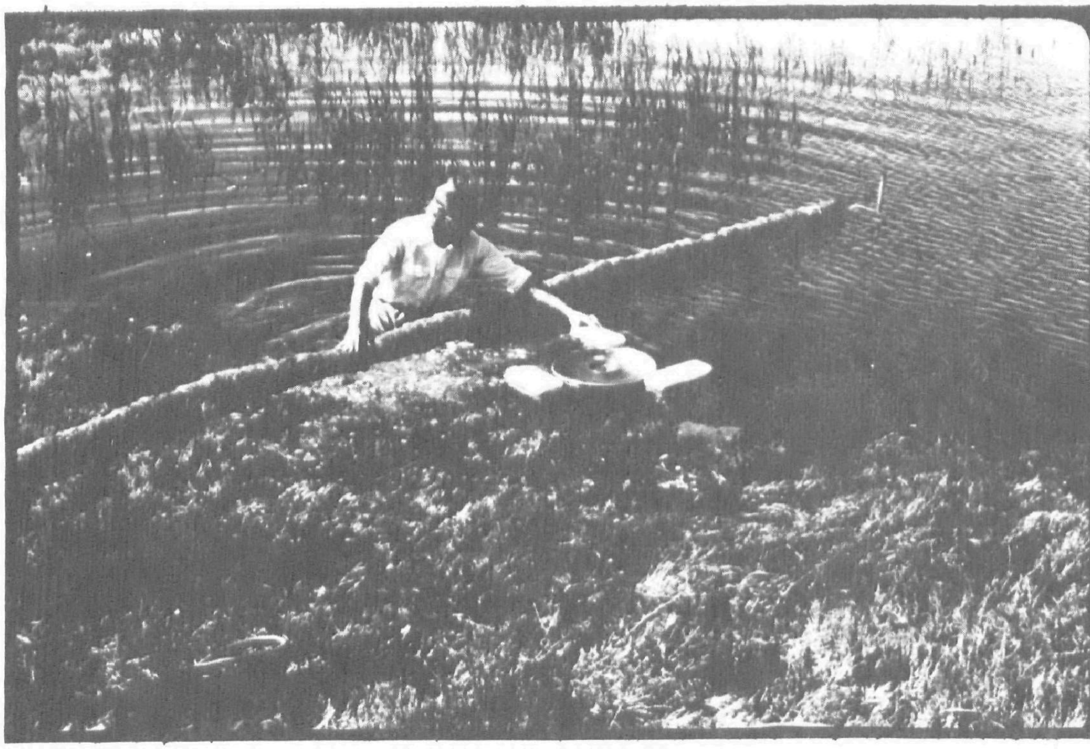

Figure C-12. Typical small weir skimmer.

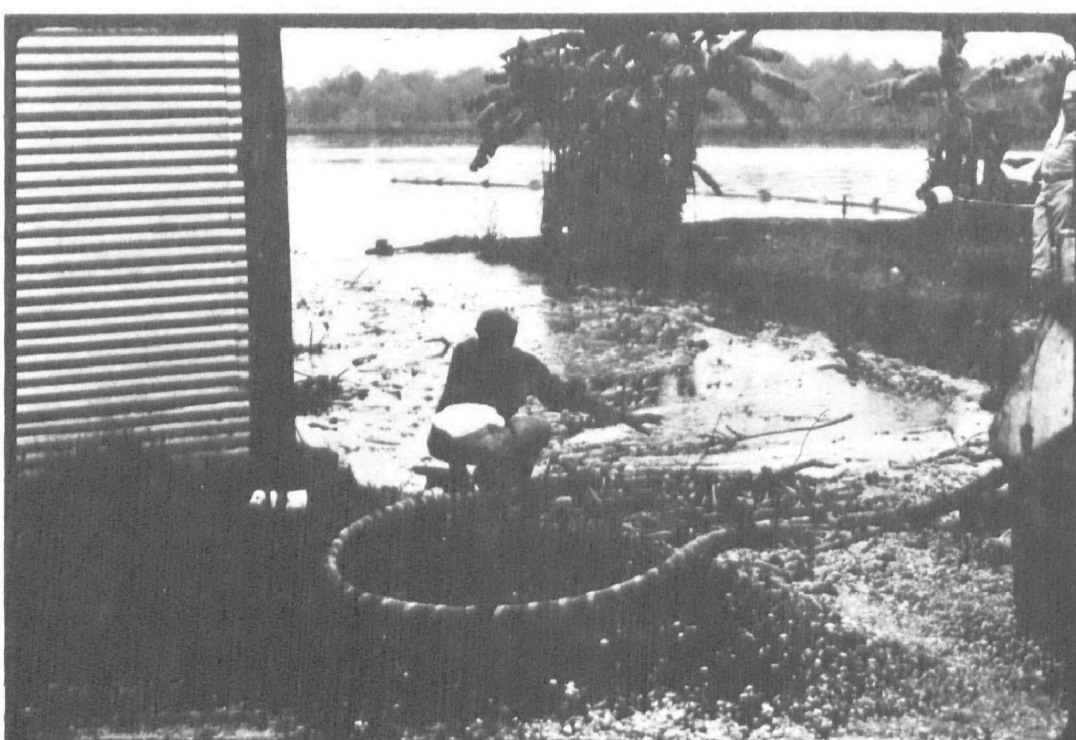

Figure C-13. Operation of vacuum suction head.

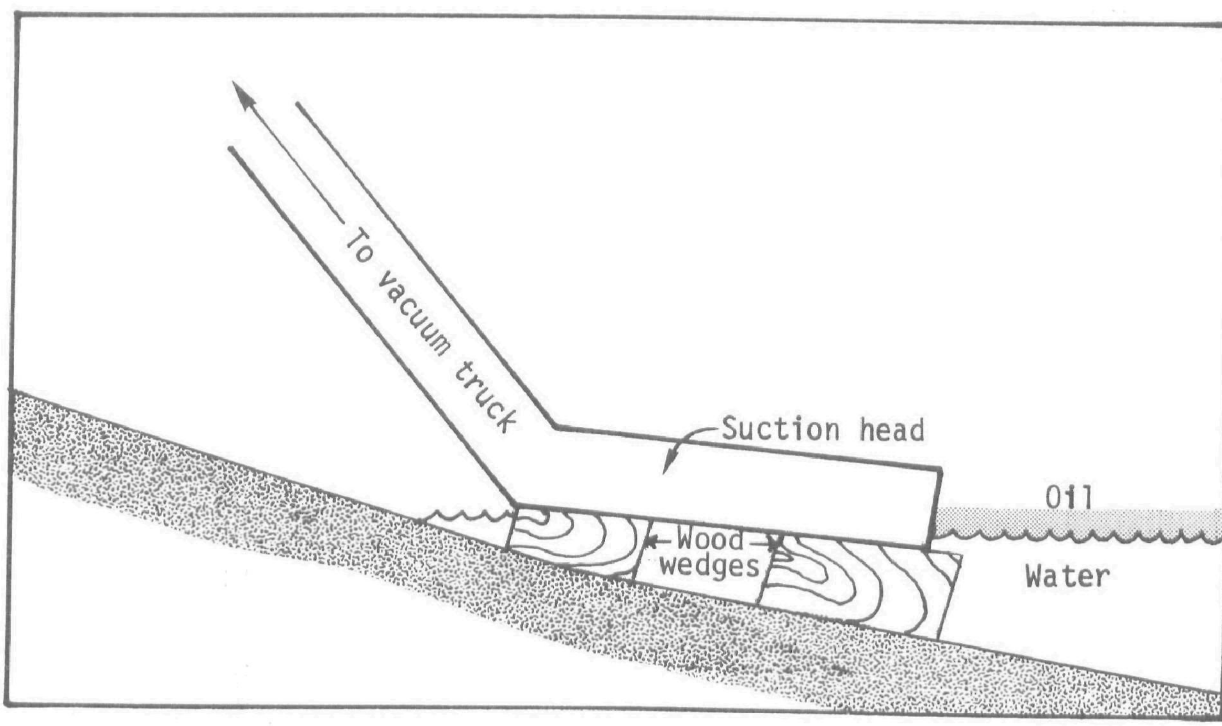

Figure C-14. Positioning of suction head with wedges.

Handling of Contaminated Materials

Cutting --

Cutting and removal of contaminated vegetation can be accomplished by two methods, mechanical cutting and hand cutting. The choice of method depends on marsh trafficability, shoreline slope, tidal variations, and water depth. Hand cutting involves using manual labor equipped with shears, power brush-cutters, sickles, or other hand-held devices. Mechanical cutting can be accomplished by a variety of commercially available aquatic weed-cutters, or, in some cases where soil-bearing capability is adequate, agricultural harvesting equipment.

Mechanical Cutting -- Aquatic weed-harvesting devices are available throughout most parts of the country. Manufactured in a variety of configurations and sizes, some of these devices are capable of operation in very shallow water and combine the process of cutting, pickup, and temporary storage in one apparatus. A typical mechanical cutting device is shown in Figure C-15.

Importantly, devices of this type offer the advantage of vegetation removal without significant traffic on, and damage to, the marsh surface.

Because the aquatic cutters are floating devices, their application is limited to shoreline marshes. By raising the cutting edge above the water surface, plants may be cut several yards beyond the water line. When operated at high tide, fairly wide bands of marsh can be removed.

The most common cutters operate off the bow of the vessel. A typical cutting pattern is indicated in Figure C-16. After the initial pass parallel to the shoreline, the device must be "nosed" into the shoreline for the remainder of the cutting, starting at the upstream end of the area to be treated, and working downstream.

Side-mounted cutters may be operated in a sequence similar to that indicated in Figure C-17 with successive passes into the marsh as the tide rises.

Aquatic harvesters are designed for the recovery of plant material only, and as such, a percentage of the oil will be lost through the conveyor screen unless modified. Rather than attempt to "drip-proof" the cutter, it is recommended that lost oil be recovered by another system. In any case, booms should be deployed to control the possible spread of oil and debris. In deploying these booms, space must be provided for maneuvering the cutter.

Hand Cutting -- Hand-cutting operations require moderate-to-large crews working on land in the marsh. Each crew should be split into two groups, cutters and debris handlers. Equipped with hand tools or small power brush-cutters (Figure C-18), the cutting groups cut the plants

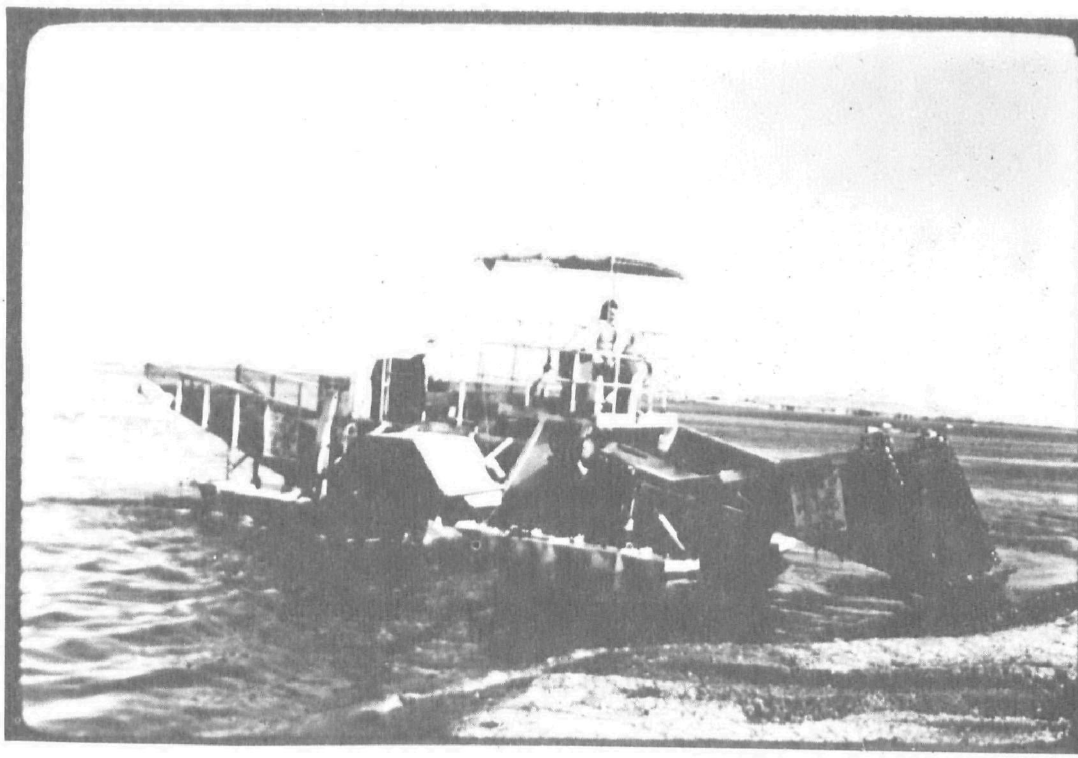

Figure C-15. Typical aquatic weed harvester.

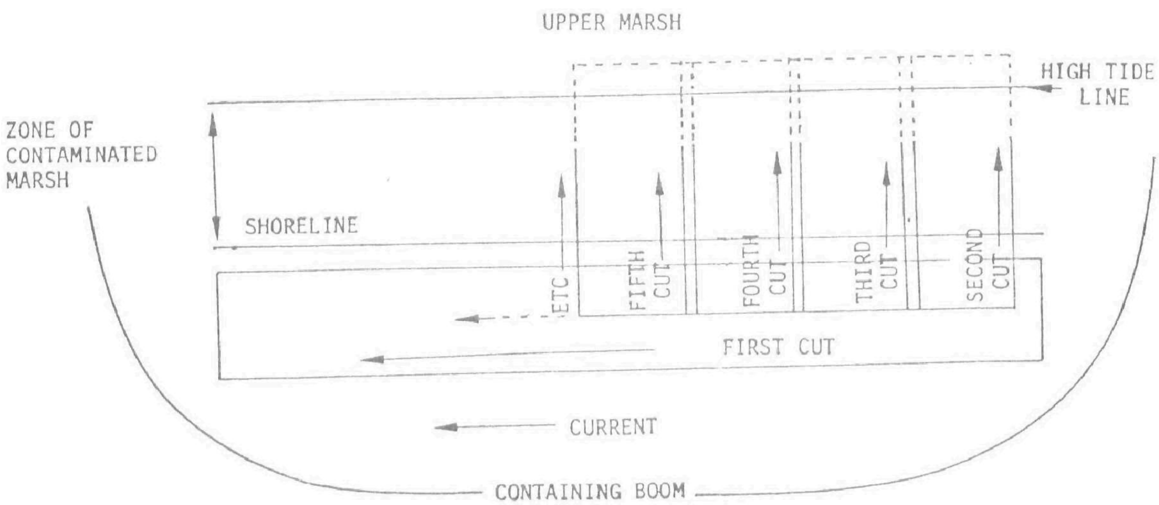

Figure C-16. Typical operational sequence for front-cutting harvester.

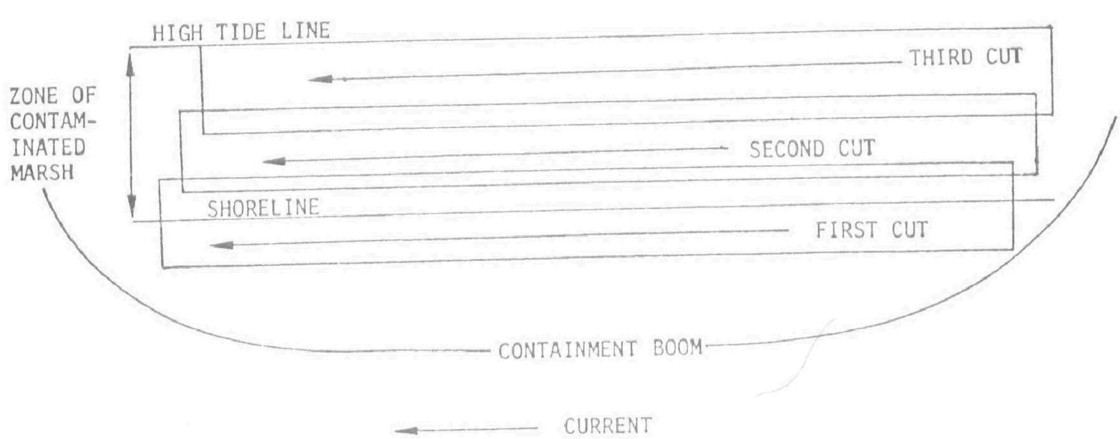

Figure C-17. Typical operational sequence for side-cutting harvester.

Figure C-18. Gasoline powered brush cutters.

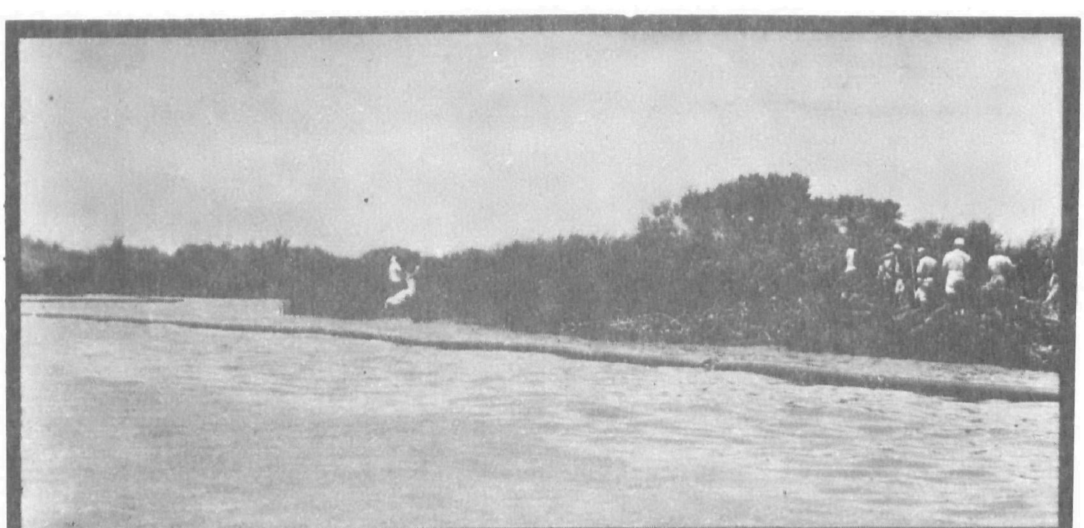

Figure C-19. Containment booming of cutting operation.

within a few inches of the substrate. As with all types of cleanup, cutting should begin at the upstream end of the area to be treated and work downstream, thus limiting recontamination (Figure C-19).

The bulk of the cutting must be done during low tide when the plants are exposed and marsh accessibility is the best. The general procedure is to start at the waterline and work ahead of the tide.

Following the cutting group, the debris handlers pick up and remove the oiled vegetation. Materials should not be stockpiled on the site for any period of time as they will be subject to leaching and the action of high tides unless protected by tarps, plastic sheets, or plastic. Collected debris may then be removed by boat, land (if access is available), or by helicopter. Oil released during the cutting process can be recovered by flushing and an oil recovery system.

Before cutting, the areas to be treated should be boomed to control oil released during the procedure. Likewise, treated areas should be protected from recontamination until the threat is eliminated.

Hand cutting is an extremely hazardous operation. The risk of injury to personnel must be weighed as part of the decision to cut. Additionally, the abuse to the marsh surface may be significant. Potential plant damage from foot traffic must also form part of the decision criteria.

Burning --

The feasibility of burning can be determined by test ignition of a sample of oiled vegetation. Relatively high temperatures may be required for first ignition. Once ignited, however, the fire must be self-sustaining for effective use. Once "burnability" has been demonstrated, burning permits must be obtained by the OSC from appropriate regulatory agencies (typically the EPA, state fish and wildlife agencies, and local air pollution agencies). Obvious factors associated with granting of permits include public safety, wildlife hazard, and air pollution.

A burn plan should be prepared as part of the permit process. In essence, this plan merely provides for the orderly and safe implementation of the burning and for its control. In many areas, game management personnel will be available to provide expertise on burning. Burning should be restricted to small sections of marsh isolated by water or by earth barriers. Generally, fires should be set on the upwind side of each section and allowed to burn with the wind until exhausted or reaching a barrier. Figure C-20, shows fire lines set by a tracked, amphibious vehicle. A well developed burn is shown in Figure C-21.

While it is impossible to describe the actual implementation of a marsh-burning operation in a manual of this nature, several details should always be kept in mind:

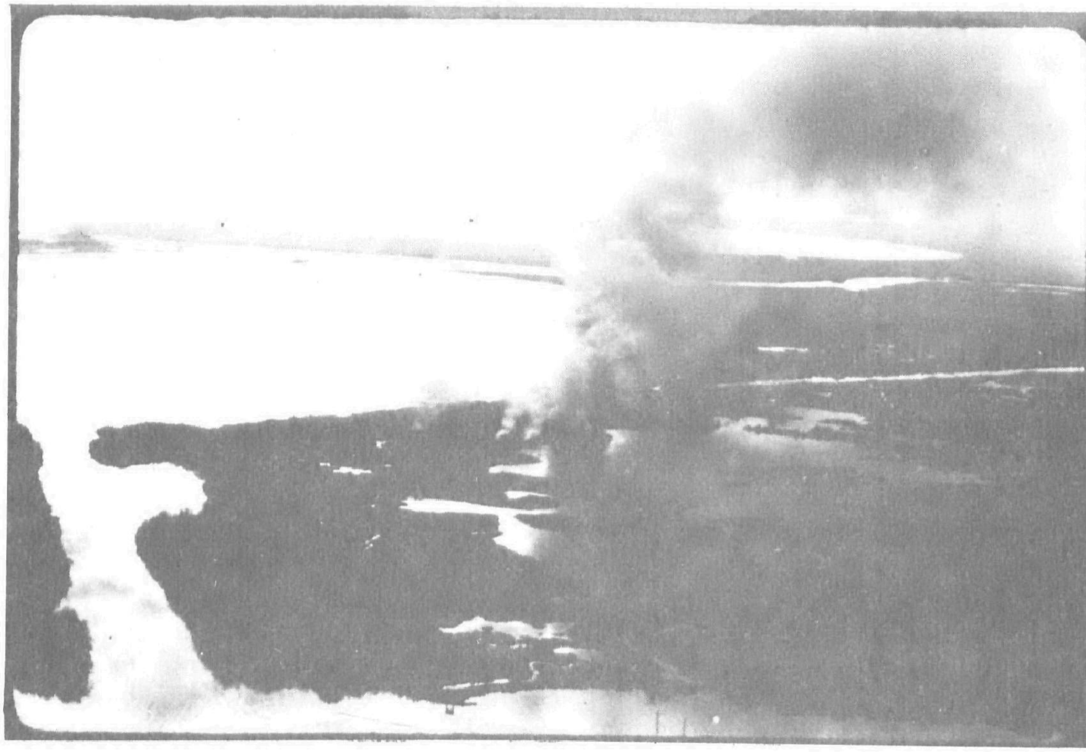

Figure C-20. Lighting of fire lines.

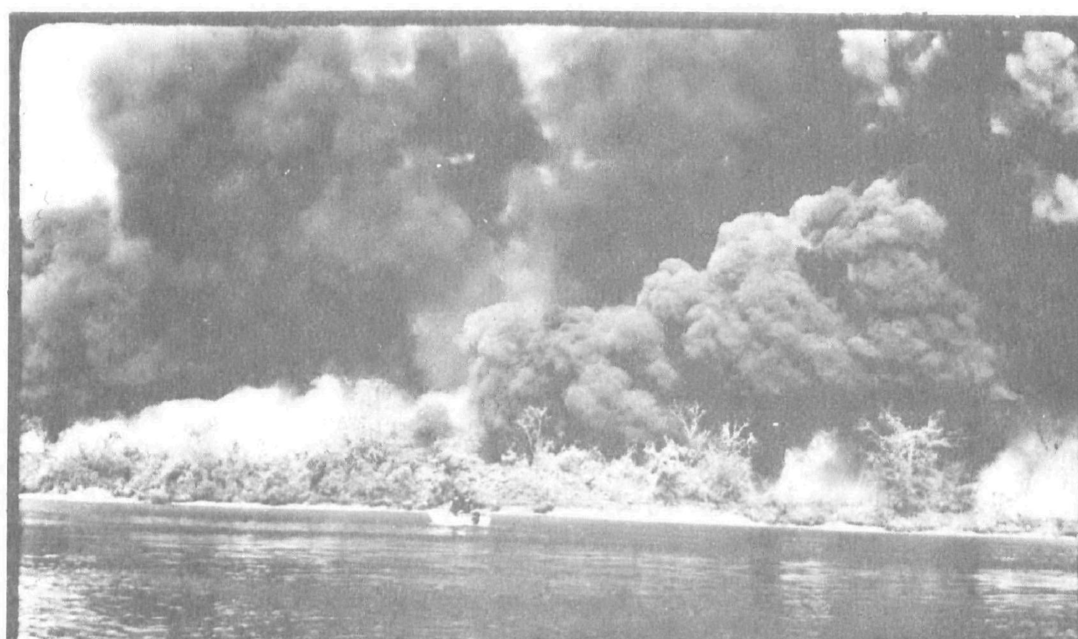

Figure C-21. Representative large marsh burn.

1. Care must be taken to insure that all personnel are out of the burn and adjacent areas before proceeding. Traffic in adjacent waterways should be restricted to emergency vessels only.

2. Burning should be conducted when winds are blowing seaward to reduce air pollution impacts.

3. Oil fires in marshes can be erratic and have been known to burn into the wind. Provision for control of fires in all directions must be included in the burn plan.

Soil Removal --

No standard instructions can be given regarding soil removal. This is a costly, environmentally damaging procedure and must be limited to the smallest possible area. Careful preliminary surveys will be useful in controlling the area to be treated. Silt curtains and earth barriers may be useful in controlling siltation during the removal process.

Any area undergoing substrate removal will require restoration. A preliminary step prior to attempting restoration procedures involves returning the substrate surface to its original elevation. Impoundment of hydraulic-dredging slurry provides the only economically reasonable method of replacing large volumes of soil.

Bird Cleaning Operations

The potential for rescue of a significant number of oiled birds is very good. With some specialized assistance from local veterinarians, a treatment center can become a highly successful part of the total cleanup effort. In fact, the public response to the problem of oil-contaminated birds is usually so negative that a cleanup effort which provides proper treatment of waterfowl can be a highly effective and beneficial public relations feature.

The first task is detection of oiled birds. Generally, severely oiled birds will be found on the shore or near shore in shallow water and can easily be seen from land or aerial observation points. While spill reconnaissance is continuing, all observers should note and report the number and location of oiled birds.

The next task is to evaluate the nature and scale of the problem. Birds which are heavily contaminated, i.e., total body and head covered with oil, must be treated or they will die. Birds which have smudges of oil, usually seen on the head or breast, will usually survive, as they are mobile, can avoid stress and exposure, and are able to feed. Therefore, only heavily oiled birds should be enumerated. If relatively few birds are affected, the situation can be satisfactorily met using local veterinary skills. If a large number of birds are affected, the Center should be asked to initiate and operate a treatment station.

Part of the evaluation of the bird problem must be the size and condition of the oil slick. If the oil is believed to be grounded or contained, the threat to waterfowl is lessened. However, if the slick is still uncontrolled or if recontamination is continuing, then the number of oiled birds may continue to increase.

In remote coastal locations, the cleanup effort should include patrols to locate and recover oiled birds, using vehicles providing the greatest access to the shoreline. The number may be large, as many as several thousand birds, and the scale of shoreline patrols should be large in the first few days until the number of affected birds becomes apparent.

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APPENDIX E. GLOSSARY OF TERMS

aerobic: able to live or grow only where free oxygen is present

anaerobic: Able to live and grow where there is no air or free oxygen.

annual: A plant that lives only one year or season.

aquatic weed cutter: A specially designed mechanical device that is used in water to cut aquatic vegetation.

aromatic: Organic compounds containing any of a series of benzene ring compounds. They are unsaturated organic ring compounds with low boiling points and are generally toxic to aquatic life.

bearing strength: Resistance of soil to pressure. This is important because trucks, shoes, etc., are affected by it.

benthos: The plants and animals that live in and on the bottom of a water body.

blokker equation: An equation which approximates slick spreading by use of an oil dependent constant, density of the oil and water, respectively, the volume of oil and the initial slick diameter.

brackish: Intermediate in salinity between sea water and fresh water.

clam shell: A mechanical device mounted at the end of a crane which picks up soil or mud with a pincerlike movement.

coagulating agent: Chemical additives applied to oil to form a more cohesive mass.

contact period: The time required to maximize the efficiency of the sorbent or chemical agent or the time before plant or animal damage occurs.

detergent: Chemical agent used to disperse and suspend oil in water leading to enhanced biodegradation.

dispersant: See detergent.

distillate: A refined hydrocarbon which is obtained by collection and condensation of a known vapor fraction of the crude oil.

distillate range: The range of temperature in which a hydrocarbon distillate such as gasoline, kerosene, and fuel oil is manufactured at a refinery.

drag line: A mechanical device that excavates or transports soil, using a container pulled over earth by cables or chains.

dredge: A device used to remove sediment from the bottom of a water body.

emulsification: The process by which oil is mixed with water.

endless rope: A continuous rope-like oil sorbent device that is pulled across the surface of the water to pick up oil.

erosion: The wearing away by action of water or wind of unprotected or exposed earth.

estuary: A tidal coastal feature where salinity is intermediate between fresh and salt water.

evaporation: The conversion of a fluid, including hydrocarbons, to a gaseous state.

fertilizer: A substance or agent that helps promote plant or seed growth.

flash point: The temperature at which an oil will burn in air.

flushing: Use of a water stream to make oil flow to a desired location or recovery device.

fouling: Accumulation of oil or other materials, such as debris, that makes a device inoperative.

gelling agent: See coagulating agents.

germination: The sprouting of a seed.

habitat: The chemical, physical, and biological setting in which a plant or animal lives.

herding agent: Chemical agent which confines or controls the spread of a floating oil film.

hydraulic slurry: A suspension of particles in water.

landfill: A dump that has progressive layers of waste matter and earth.

marsh fringe: The outermost edge of shoreline vegetation.

migration: Season movement of a group of animals from one location to another.

mobilization: Movement of oil caused by physical forces such as gravity, tides, wind. Mobility of oil is limited by its viscosity.

mousse: A type of oil/water emulsion.

nursery stock: Small plants in flats or pots suitable for transport and transplanting.

oil/water separator: A device for separating oil from water.

oleophilic: A material that has affinity for oil.

paraffin: The waxy saturated component of crude oil, having relatively high boiling point and low volatility. Any member of the methane series having the general formula $C_nH_{2n}+2$.

perennial: Vegetation that continues to grow for several years.

physiography: The elevation of the marsh's substrate.

pneumatophore: A respiratory organ of the black mangrove which protrudes from the ground like a leafless shoot.

porosity: The permeability of the substance to water or air.

propagation: Reproduction.

prop root: Short specialized roots which branch from a plant's stem, which fasten the plant to a soil system.

recontamination: Contamination by oil of an area that has been already cleaned up.

rhizome: A rootlike stem under or along the ground, ordinarily in a horizontal position, which usually sends out roots from its lower surface and leafy shoots from its upper surface.

salt pan: A pool above high tide, "drained" only by evaporation so that salt is accumulated and concentrated.

seine: A fish net which can be used to collect sorbent or debris.

skimmer: A mechanical device that removes an oil film from the water surface.

specific gravity: The ratio of the density of a substance such as oil or seawater to the density of pure water at standard conditions.

solubility: The amount of oil that dissolves into the water column; always a very low number (few ppm).

solvent: A chemical agent which will dissolve oil.

substrate: The soil on which vegetation grows.

substrate penetration: Oil which has soaked into the ground.

sump: A pit or reservoir that serves as a drain from which oil can be collected.

tank barge: A barge for transporting liquids.

tarballs: Lumps of oil, weathered to a high density, semi-solid state.

tidal variation: The vertical range between high and low tides.

toxicity: The poisonous effect of crude oil or petroleum products.

trafficability: See bearing strength.

viscosity: Flowability; a function of oil type and temperature.

water table: Depth from the ground surface to water saturation.

weathering: Natural influences such as temperature, wind, bacteria, that alter the physical and chemical properties of oil.

weir: A vertical barrier placed just below the surface of the water so that a floating oil slick can flow over the top.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This manual addresses the response of the protection, cleanup, and restoration phases of spilled oil endangering or contaminating tidal marshlands. The manual follows a step by step approach to response actions. Common to both the cleanup and protective phases are a gathering of general information, knowledge of the characteristics of the spilled oil, identification of the sensitivity and unique features of the endangered marshland, and an investigation of any threat against public and personnel safety. Decisionmaking criteria are provided for both the protection and cleanup.

Special attention is given to the cleanup phase which involves foot and vehicular traffic in the marsh and which may lead to serious adverse impacts. The user is presented with criteria for termination of activities for both protection and cleanup activities. Final sections discuss requirements for debris disposal and restoration of the damaged marsh. Recovery includes evaluation of the need for restoration versus natural recovery, and restoration techniques.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Swamps Manuals Sorbents Skimmers Conveyors Oils Crude oil Combustion	Oil spills Mangrove swamps Oil Slicks Rigid barriers Oil spill - removal Oil pollution equipment Oil pollution abatement Oil booms Marsh restoration Vacuum systems	68D

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