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# Environmental Considerations for Marine Oil Spill Response

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# Environmental Considerations for Marine Oil Spill Response

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# ABSTRACT

When planning response activities for an oil spill, decision-makers must react to a wide range of circumstances. Decisions will vary depending on the type of petroleum product spilled and the nature of the impacted habitat. Response decisions will be based on tradeoffs dealing with the environmental consequences of the spilled oil and the response method selected, as well as the efficiency and effectiveness of the method. Selecting appropriate protection, response, and cleanup techniques, both before and following an oil spill, affects the ultimate environmental impact and cost resulting from a spill. The American Petroleum Institute, the National Oceanic and Atmospheric Administration, the US Coast Guard, and the US Environmental Protection Agency jointly developed this document as a tool for contingency planners and field responders to identify response techniques that have minimal ecological impacts and also minimize the impact of the oil. Guidance is provided through matrix tables indicating the relative environmental consequences of the different response options used for various categories of oil in open water and shoreline habitats. The document provides information on 28 response methods and classifies their relative environmental impacts for combinations of five oil types and 25 marine habitats.

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# CHAPTER 1.0
# HOW TO USE THIS DOCUMENT

Oil is a complex and variable natural substance. When released into the sea it can be transported long distances, undergo various physical and chemical changes, and adversely affect marine ecosystems. Oil's fate and effects depend on the type and quantity of oil spilled, properties of the oil as modified over time by physical and chemical processes, the organisms and habitats exposed, and the nature of the exposure. All these factors should be considered when evaluating response methods. Interactions among these variables result in an infinite range of spill situations. Accordingly, spill responders need a wide variety of tools.

Response techniques have "windows of opportunity," specific timeframes when each response method works the best. These windows are defined by the type of product spilled, the initial spill conditions, product weathering and emulsion rates, and the very different environments and ecosystems that are, or will be, impacted. When the techniques are used within these windows, they are more effective and less damaging to populations that survive the oil, allowing the affected ecosystem to recover quicker.

In every oil spill, government and industry decision-makers are presented with a unique set of challenges requiring timely application of appropriate response methods.

- How does an on-scene coordinator or a responsible party sort through the myriad of options and select those methods that will effectively mitigate and clean up the oil in the given circumstance?
- What is the rationale for selection?

This document addresses these issues to provide appropriate information to decision-makers relating to tradeoff decisions for specific habitats and response options. It focuses on maximizing response while minimizing impacts to resources.

This document provides the technical basis and rationale for pre-spill planning and response decision-making, and will assist the user in selecting response options to minimize adverse environmental impacts of a marine oil spill. On-water, shallow subtidal, shoreline intertidal, and ice habitats are discussed. Specific response options, including natural recovery, mechanical, chemical, biological, and *in-situ* burning, are evaluated.

## CAUTION!

**Deciding on response methods during an actual spill usually also depends on legal, social, and economic factors specific to the incident, as well as the practicality and timeliness of using the response method.**

The user must remember that the selection of a proper response method is highly dependent on incident-specific conditions, and that the strengths and weaknesses of a given response tool affect the suitability for its employment in a given habitat for a specific spill. Accordingly, using multiple methods simultaneously throughout an incident may produce a more effective response and minimize environmental impacts.

The selection of response options, including natural recovery, involves considering tradeoffs among their potential environmental impact, appropriateness for habitat, and application timing.

This document has been developed primarily to facilitate pre-incident response decisions which, since the Oil Pollution Act of 1990 (OPA 90), are made by Area Committees (ACs), Regional Response Teams (RRTs), and industry. During pre-spill planning, this document may be used to assist with:

- Developing response strategies for contingency plans and identifying equipment needs for response;
- Evaluating the area-specific response strategies and related adequacy of area equipment stockpiles;
- Assessing consistent application of effective response strategies across and between regions by RRTs;
- Assessing industry planning strategies as laid out in their facility, vessel, or pipeline response plans;
- Assessing the continuing vitality of the response community in a given area or region by exercise designers, executors, and evaluators; and
- Training for developing and implementing Area Contingency Plans.

During an oil spill response, this document can be used as a reference by the On-scene Coordinator and the Unified Command for communicating with government, the news media, and the public concerning the rationale for, and confidence in, the efficiency and effectiveness of the response methods employed. However, this document is not a cookbook decision text nor a substitute for training, qualified technical advice, or good sense. Proper use of the guidance contained in this document during response operations requires timely, expert assessment of existing and projected environmental conditions, and an assessment of the probable effectiveness of each response method under these conditions.

This document may be customized for specific geographic areas to address special priorities and concerns, but it does not address:

- Environmental considerations for chemical spills;
- Wildlife management;
- Spills on land;
- Human-health and safety concerns;
- Non-ecological resources (e.g., recreation, tourism, aquaculture);
- Legal or regulatory issues; nor
- Planning, organizing, and conducting a spill response effort.

The document is organized to provide the user with a progressive understanding and rationale for selecting response options that minimize adverse environmental effects. The general organization for the present document, and much of the information on response options, has been adapted from a 1994 API/National Oceanic and Atmospheric Administration (NOAA) publication which focuses on response options in the freshwater environment. Information on shoreline habitats was taken, in part, from a 1992 NOAA Shoreline Countermeasure Manual.

The document is structured to allow the reader to obtain information on an oil type and a habitat type, and then find out the various options to respond to a spill of that oil in that habitat. For instance, the reader can find out about the characteristics of a Category III oil by referring to Table 1, obtain information on sand beaches by reading the discussion in Chapter 5, and then look at Table 19 to see what response options are recommended for dealing with a spill of Category III oil on a sand beach.

Chapter 2 provides a discussion of technical concepts and information to lay a foundation for subsequent chapters. This chapter:

- Summarizes oil properties and classification, physical and chemical fate of oil on water and shorelines, and effects of oil in marine ecosystems; and
- Discusses strategies for selecting response methods.

Chapter 3 contains detailed descriptions of the response methods listed in the matrices. For each, the following information is provided:

- Objective;
- Description;
- Applicable Habitats;
- When to Use;
- Biological Constraints;
- Environmental Impact; and
- Waste Generation.

To understand the relative impact of oil plus the response method, the reader must first have an understanding of the baseline impact of methods in the absence of oil. This information is also presented in Chapter 3.

Chapter 4 describes guidelines for developing strategies for on-water and shoreline response.

Chapter 5 presents the "bottom-line" portion of the document by identifying the appropriateness of using different response methods in the various habitats. This chapter is organized by habitat and, for each, contains:

- A detailed description of the habitat;
- A discussion of habitat sensitivity; and
- A matrix, along with associated text, of response methods recommended for use in that habitat for each of the five general oil categories (oil categories are discussed in Section 2.1).

Chapter 6 presents the matrices from Chapter 5 in a slightly different format: by oil type instead of by habitat.

The appendices include:

- Regulatory considerations (A);
- Oil characteristics (B);
- Grain-size scale (C);
- Table of synonyms of shoreline types (D);
- References and additional reading (E); and
- Synopsis of document preparation (F).

# CHAPTER 2.0
# TECHNICAL BACKGROUND

Understanding important technical concepts is essential to lay a foundation for selection of response options that minimize adverse environmental effects. Summaries are provided of oil properties and classification, physical and chemical fate of oil on water and on shorelines, and effects of oil in marine ecosystems. An overview of response objectives and strategies follows.

## 2.1 PROPERTIES AND FATE OF OIL

This section summarizes basic information on oil properties and classification and then discusses physical and chemical fate of oil on water and on shorelines.

### OIL CLASSIFICATION

A common oil classification scheme, based primarily on specific gravity, defines five categories. Table 1 summarizes the properties of the five oil categories used in the document. Although diesel is often classified as a Category I oil (because it is considered non-persistent), it is placed in Category II because methods used to respond to a diesel spill are similar to those used to respond to a Category II spill.

Weathering changes the physical and chemical properties of oil over time, generally making it less volatile, more viscous, and heavier (increased specific gravity); so, response methods should be re-evaluated as the oil changes in character.

Marine oil spills occur within the full range of crude oils and refined products, and an understanding of the type of oil spilled and its properties is critical to the development of effective response strategies. The following information highlights key considerations relative to the oil properties most critical to marine oil spill response.

**Table 1.** Characteristics of the five oil classifications used in this document.[1]

| Gasoline Products (Category I) | Diesel-like Products and Light Crude Oils (Category II) | Medium-grade Crude Oils and Intermediate Products (Category III) | Heavy Crude Oils and Residual Products (Category IV) | Non-floating Oils - Heavier than Water (Category V)[2] |
|---|---|---|---|---|
| Examples – Gasoline types of products | Examples – No. 2 fuel oil, jet fuels, kerosene, West Texas crude, Alberta crude | Examples – North Slope crude, South Louisiana crude, No. 4 fuel oil, IFO 180, lube oils | Examples – Venezuela crude, San Joaquin Valley crude, Bunker C, No. 6 fuel oil | Examples – Very heavy No. 6 fuel oil, Residual Oils, Vacuum Bottoms, Heavy slurry oils |
| • Very volatile and highly flammable | • Moderately volatile | • Moderately volatile | • Slightly volatile | • Very low volatility |
| • High evaporation rates; narrow cut fraction with no residues | • Refined products can evaporate to no residue; crude oils leave a residue after evaporation is complete | • Up to one-third will evaporate in the first 24 hours | • Very little product loss by evaporation | • No evaporation when submerged |
| • Low viscosity; spread rapidly to a thin sheen | • Low to moderate viscosity; spread rapidly into thin slicks | • Moderate to high viscosity | • Very viscous to semisolid | • Very viscous to semisolid |
| | • Specific gravity of <0.85; API gravity of 35-45 | • Specific gravity of 0.85-0.95; API gravity of 17.5-35 | • Specific gravity of 0.95-1.00; API gravity of 10-17.5 | • Specific gravity greater than water |
| • High acute toxicity to biota | • Moderate to high acute toxicity to biota; product-specific toxicity related to type and concentration of aromatic compounds | • Variable acute toxicity, depending on amount of light fraction present | • Low acute toxicity relative to other oil types | • Low acute toxicity relative to other oil types |
| • Does not emulsify | • Can form stable emulsions | • Can form stable emulsions | • Can form stable emulsions | • Can form stable emulsions |
| • Will penetrate substrate; nonadhesive | • Tend to penetrate substrate; fresh spills are not adhesive | • Variable substrate penetration and adhesion | • Little penetration of substrate likely, but can be highly adhesive | • Little penetration of substrate likely, but can be highly adhesive |
| | • Stranded light crudes tend to smother organisms | • Stranded oil tends to smother organisms | • Stranded oil tends to smother organisms | • Stranded and submerged oil tends to smother organisms |

1 Source: modified from API and NOAA, 1995.

2 Work by the National Research Council (1999) has renamed Category V oils from "Low API Oils" to "Non-floating Oils". To reflect the most current terminology and research, Category V Oils will be labeled as Non-floating Oils.

### *Flash Point and Evaporation*

Flash point is the temperature at which the vapors of a substance ignite when exposed to a flame or spark. Highly volatile oils that evaporate rapidly may pose significant fire and explosion risks. Often, the safest option is to allow such products to evaporate. Evaporation is an important mechanism for removing the oil because it can lessen the need for response and concern for associated impacts. Highly volatile oils, e.g., Category I, can completely evaporate in one to two days under most conditions.

### *Specific Gravity/Density/API Gravity*

Specific gravity is the density of a substance relative to fresh water. API gravity is related to specific gravity as follows:

$$\text{API Gravity} = \frac{141.5}{\text{Specific gravity at } 60\infty\text{F}} - 131.5$$

Oils with a specific gravity greater than 1.00 (API gravity < 10) will sink in fresh water. Oil will sink in seawater if its specific gravity exceeds approximately 1.02 (API gravity < 7). When lighter oils have stranded on a shoreline, incorporated sediment can cause sinking if the oil re-enters the water.

### *Viscosity/Pour Point*

Viscosity is an oil's internal resistance to flow and is measured in centistokes (cST). Viscosity controls the rate that oil spreads on water and its likely depth of penetration into the substrate once on shore. Low-viscosity oils spread rapidly into thin sheens, increasing their surface area and making recovery difficult. They readily penetrate sediments and debris. Oils can be so viscous that they do not spread, particularly in cold water, and such oils are more likely to coat, rather than penetrate, surfaces. Viscosity changes with temperature. For example, viscosity reduces with increasing temperature and vice versa. Oils at temperatures greater than the pour point will flow, below the pour point, they won't. However, they are generally not solid and will "creep", which is an important consideration in some situations such as with sunken vessels where oil below the pour point still leaks. An oil's pour point is the temperature below which oil will not flow. A highly viscous oil will have a higher pour point compared with less viscous oils.

## *Processes that Change the Location and Properties of Oil on Water*

When oil is spilled on water, it immediately begins to move and its physical and chemical properties change. These changes can have a significant influence on spill response activities. Understanding how an oil spill changes through time is important in order to understand how the appropriateness of different spill response options changes through time.

If oil stayed put once it was spilled, cleanup would be easier and environmental impacts would be less. Unfortunately, the oil's location will be changed by advection, spreading, and submersion.

### Advection

Oil moves on the water's surface due to forces generated by winds and water currents in a process known as advection. Wind, when blowing over the water's surface, produces a surface current of about 3% of the wind speed in the direction the wind is blowing.

There are several types of ocean currents (ocean current direction is described as the direction to which the current is flowing). Long-term or seasonal currents are generated by regional changes in ocean circulation and are influenced by the effect of the earth's rotation, bathymetry, and coastal geometry. Currents cannot be assumed to be constant over the course of an incident.

Tidally-generated currents vary on a tidal time scale (12 or 24 hours), depending on the region. In water depths greater than about 30 feet (10 meters), these currents transport the oil backward and forward (i.e., they do not cause a net motion of the oil when averaged over a long time scale). If the tidal motion causes the oil to come near shore or into shallow water, these currents can force the oil near a shoreline or cause a net motion of the oil. An on shore wind is necessary for the oil to strand on a shoreline.

Estimating or predicting oil movement on water is called oil spill trajectory modeling. Using the concepts discussed above, oil spill movement can be estimated by hand, using graphical techniques, or predicted in a more sophisticated fashion, using a computer. It is important to remember that the speed and direction of the wind can vary rapidly over time; therefore, weather forecasts must be frequently obtained when calculating oil spill trajectories.

## Spreading

As soon as oil is spilled in the water, it starts to spread, driven by gravity. In the initial stage of spreading, the oil's viscosity provides most of the retarding force; thus, a light oil will spread more rapidly than a heavy oil.

In the final stage of spreading when the oil layer is very thin, the main driving force is the surface tension of the oil, rather than gravity.

During the gravity-spreading phase, the oil separates into two slick-thickness regions. Most of the oil will form thicker patches [from 0.004 to 0.04 inches (0.1 to 1 millimeter)] for temperate regions and medium oil. Surrounding these patches will be large areas of thinner oil [0.000004 to 0.0004 inches (0.1 to 10 micrometers)], commonly called sheen. Since most of the volume of the oil is in the thick regions, a rule of thumb is that 90% of the oil is in 10% of the oiled area, and, conversely, 10% of the oil is in 90% of the oiled area. Oil thickness will not be homogeneous, and response activities may need to be focused on small areas of the thicker oil in order to be effective.

Due to a combination of wind and wave action, the contiguous slick will soon become discontinuous, forming windrows, which are typically a few meters wide, and are separated by areas of clear water or sheen. Under suitable conditions, skimmers can effectively collect oil from windrows.

The rapid spreading of oil on water can limit certain response options. For example, *in-situ* burning requires a minimum thickness of 0.08 to 0.2 inches (2 to 5 millimeters). Since most oils spread rapidly to an average thickness of between 0.00394 and 0.04 inches (0.1 and 1 millimeter), such slicks cannot be burned without the use of fire-resistant booms or other types of containment to help maintain this thickness. Spreading increases the area of a slick, thus limiting skimmer encounter rate and recovery effectiveness.

## Submersion

Most oils float because they are less dense than water. If oil is (or becomes) more dense than water, it will submerge; but, this is a relatively rare occurrence. Sea water specific gravity varies depending on the salinity, temperature, and depth (pressure), but a typical value is 1.02.

Oils increase in density as the lighter fractions evaporate, and, for Categories IV and V oils, the increasing density may result in the weathered oil submerging. Submerged oil will sink below the surface and "float" above more dense water, deeper in the water column. Some *in-situ* burn residues also may become heavier than water and submerge.

If the oil is (or becomes) neutrally buoyant (has exactly the same density as the water), it will quickly diffuse into the water column, achieving a very low concentration after a few hours to days. Submerged or neutrally buoyant oil that attaches to suspended sediment may sink to the bottom and remain there, unless resuspended by heavy wave action.

## *Early Processes that Change Oil Properties*

The processes of evaporation, dispersion, and dissolution that occur in the early stages of an oil spill are most important within the first few hours to days of a spill and cause significant changes to the physical and chemical properties of the oil. Collectively, these processes are known as weathering. These changes help drive the decision-making process as responders consider their response options.

### Evaporation

For light oils, evaporation will be the most rapid and extensive weathering process, as the lighter ends of the oil vaporize. The amount and rate of evaporation is a function of the properties of the spilled oil and the existing environmental conditions. For example, low temperatures and light winds reduce the rate of evaporation.

Different oils will evaporate at varying rates and proportions (Table 2). Precise evaporation calculations can be made if the oil's specific properties are available. Most computer models can provide specific time-dependent information on evaporation, but they require detailed information about the boiling curves or composition of the oil.

For very light crudes and products, such as gasoline, evaporation may eliminate nearly all the spilled oil in a few hours. Under certain environmental conditions, the vapors may develop into a flammable mixture, so it is generally advisable not to contain a gasoline spill.

Evaporation of the light ends (the lower molecular weight molecules) causes an increase in the oil's viscosity, and changes the ratios among the different kinds of molecules. These changes alter the oil's behavior, thus influencing the selection and success of response actions. The increase in viscosity generally reduces the

**Table 2.** Approximate evaporation percentages for various classes of oil.[1]

| Oil Category | 12-hour Evaporation | 48-hour Evaporation | Total Fraction Evaporated |
|---|---|---|---|
| I. Gasoline | 50-100% | 100% | 100% |
| II. Diesel and Light Crude Oils | 10-40% | 25-80% | up to 100% |
| III. Medium Crude | 5-30% | 15-40% | 45% |
| IV. Heavy Oils | 1-3% | 5-10% | 15% |
| V. Non-floating Oils | 0-2% | 1-5% | 10% |

1 Lower limits are for 5°C (40°F) and the upper limit for 30°C (85°F). For this table, a moderate wind speed of 5 m/sec (10 kts) has been assumed. These calculations are based on OILMAP algorithms. Other models may produce slightly different results, but modern models will predict within the ranges in Table 1.

effectiveness of both skimmers and dispersants. The loss of light ends makes ignition (*in-situ* burning) of the oil more difficult. The change in the ratio of aromatics, resins, and asphaltenes increases the likelihood of emulsification.

Evaporation may be so complete for gasoline that no removal action is needed. In the case of a light to medium crude, evaporation may reduce the amount of oil on the water by half.

## Dispersion

Dispersion is the breaking up of a surface slick into small particles [0.0004 to 0.004 inches (10 to 100 micrometers) in size] that are subsequently mixed into the water column. The amount of dispersion depends on the properties of the oil and the amount of wave energy involved.

For low viscosity oils, a controlling parameter of dispersion is the interfacial tension between the oil and the water. The higher the interfacial tension, the more wave energy is needed to form the dispersible small particles. Viscosity becomes the controlling parameter for more viscous oils.

Wind-induced vertical eddy motion will move small oil particles into the water column to a depth of about four times the significant wave height. If this vertical mixing stops, the dispersed particles will eventually resurface (smaller particles take longer). In even a low sea state (Beaufort 2), particles as large as 0.004 inches (100 micrometers) will remain in the water column as long as their rise velocity is less than the orbital velocity of the waves.

Natural dispersion, for a medium oil and moderate sea state, can remove between 1% and 15% of the slick from the surface. Oil particles in the water column will experience a rapid horizontal diffusion, reducing the dispersed oil concentration by two orders of magnitude in less than an hour. Thus, dispersion results in only a short-term exposure in the top few meters of the water column.

Because the small oil particles in the water column have a much larger surface area in contact with the water than those in the surface slick, the rates of dissolution (see below) and biodegradation (see below) are increased. Whether dispersion reduces or increases the environmental impact of the spill depends on the environmental situation and the oil properties. For most spill situations, removing oil from the water surface before it disperses (and the subsequent rapid reduction of the oil concentration in the water column) will reduce the overall environmental impact. In some situations, chemical dispersion may be desirable. Chemical dispersants lower the interfacial tension by an order of magnitude or more, accelerating both the rate of dispersion and the amount of oil dispersed into the water column.

**Dissolution**

The old adage that "oil and water do not mix" is not true. The light ends of oil are partially soluble in water in a process called dissolution. The rate of dissolution depends on the contact surface area between oil and water as well as the oil's chemical composition. As the slick spreads or is dispersed (naturally or chemically), the resulting larger surface area will increase both the rate of dissolution and the amount of oil dissolved. Only a few components of oil are soluble in water, so dissolution involves only a small fraction of the oil, generally a few parts per thousand of most crude oils.

Some of the dissolved components (water-soluble fraction) are toxic to marine organisms, so even though the volume of oil may be low, the process is important for assessing a spill's environmental impact.

## Water-in-Oil Emulsification

Physical mixing of water into the oil can produce an emulsion, a fluid that can be larger in volume (i.e., 80% water and 20% oil) and orders of magnitude greater in viscosity than the original oil. Often called "chocolate mousse," this type of emulsion consists of small water droplets [0.00004 to 0.0004 inches (1 to 10 micrometers)] surrounded by a thin film of oil; the water droplets are closely packed, and the oil is contained in the interstitial spaces.

In the initial stages of emulsification, only a small amount of water is mechanically incorporated into the oil. Such emulsions are very unstable and will readily separate into oil and water if left undisturbed. As the amount of water in the oil increases, droplet size decreases, and natural surfactant (in the oil) accumulates at the interfaces, and the emulsion becomes stable and viscous. A "mousse" emulsion generally has a brown or orange tinge when viewed from the air, as opposed to black for unemulsified oil.

The increase in volume and viscosity significantly impacts the effectiveness of most response techniques:

- An emulsion does not flow easily into skimmers;
- A larger amount of material must be removed;
- Viscous emulsified oil is difficult to pump;
- Dispersants are not as effective (due to the high viscosity and water in the fluid), but there is evidence that dispersants can break some emulsions, allowing the oil to disperse normally; and
- *In-situ* burning is more difficult (or impossible) because of the water in the oil. Also, continued burning is inhibited because it depends on the release of volatile compounds by radiant heat; but, since much of the radiant energy is used in vaporizing the water and breaking the emulsion, volatile compound release is limited.

## *Long-term Processes that Change Oil Properties*

A number of long-term weathering processes can alter spilled oil's chemical or physical nature. These processes, which take place over days to months, include biodegradation, photo-oxidation, auto-oxidation, and sedimentation.

### Biodegradation

Biodegradation (aerobic or anaerobic) is a process in which indigenous microorganisms (e.g., fungi, bacteria) degrade oil (use it as an energy source, i.e., food), producing carbon dioxide, water, and biomass. Aerobic degradation of oil requires the presence of oxygen; anaerobic degradation does not. The rate of biodegradation depends on the oil type, the surface area of the oil, and the concentrations of oxygen, nitrogen, and phosphorus (the aerobic process is faster). Increasing the surface area of a slick by spreading and/or dispersion will increase the rate of biodegradation. The ultimate removal of oil from the sea, whether from spills or natural seeps, is largely due to biodegradation.

### Photo- and Auto-oxidation

In photo-oxidation, an oil's chemical characteristics are changed when solar radiation (particularly in the near ultraviolet) interacts with it to produce hydrocarbon oxides and hydroxides. The resulting compounds have very different properties than the parent oil; they are generally more soluble in water.

For most spill situations, the amount of oxidized compounds is very small and dissolution of these compounds will reduce the spilled oil volume only slightly. While the most dominant process is photo-oxidation, oxidation can result from bacterial fermentation or by simple contact with the atmosphere (auto-oxidation).

### Sedimentation

If sediment particles are suspended in the water column, oil can stick to them, forming a sediment-oil agglomeration that is likely to be denser than water. In general, the oil particles will be smaller and will, therefore, coat the sediment. In some situations, sedimentation can deposit oil on the ocean floor, resulting in its incorporation into the bottom sediments and slower degradation. A number of mechanisms have been proposed to explain the oil sedimentation process but, to date, there is no detailed, published explanation of the processes.

## PROCESSES THAT CHANGE THE LOCATION AND PROPERTIES OF OIL ON SHORELINES

Some weathering processes that affect oil on the water will also affect it on shorelines. Dispersion, dissolution, and emulsification do not affect oil on shorelines, but still can affect oil in the near-shore aquatic environment; and, since near-shore breaking waves may generate more energy than those in the open ocean, dispersion and emulsification rates may be higher closer to shore. Oil on shorelines can be remobilized and transported to adjacent areas by nearshore currents. Where oil is stranded, the dominant physical processes are evaporation, biodegradation, spreading, demulsification, subsurface movement, natural removal, oil/fine-particle interaction, and adhesion.

### Evaporation

This is the same process that occurs on the sea surface. Because the shoreline is a thermal insulator, solar energy may heat the oil to higher surface and internal temperatures than on water, thus increasing evaporation. The higher temperatures will also allow the oil to flow more readily, increasing the surface area exposed to sunlight and further increasing evaporation. There have been few studies of oil evaporation on shorelines, and most models either exclude the process or use the same rate as for water.

### Biodegradation

When stranded on a beach, oil is generally immobile, and biodegradation becomes an important weathering process. Adding nutrients (phosphorous, nitrogen) or microbes to stranded oil to enhance natural biodegradation is known as bioremediation and is used to remove small amounts of oil after other cleanup activities have removed the bulk. In the case of lightly oiled shorelines, bioremediation may be the favored cleanup option. Since oil is a natural product, native oil-degrading bacteria are frequently in abundance, and the rate of biodegradation will depend on temperature, oil properties, and nutrient availability.

### Demulsification

Heating emulsified oil may cause some semi-stable emulsions to break down, releasing the water and reducing the mousse volume by a factor of two or more.

## Subsurface Movement

If the spilled oil has a low viscosity, or if the impacted shoreline is composed of pebbles and cobbles, the oil will penetrate the beach. This means that weathering and biodegradation can slow or cease, and the oil may remain for months to years.

## Natural Removal

If the shoreline is a medium-to-high energy environment, the shoreline material may be moved during storms, exposing any beached oil and mixing it into the nearshore water column.

## Oil/Fine-particle Interactions (OFI)

There is considerable evidence that fine mineral particles present in the water will help to gradually remove stranded oil from the shoreline in the form of clay-oil flocculations. This material has a density near 1.0, and may float, be neutrally buoyant, or submerge. This process is only beginning to be understood, but oil/fine-particle interactions may account for the natural cleansing observed in many beach spill situations.

## Adhesion

There is a limited understanding of the physics of oil adhesion to rocks, and attempts to predict the amount of oil adhesion, using either computer models or adhesion theory, have not been successful. Under certain conditions, some oils adhere strongly to rocks; in other situations, the oil is often easily removed by tidal action. Moisture seems to be important, as wet rock is less prone to oil adhesion, and rock coated with a microbial film seems to be resistant to adhesion. The amount and strength of adhesion seem to depend on the oil type, with heavier oils or weathered oils being more adhesive than light oils.

Heavy oil on shorelines may spread and increase in area due to surface heating from solar radiation.

## Sedimentation

### *Asphalt Pavements on Shorelines*

Asphalt pavements form when oil penetrates porous sediments (sand, grave, shell, or mixtures of these), filling the pore spaces between the sediments with oil. A minimum amount of oil (estimated to be 10-20 percent by volume) is required to create asphalt pavements, though the "oil" that fills the pores can be emulsified oil, containing up to 60-80 percent water. The oil has to be relatively viscous and adhesive so that it plugs the pore spaces; otherwise, the oil continues to penetrate to the point that the oil concentrations are too low to form pavements. Surface pavements are most likely for viscous black oils because they form a heavy surface layer. They usually occur in the mid-to-upper intertidal zone, where the water table is lowered below the sediment surface at low tide, allowing oil to penetrate the drained sediments. They persist where wave energy is low or episodic, such as oil stranded during storms high above the normal zone of reworking by waves, or on sheltered gravel beaches. The oil forms a hard, weathered skin or crust, which tends to slow weathering of the oil inside the pavement. This process was well-documented for pavements formed during the 1974 *Metula* spill in the Strait of Magellan. Surveys conducted 12.5 years later reported fresh oil inside of hardened pavements 10-15 cm thick (Owens, *et al.*, 1987).

Surface pavement can be buried by the deposition of clean sediments on top, which further slows weathering processes. Pavements can also form in subsurface sediments, though this is not common. Subsurface pavements usually form where there is a change in sediment grain size with depth. That is, the oil penetrates to a finer-grained layer where it accumulates at concentrations high enough to form pavements.

*Tarmats in Nearshore Subtidal Habitats*

Tarmats are thick (>2-3 cm) accumulations of oil-sediment mixtures which form when oil strands onshore, picks up sand or broken shell, and then erodes from the beach and deposits in nearshore areas. They can also form without the oil stranding onshore, where the oil mixes with sand suspended by nearshore breaking waves. In both cases, a buoyant oil becomes heavier than seawater by picking up only a few percent sand or shell. Key factors which lead to formation of subtidal tarmats from intertidal oil are: 1) heavy accumulations of a highly viscous oil which does not penetrate the sediment after stranding onshore, but picks up some sediment by adhesion; 2) moderate wave energy which erodes the oil in large pieces (very high wave energy would break up the oil into too small pieces; low wave energy would lead to asphalt pavement formation onshore); and 3) troughs between offshore bars or other depressions in the near subtidal zone where the heavy oil/sediment mixture can accumulate into thick mats. Classic examples of tarmat formation were the *Ixtoc* I oil after it stranded in Texas and the *Alvenus* spill of heavy Venezuela crude which stranded near Galveston (Michel and Galt, 1995). Tarmats are soft but stiff, and they weather very slowly.

## 2.2 EFFECTS OF OIL ON MARINE ECOSYSTEMS

This section describes the diversity and basic functions of marine life and ecosystems, the effects of oil on them, environmental sensitivity, and post-spill recovery.

### OVERVIEW OF MARINE ECOSYSTEMS

During a spill response, the news media often show video of an oiled bird or marine mammal to capture the public's attention. In reality, such portrayals fall far short of the actual complexity and diversity of marine life that must be considered in an effective spill response. We must also be conscious of what is not easily seen: the small species of seaweed, worms, slugs, snails, and microbes that contribute greatly to marine biodiversity and provide the basic building blocks of marine food webs.

### *Organization of Marine Ecosystems*

Life in the sea and on shore is concentrated in many different habitats and zones, each of which poses unique challenges for responders, as detailed below and in Chapter 5. The broad categories of habitats include the sea surface, the water column, the nearshore and deep water sea floor, and the intertidal shoreline.

**Life on the Surface (Neuston)**

The first environment affected by a marine oil spill is the sea surface.

- Birds, mammals, turtles, and many kinds of fish and invertebrates live and/or concentrate at the sea surface, putting them at high risk.
- For short periods of the year (days, weeks) the eggs, larvae, and juveniles of fish, crab, and many other species congregate at the surface, together with high concentrations of bacteria and phytoplankton (single-celled plants).

Life at the surface is not evenly distributed, but occurs in concentrations and patches created by the same ocean processes that disperse and concentrate oil. For example, convergence zones near headlands serve not only to concentrate oil, but also the eggs and larvae of various fish and invertebrates.

**Life in the Water (Nekton and Plankton)**

Pelagic (free-swimming) fish, squid, and krill live throughout the water column, but are more abundant nearshore and are most often concentrated as schools, shoals, and patches.

- The water column has "life-zones" at various depths, with different mixes of species in each; however, many species undergo vertical migrations, rising at night and descending in the day, a fact that might be of concern during oil dispersion; and
- The drifting life – plankton – includes not only short-lived plants (phytoplankton) that remain small and microscopic, but also the eggs and larvae of both pelagic and nearshore fish and invertebrates.

<u>Life on the Bottom (Deep Water and Shallow Subtidal)</u>

- Much life in the sea is attached to, buried in, or lives just above, the bottom;
- A square meter of healthy, muddy sea floor can contain 5,000-10,000 small animals (1 mm-1 cm) including clams, snails, stars, shrimp, amphipods, ostracods, crabs, etc. These serve as prey for dozens of species of bottom-dwelling fish and many commercially-important species of crab, lobster, and shrimp;
- One cubic centimeter of marine mud or sand contains one to ten thousand bacteria of hundreds of species, dozens of which are capable of degrading alkanes and polycyclic aromatic hydrocarbons (PAHs); however, when sediment is oiled, the bacteria counts go up to one hundred thousand to ten million oil-degrading organisms per cubic centimeter;
- Generally, diversity (numbers of species) remains constant, but abundance decreases with water depth;
- In well-lit, shallower water nearshore (less than 100 m deep), long stretches of sandy or muddy bottom are often interspersed with cobble and rocky reefs, all home to a wide variety of conspicuous and inconspicuous marine plants and animals;
- Tropical barrier reefs are totally composed of, and built by, marine plants and animals (corals);
- Along temperate coasts, sediments harbor large populations of worms, crustaceans, and clams. These and their reproductive products provide food for a variety of sea stars, sea urchins, brittle stars, bottom fish, rays, sharks, squid, lobster, and other larger animals; and
- Rocky reefs are colonized by hundreds of species of attached animals (soft corals, barnacles), forests of kelp, and layers of seaweeds that provide expanded cover and protection for fish, crab, lobster, and shrimp.

<u>Life Between the Tides: Intertidal Communities</u>

- The intertidal shoreline offers a wide variety of densely-populated habitats, including bedrock, boulder-cobble, sand, mudflats, marshes, and other environments. Because these habitats vary in sensitivity to oil, the shoreline countermeasures described in Chapter 5 are tailored specifically to protect them and the types of plants and animals that live there;

- Intertidal mud- and sand-flats contain high densities of clams, oysters, crabs, urchins, and other shellfish; during low tide, a kilometer of beach can daily provide several tons of food to migrating and resident shorebirds;
- Several hundred species of seaweed, including kelp, grow on intertidal bedrock and rocky outcrops; during their brief lives (annuals and some perennials), they provide spawning habitat for some fish (herring) and refuge for the young of many nearshore and offshore fish and shellfish. In their senescence and death, seaweeds provide nutrients for complex detrital food chains nearshore and offshore;
- Mangrove forests extend seaward, protecting inshore, quiet waters that can include dense stands of marsh plants; and
- Intertidal shores are home to hundreds of species of shore and wading birds; beaches, mudflats, and marshes are areas of intense feeding and reproduction for many migratory species.

<u>Connections Between Them</u>

- Marine ecosystems are not isolated from one another, and most species depend on several ecosystems for survival, feeding, and reproduction;
- Some seaweeds, intertidal shellfish, or eggs of deepwater fish can briefly appear at the sea surface or offshore in the water column; and
- Many bottom-dwelling fish, shrimp, and crab make round-trips into the intertidal zone to feed or reproduce.

## *Marine Ecological Processes: Economy of Life in the Sea*

It is important that response activities are planned with due regard for the dynamics of life in marine environments since the public expects that affected areas will return to some norm following a spill and response. Volumes have been written about marine life processes, but only a few examples need be presented here to underscore the kinds of changes that take place.

Life in the water, on the seafloor, and on the shoreline is constantly changing as food supplies, reproductive products, and predators rise and fall with the tides, currents, and seasons. Only in a few specialized – and sensitive – environments such as coral reefs, kelp beds, and perhaps the deep sea itself, is there some semblance of permanence of structure, species, and individuals. Everywhere else, turnover and replacement are the norms.

<u>Food Webs and the Flux of Materials</u>

There are numerous physical and biological sources of inorganic and organic material in the sea and coastal zone.

- The initial input of food in the sea, in the form of microscopic dispersed particles (detritus, phytoplankton), restricts the nature of marine life: except for terrestrial expatriates – marine mammals and birds – all marine life begins and ends with microscopic forms;
- Runoff disgorges tons of silt, soil, and sand that create and build beaches, shorelines, and marshes. Delta ecosystems and wetlands are constantly changing and evolving, especially where river flow is relatively uncontrolled and subject to major year-to-year variations in flooding and drought;
- Organic compounds and inorganic nutrients seep from decaying vegetation and dead animals, as well as from nonbiological sources such as eroding land; and
- Phytoplankton, zooplankton, eggs, mucus, urine, feces, and detritus from decaying shoreline plant and animal material provide the bulk of dissolved and particulate organic material input to the sea.

**Primary Production: Bacteria and Plants**

- With a notable exception (hydrothermal vents), marine life starts and ends with plants – mainly single-celled phytoplankton and bacteria;
- Plants require sunlight, oxygen, major nutrients (nitrogen, phosphorous, potassium), and some minor trace elements (e.g., iron) to convert carbon dioxide to organic compounds (including hydrocarbons) and their own tissues;
- Production of marine life requires chemical building blocks (hydrogen, carbon, nitrogen, phosphorous), adequate oxygen and temperatures, and a variety of trace substances. If even one of these is limited, production will be limited, even when all the others are abundant or in excess. Thus, except in nearshore areas exposed to high inputs of nutrients, production in most areas is limited. Therefore, it would be unproductive to artificially enhance a building block that is not itself the limiting factor. In some situations, this is potentially the case for bioremediation; and
- There are many functional kinds of marine bacteria. Some are autotrophic, capable of self-nutrition. Other bacteria (and fungi) degrade organic material, and require nutrients, although not necessarily light.

**Secondary Production: Herbivores**

- Many animals are specialized to feed on marine plants, the next step in production of sea life;
- In open water, many species of copepods, isopods, and small forage fish capture or filter-feed on tiny phytoplankton, growing rapidly during the brief periods of bloom. Inshore, mollusks such as limpets, chitons, and some snails graze continuously on thin mats of benthic algae, keeping rock surfaces relatively free of slime growths. For example, the once-dense Chesapeake Bay

oyster population effectively filtered most of the phytoplankton, keeping the waters relatively clear; and

- Larger algae and vascular plants are less subject to consumption; and many seaweeds produce organic chemicals toxic to grazing fish and invertebrates.

<u>**Secondary Production: Detritivores and Carnivores**</u>

- *Food and Feeding*. Herbivorous animals (some types of zooplankton, forage fish, snails, and many clams) are prey for the more conspicuous species of invertebrates, fish, birds, and mammals of the sea and shore. To appreciate the magnitude of predation and feeding, Thorson (1976) describes how 30,000 overwintering Oyster Catchers (a wading bird) consumed 642 million cockles (a clam) from one British mud flat over a period of several weeks.;
- *Excretion*. Animals convert some of their food to energy and the rest is excreted in the form of fecal material, urine, mucus, and material such as skin molts. The nutrients and organic material from these excreta are recycled by the sea's bacteria, phytoplankton, and detritivores. One theory holds that urination by schools of forage fish provides centers of excess nutrients that re-stimulate discrete patches of production;
- *Growth*. Unlike most terrestrial animals and marine birds and mammals, most species of marine creatures continue growing (and, therefore, diluting incoming toxins), subject only to limiting factors of food supply, predation, and disease;
- *Reproduction*. Again, unlike their terrestrial counterparts, most marine creatures annually produce and disgorge much of their body weight as eggs, sperm, and other reproductive products, most of which is consumed and recycled near the beginning of the food web. These reproductive products, together with the excreta, are thrown back down the food web. Survivors owe their lives to protection from predation either through huge numbers or hiding;
- *Recruitment*. For most marine plants and animals, those that survive to adulthood represent one percent or less of the original eggs and larvae; the exceptions are the sea mammals and birds, where fewer young are produced with greater survival to adulthood. Successful recruitment is neither assured nor predictable: there are many populations of adult clams, shrimp, and fish composed of adults that came from only one or two "good" year classes per decade; and
- *Migration*. Unattached marine organisms can move considerable distances over various time scales. Plankton can be transported dozens or hundreds of miles in ocean currents, or become trapped in ocean and coastal eddies and gyres. Many bottom and demersal (near-bottom) fish and macro-invertebrates (shrimp, crab, lobster) undergo seasonal inshore-offshore, round-trip migrations. Tropical fish, transported north by the Gulf Stream, are common off New York in the summer, but may not survive falling

temperatures. Salmon are classic migratory fishes, entering the coastal zone as "smolts" in the winter or spring, then migrating in large loops around the North Pacific or North Atlantic, returning to natal streams one, two, three, or four years later (depending on species and stock). Offshore, many species of deep sea fish and crustaceans rise to the surface at night and return to the depths by daylight. The longest migration paths are made by sea turtles, marine and shore birds, whales, and seals and sea lions. Arrival dates at specific locations are often very precise and predictable.

Given these and many other dynamic processes, responders, resource trustees, and the public must be alert to sudden appearances, as well as disappearances, of marine organisms and must not presume that a response or restoration will return things to the way they were just prior to a spill.

## EFFECTS OF OIL ON MARINE LIFE

Although oil affects marine organisms in many ways, there are some very predictable impacts. Following are the effects of most concern.

### *Coating and Smothering*

Adhesive, viscous oils can coat and smother organisms that come into direct contact with it. Species that penetrate the water surface to breathe, feed, or rest are at particularly high risk of direct exposure. Sea birds and fur-bearing marine mammals are especially vulnerable because feathers and fur absorb oil, interfering with buoyancy, locomotion, and insulation. Oil ingested during preening can cause death directly from acute toxicity, or indirectly from starvation, pneumonia, and internal injury. Contamination of fur and feathers can cause drowning and hypothermia. Oiled birds returning to nests can contaminate eggs, which may be highly sensitive to even very small quantities of fresh oil.

Oil stranded on shorelines can coat vegetation, smother clam and other shellfish beds, and penetrate gravel, cobble, and sand beaches, possibly resulting in prolonged exposure and death of sediment-dwelling organisms. Heavier oils can form highly persistent pavements that alter shoreline habitats.

### *Toxicity*

At high enough concentrations, with long enough exposure, many of the soluble chemicals in oil can cause adverse effects (kill, injure, or narcotize) to small marine animals and plants. Soluble components – including benzene, toluene, and naphthalenes – are highly toxic but not very persistent, and can be quickly diluted in areas of strong currents and wave action (or may accumulate for longer periods in areas of poor circulation and flushing). Exposure for several days to concentrations as low as a few parts per million can cause adverse effects in many small plants and animals in the water column. Conversely, dispersant use on slicks in the open sea can result in lethal concentrations only in the upper few meters of the water and for much shorter periods (minutes to hours).

Toxicity of various compounds in oil is determined by exposing small plants and animals to a range of concentrations in laboratory experiments. Numerous studies show that refined fuels are generally more toxic (due to their relatively higher aromatic content) than crude oils.

### *Carcinogenicity and Mutagenicity*

Oil contains compounds that can cause cancer (carcinogenicity) and mutations (mutagenicity) in marine organisms at high enough concentrations and long enough exposure times. These processes are extremely complex and their occurrences depend on many variables. In birds, mammals, fish, and a few other animals, these disorders result after long-term (weeks, months) exposure to polycyclic aromatic hydrocarbons (PAHs), generally taken in via ingestion of contaminated food. Bacteria, in contrast, multiply so fast (several times a day) that they can experience mutations in a few hours, and are often used to monitor the presence of mutagens and carcinogens in environmental samples.

### *Bioaccumulation*

Marine organisms can bioaccumulate high concentrations of some pollutants in their tissues, and can also purge pollutants when returned to clean water. Dissolved aromatic oil compounds, such as naphthalenes, are primarily absorbed through skin and gills, whereas heavier compounds, such as the carcinogenic PAH benzo(a)pyrene, are mainly accumulated through feeding. Regardless of the method of accumulation, such contaminants may cause adverse effects either to the organism itself or to its consumers and predators, including people. Oil can also temporarily taint – cause an off-odor or off-flavor – fish and shellfish. The specific compounds responsible for tainting are not completely known, though sulfur-containing compounds are considered to be among this group. It is not clear whether tainting compounds are also toxic.

Some pollutants (mercury, DDT) biomagnify – increase in concentration up the food web from prey to predators. Petroleum hydrocarbons, especially the PAHs, do not biomagnify because they are broken down (metabolized) in higher organisms such as mammals, birds, fish, and some crustaceans, and the resulting metabolites are excreted via the bile. In fact, once exposure ceases, most animals completely lose petroleum hydrocarbon contamination through depuration. Tainting chemicals and smaller aromatic compounds (naphthalene) are readily metabolized and eliminated from live fish once they spend time in clean (contaminant-free) water. PAHs accumulated by shellfish (mussels and oysters) are also readily lost, with half-lives on the order of several days to a few weeks, depending on the species, its fat content, and the level of exposure to hydrocarbon accumulated.

Thus, when a marine ecosystem is contaminated by oil mixed into the water column, exposed species can experience short-term (hours, days) contamination by low molecular-weight aromatic and tainting compounds. Fish and other vertebrates will rapidly eliminate petroleum hydrocarbons, taking somewhat longer in invertebrate species low in the food web (plankton, shellfish), but petroleum hydrocarbon contamination will not biomagnify through the food chain. The fate of petroleum hydrocarbons in marine food webs, then, is basically the reverse of what happens to highly bioaccumulative pollutants, such as mercury and DDT, which persist and biomagnify.

## Post-Spill Recovery

Marine ecosystems are dynamic, constantly changing in response to such influences as major climatological events. For example, alternating periods of flood and drought alter the supply of sediment, fresh water, and nutrients to coastal and estuarine systems, influencing habitats such as marshes and mangroves and their associated flora and fauna. On the western coast of the United States, El Niño/Southern Oscillation events can cause fluctuations in the abundance and distribution of seaweed, fish, shellfish, and other marine species over thousands of miles. These changes can, in turn, affect populations of predator species, such as sea birds. Against such a background of natural change, returning marine systems affected by oil spills to pre-existing conditions may not be possible.

The expectation following an oil spill response is that injured habitats and populations will "recover," implying a return to conditions the way they were before a spill. But "recovery" has different meanings to different people. Some consider a site recovered when all the oil is gone. Others may consider a site recovered when all species have returned to their former abundance. Still others acknowledge the variability in natural communities: recovery is complete when ecological conditions have returned to those within the normal range of variation.

### *Loss of Oil and Toxicity*

The process of recovery is complex, difficult to define, and occurs over variable time frames. The rate at which oil is lost from a system and the rates of biological recovery are not necessarily the same nor even related. For example, oil remaining in shorelines following response activities may rapidly lose its toxicity in days, whereas biological recovery may take months to years. Several research studies have documented how long it takes for untreated oil to disappear naturally and become non-toxic. One of the most recent, involving an intentional release of light crude oil on a sandy beach in Delaware, was conducted in the summer of 1994. The oil initially was very toxic to several species, but began to lose its toxicity within two weeks; after 14 weeks one-tenth of the initial oil remained, and it was not toxic to four of five test species. In the absence of treatment, half the remaining oil was lost every 28 days, mostly due to washout from wave and tidal action, and natural biodegradation processes produced an even faster loss of toxic compounds such as PAHs. In comparison, about half of the oil spilled by the *Exxon Valdez* in the spring of 1989 was removed or treated; the rest underwent dispersion, biodegradation, or was buried deep in shoreline substrates. However, shoreline toxicity from the *Exxon Valdez* spill occurred only during the first few months of the spill: toxicity and mutagenicity decreased rapidly during the first summer and disappeared completely between the first and second summers after the spill.

Another factor affecting spill recovery is background contamination. Low-level petroleum hydrocarbon contamination is ubiquitous in many coastal areas; although some is due to past spills, the majority of existing contamination in the US coastal sediments and shellfish is from other sources, mainly combustion and runoff. In some areas, natural oil and gas seeps are sources of contamination. Sediments, water, and shellfish in many urbanized areas contain PAHs up to several hundred times background levels. Consequently, when a spill occurs in populated areas, responders will need background contamination information.

### *Biological Recovery*

When life in a marine environment is decimated by a toxic spill, intrusive cleanup, or a natural "disaster," it does not long remain barren. The area will be initially re-colonized by opportunistic species and then, over periods of months to years, the newly-developing community will undergo a somewhat predictable succession of species of plants and animals. Biota that survive oiling aid in the oil removal and subsequent recovery process. For example, surviving motile animals like snails and limpets may loosen thin layers of weathered oil as they move in and resume feeding on freshly-attached algal mats that grow within the first year following a spill. Plant seedlings may germinate, forming new root systems that aerate soils and promote biodegradation. On substrate surfaces laid bare by oiling or high-impact cleanup techniques, new planktonic larvae will settle, attach, and begin growing.

## 2.3 STRATEGIES FOR SELECTING RESPONSE METHODS

During emergency response operations, available information may be highly uncertain and fragmented at best, as will forecasts of environmental conditions or evaluations of response equipment needs. Nonetheless, the response community must sort out what is actually known about the spill, and select and deploy equipment as soon and as effectively as possible. What information is needed to help guide the response? What can be done to promote any gains in environmental protection?

Because the goal of oil spill response is to minimize the overall impacts on natural and economic resources, some resources will be of greater concern than others, and response options offering different degrees of resource protection will be selected accordingly. Decisions regarding cleanup method(s) must balance two factors: 1) the potential environmental impacts with the no-action alternative, and 2) the potential environmental impacts associated with a response method or group of methods. The first factor incorporates an evaluation of:

- Spilled and/or weathered oil toxicity; and
- Organisms which may be exposed to oil.

The second factor considers the potential impact(s) and benefits associated with each of the various cleanup techniques.

Potential impacts can be determined prior to considering the need for, or type of, response strategies. For example, evaluating a gasoline spill in an exposed seawall environment might lead to the conclusion that, due to environmental fate processes (i.e., evaporation) and low habitat use, minimal environmental effects will occur and further evaluation is unwarranted. On the other hand, assessing a spill of a middle-weight crude oil in a soft intertidal area would likely indicate a high potential for environmental effects; therefore, response methods would need to be evaluated.

The decisions to select response methods should consider the potential of each possible method for reducing the environmental consequences of the spill and the response (including a natural recovery alternative). The method, or combination of methods, that most reduces consequences effectively, should be the preferred response strategy. A method that increases impacts in the short term can be the preferred alternative if the time for recovery is accelerated. In Figure 1, this situation is illustrated by the curve representing response method 1. Among the idealized impact/recovery curves that Figure 1 illustrates, methods 1 and 2 reduce the overall environmental consequences in comparison to no cleanup. Method 3 would have greater environmental consequences than the other methods. In many situations, method 3 would not be chosen for environmental reasons. Recovery cannot be defined as pre-spill conditions since natural changes in biological communities will introduce variability to organisms affected by the spill.

The environmental consequences of a spill and the response will depend on the specific spill conditions, such as the type and amount of oil, weather conditions, and effectiveness of the response methods. It is imperative that planners and responders discuss and develop resource protection priorities during contingency planning so that valuable time is not lost during an actual response.

## SETTING PRIORITIES: ENVIRONMENTAL VULNERABILITY

Environmental vulnerability is only loosely defined in most people's minds, and significant misunderstandings can result when various participants in the oil spill planning and response process have very different ideas about what this concept means. If rational and justifiable environmental response decisions are to be made, the concept must be accurately defined.

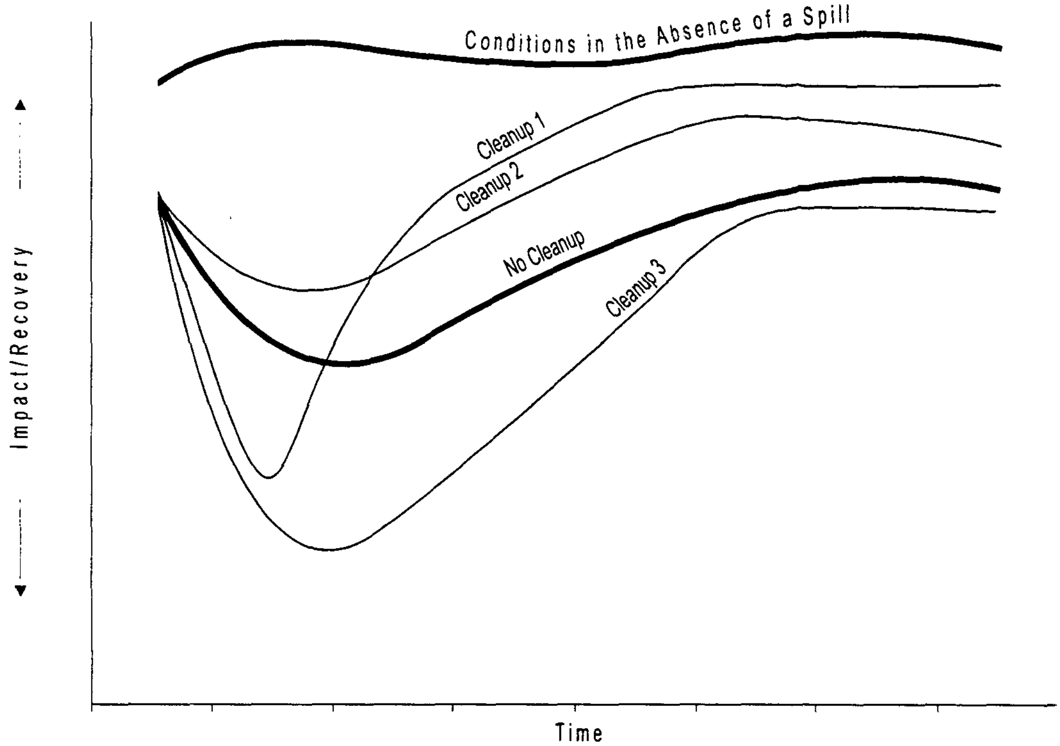


**Figure 1.** A comparison of the environmental consequences of three different response methods, plus natural recovery, on a single spill over time.

The difficulty of weighing many environmental and economic priorities has led some planners to create indices based on quantitative measures of environmental consequences, the purpose of which is to simplify decision-making in emergency situations. However, these indices, where economic and environmental factors are mixed, are often not useful because a common currency is not available for comparing economic and environmental consequences. Economic damage is relatively easily measured: dollar value is an adequate yardstick. Environmental injury often cannot be so easily quantified nor effectively ranked against economic injury, although attempts have been made to do so by assigning dollar values to environmental components.

The vulnerability of an environmental component to oil spills and response can be evaluated by asking:

- How likely is it to encounter oil?
- To what extent will it be affected if it does encounter oil?
- What proportion of a regional, national, or world stock will be affected?

- How long will it take for the population/community to recover?
- Is it part of a regional or national resource identified for conservation (e.g., national park)?

Assuming that the environmental component will encounter, and be affected by, oil, perhaps the most important question to ask is, "How long will it take for regeneration or recovery?" Time to recovery can serve as the equivalent of the dollar value of economic injury as a yardstick by which we can scale environmental sensitivities.

A beach coated with oil in the aftermath of an oil spill is a powerful and distressing image, and we tend to forget how rapidly most shorelines can regenerate. If the cleanup is done with care and sensitivity, within time, ecological integrity and human use of the shoreline can be fully restored, and the injury of a spill, particularly if it has been properly cleaned, can be difficult to detect. Most shorelines, no matter how bad the apparent damage by oil coating, will recover with repopulation by invertebrates and marine plants from adjacent areas. Cleanup and regeneration of even more highly complex shorelines such as salt marshes and mangroves can be accomplished, though the times required for regeneration are long enough to flag these habitat types as priorities for protection.

A marine spill of a highly toxic petroleum might destroy the phytoplankton and zooplankton in the surface waters of the few square miles it covers. Yet only a minuscule proportion of the ocean's planktonic biomass would be injured in even the largest oil spill. Recovery would be rapid, and no long-term population effects would be anticipated. This is because of the capacity for nearby populations to provide sources of organisms. Even fish are largely invulnerable: only a small portion of a regional population is likely to be affected, and regeneration times would be rapid. Significant loss can be suffered by aquaculturists if captive fish are tainted by exposure to oil, but this is an economic, rather than a biological, impact.

Species that already have negative population trajectories, often those with a "Threatened" or "Endangered" designation, might not regenerate at all unless concerted, and often expensive, rehabilitation efforts are made. In the marine environment, use of the time-for-population-recovery criterion will allow us to rapidly identify those environmental components requiring priority protection. Often, species near the top of the marine food chain, marine birds and mammals, will be the species with the longest times to population recovery.

Within the marine bird community, population criteria allow us to make difficult protection decisions. Coastal bird species that are vulnerable to oil, such as cormorants, Common Eiders, or Black Ducks, all breed at a relatively young age and produce clutches of four or more eggs each year. In contrast, pelagic birds, such as Atlantic Puffins, Common Murres, or Northern Gannets, have a delayed sexual maturity and produce only a single egg each year. Obviously, populations of pelagic birds require much longer times to population recovery and, all things being equal, will merit more strenuous protection efforts.

Population recovery criteria identify the ecological vulnerability of pelagic realm and of pelagic seabird populations. This objective assessment demonstrates the need to rethink traditional response philosophies which can be paraphrased as "oil out to sea is good, oil on the shore is bad." Indeed, oil which drifts out to sea might result in fewer shoreline cleanup problems, but more serious environmental impact. Oil out of sight should not be oil out of mind.

There are situations in which even a small amount of oil may have a major environmental impact, or others where a major spill, an apparent disaster, has few long-term consequences. The vulnerability of a particular habitat or region is defined by the most vulnerable environmental component. However, many of the most vulnerable environmental components are migratory species which will not be present in a particular habitat at all times. Response criteria must be considered to be time-dependent. Knowledge of the numbers and movements of the most vulnerable species is a prerequisite to an accurate assessment of regional vulnerability.

The same consideration of vulnerability to oil must be applied to operations to remove oil, or to set priorities for oil exclusion. Decisions on techniques used must give first consideration not only to aesthetics and human use of the area, but to restoration of natural ecosystems in the shortest possible times. Areas given priority for protection should be those in which oiling and cleaning could cause the most environmental injury; that is, those that will take the longest time to recover to a normal condition. Human use and aesthetics will, of course, be valid considerations in priority-setting but, if cleanup decisions are to be rational, they must be clearly balanced against environmental considerations.

# CHAPTER 3.0
# SUMMARY OF SPILL RESPONSE METHODS

This chapter describes methods currently in use during response to oil spills in marine environments and habitats. Information is first presented on the relative environmental impacts of each method in the absence of oil in each habitat under consideration (Section 3.1). Following this discussion, each method is described separately (Section 3.2).

The objectives of each method used in the protection, recovery, and cleanup phases of a response include:

- Protection – keep oil out of a habitat or reduce the amount that enters;
- Recovery – remove floating oil from the water surface; and
- Cleanup – remove stranded oil from shoreline habitats using physical, chemical, and enhanced biological means.

In most spill response situations, protection and oil recovery are the immediate goals. Combinations of protection, recovery, and cleanup are commonly used simultaneously, though these guidelines treat each method separately.

## 3.1 IMPACT OF METHODS IN THE ABSENCE OF OIL

The *relative impact* of each technique (assuming the absence of oil) was evaluated regarding likely physical disturbances resulting from mechanical methods (e.g., sediment reworking/tilling in a salt marsh would cause an adverse impact even in the absence of oil) and environmental impacts from chemical and biological methods. Tables 3 and 4 show that some response techniques have environmental impacts, but in the presence of oil they may be an appropriate response option. It is important not only to demonstrate the likely physical disturbance, but also to provide baseline information so that environmental impacts caused by response methods in oiled habitats can more accurately be predicted.

Although impacts from individual products and equipment types vary, the information provided (in the absence of oil) addresses generic characteristics of the response techniques and does not consider those variations. Additional

**Table 3.** Relative impacts of response methods in the **ABSENCE OF OIL** in on-water and shallow subtidal environments (<30 ft/10 m). *These response options may be appropriate in the presence of oil* (see Chapter 5 for details)

| | On-Water | | Shallow Subtidal | | | | |
|---|---|---|---|---|---|---|---|
| Response Method | Offshore and Deep Nearshore | Bays and Estuaries | Coral Reefs | Seagrasses | Kelp | Soft Bottom | Mixed and Hard Bottom |
| Natural Recovery | A | A | A | A | A | A | A |
| Booming | B | B | C | B | B | A | A |
| Skimming | B | B | B | B | B | A | A |
| Barriers/Berms | – | – | – | – | – | – | – |
| Physical Herding | B | B | B | B | B | B | B |
| Manual Oil Removal/Cleaning | – | B | D | C | B | B | C |
| Mechanical Oil Removal | – | – | D | D | D | C | – |
| Sorbents | B | B | D | B | B | B | C |
| Vacuum | – | – | C | C | B | B | C |
| Debris Removal | B | B | B | B | B | B | B |
| Sediment Reworking/Tilling | – | – | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | – | B | C | – | – |
| Flooding | – | – | – | – | – | – | – |
| Low-pressure, Ambient-Water Flushing | – | – | B | – | – | – | – |
| High-pressure, Ambient-Water Flushing | – | – | – | – | – | – | – |
| Low-pressure, Hot-Water Flushing | – | – | – | – | – | – | – |
| High-pressure, Hot-Water Flushing | – | – | – | – | – | – | – |
| Steam Cleaning | – | – | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – | – | – |
| Dispersants | B | B | D | D | D | D | C |
| Emulsion-Treating Agents | B | B | I | I | I | I | I |
| Elasticity Modifiers | B | B | I | I | I | I | I |
| Herding Agents | B | B | I | I | I | I | I |
| Solidifiers | B | B | I | I | I | I | I |
| Surface Washing Agents | – | – | – | – | – | – | – |
| Nutrient Enrichment | – | – | – | – | – | – | – |
| Natural Microbe Seeding | – | – | – | – | – | – | – |
| In-Situ Burning | B | B | B | B | B | B | B |

A=may cause the least adverse impact; B=may cause some adverse habitat impact;
C=may cause significant adverse habitat impact; D=may cause the most adverse habitat impact;
I=incomplete information; – = not applicable for this habitat type

**Table 4.** Relative impacts of response methods in the **ABSENCE OF OIL** in shoreline intertidal and ice environments.
These response options may be appropriate in the presence of oil (see Chapter 5 for details).

| | Shoreline Intertidal | | | | | | | | | | | | | | | | Ice | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Response Method** | **Exposed Rocky Shores** | **Exposed Solid Man-made Structures** | **Exposed Wave-cut Platforms** | **Sand Beaches*** | **Tundra Cliffs** | **Mixed Sand and Gravel Beaches*** | **Gravel Beaches** | **Riprap** | **Exposed Tidal Flats** | **Sheltered Rocky Shores** | **Sheltered Solid Man-made** | **Peat Shores** | **Sheltered Tidal Flats** | **Marshes** | **Mangroves** | **Inundated Lowland Tundra** | **Accessible Ice** | **Inaccessible Ice** |
| **Natural Recovery** | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| **Booming** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | – |
| **Skimming** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | B |
| **Barriers/Berms** | – | – | – | B | D | B | C | – | C | – | – | – | C | C | C | – | B | – |
| **Physical Herding** | – | – | – | – | – | – | – | – | B | – | – | – | – | – | – | – | B | B |
| **Manual Oil Removal/Cleaning** | B | B | B | B | D | B | B | A | C | B | B | B | D | D | C | D | B | – |
| **Mechanical Oil Removal** | – | – | – | C | D | C | C | C | D | – | – | D | – | D | – | D | B | B |
| **Sorbents** | B | B | B | B | C | B | B | A | B | B | A | B | B | C | C | C | B | B |
| **Vacuum** | B | – | B | B | D | B | B | A | B | B | – | B | B | C | C | D | B | B |
| **Debris Removal** | B | – | B | B | A | B | B | A | B | B | A | B | C | C | C | D | B | B |
| **Sediment Reworking/Tilling** | – | – | – | C | D | C | C | – | D | – | – | B | – | D | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | C | D | C | – | – | D | D | – | C | D | D | – | D | – | – |
| **Flooding** | – | – | B | B | C | B | B | B | B | B | – | B | B | B | B | C | – | – |
| **Low-pressure, Ambient-Water Flushing** | B | B | B | B | D | B | B | B | C | B | B | B | C | B | B | D | B | B |
| **High-pressure, Ambient-Water Flushing** | C | C | C | – | – | C | C | C | – | C | C | – | – | – | – | – | – | – |
| **Low-pressure, Hot-Water Flushing** | D | D | D | D | – | D | D | D | – | D | D | – | – | – | – | – | B | B |
| **High-pressure, Hot-Water Flushing** | D | D | D | – | – | D | D | D | – | D | D | – | – | – | – | – | – | – |
| **Steam Cleaning** | D | D | D | – | – | D | D | D | – | D | D | – | – | – | – | – | B | B |
| **Sand Blasting** | D | D | D | – | – | – | – | D | – | D | D | – | – | – | – | – | – | – |
| **Dispersants** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | B |
| **Emulsion-Treating Agents** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | B |
| **Elasticity Modifiers** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | B |
| **Herding Agents** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | B | – |
| **Solidifiers** | – | – | B | B | C | B | B | B | B | B | – | – | B | C | C | C | B | B |
| **Surface Washing Agents** | B | B | B | – | – | C | B | B | – | B | B | – | – | B | I | – | – | – |
| **Nutrient Enrichment** | – | – | – | B | C | B | B | B | I | B | I | B | I | B | I | I | I | I |
| **Natural Microbe Seeding** | – | – | – | I | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| **In-Situ Burning** | – | – | D | C | – | C | C | D | – | D | – | – | – | C | – | D | B | B |

* = special biological need consideration – if birds and turtles are nesting, the ranking would be "D".
A=may cause the least adverse impact; B=may cause some adverse habitat impact; C=may cause significant adverse habitat impact; D=may cause the most adverse habitat impact; I=incomplete information; – = not applicable for this habitat type

information on environmental impacts is provided in the discussions of each technique later in this chapter.

## 3.2 APPROACH USED IN THE EVALUATION OF METHODS

### CLASSIFICATION OF OIL RESPONSE IMPACTS

The classifications developed for this guide compare the relative environmental impact of specific response methods for a given environment or habitat and oil type. Please note that the methods were compared among themselves, and no one method was used as a standard. Selection of a response method for a specific incident should be based on an evaluation of the benefits and consequences using available data at the time of the spill (see discussion in Section 2.3).

The classification categories are defined as follows:

| | |
|---|---|
| **A** | May cause the least adverse habitat impact |
| **B** | May cause some adverse habitat impact |
| **C** | May cause significant adverse habitat impact |
| **D** | May cause the most adverse habitat impact |
| **I** | Insufficient Information – impacts or effectiveness of the method could not be evaluated |
| **–** | Not applicable. |

These categories represent a gradient of adverse habitat impacts and are not discrete categories. The number of categories is based on the ability to discern differences among degrees of relative impacts along a continuum from least to most impact.

## EVALUATION OF RELATIVE IMPACT OF METHODS

The impact of each response method was evaluated independently for each habitat. In an actual response, however, the methods cannot be evaluated in isolation from each other. Specific spill conditions often will dictate the need for different techniques to be used in the same habitat. For example, a high degree of oiling or low natural removal processes may require a more intrusive technique to accelerate recovery. Even though a method is appropriate for a specific habitat, it may not be a viable option if an adjacent sensitive habitat could be secondarily impacted. This document considers how the type and quantity of wastes generated from a given cleanup method will affect its use as an appropriate method for removing oil from a particular habitat. Each cleanup option should be examined with the problem of waste generation and disposal in mind.

## INTEGRATING RESPONSE METHODS

This document acknowledges that multiple response methods are sometimes used throughout the spill event. Response methods are sometimes used sequentially, that is, on-water recovery generally occurs before shoreline cleanup. Also, certain methods may be employed early during a spill while waiting for equipment or materials to arrive or teams to be trained in use of another technique.

## PROPER APPLICATION OF METHODS

This document is predicated on proper application of various response methods by trained personnel. For example, if booms are recommended, these guidelines assume that the booms will be effectively located and correctly deployed. Improper application of almost any technique can render it ineffective or cause additional damage. In cases where instruction for using a protection or cleanup method may be habitat-specific, see Chapter 3.

## INTERPRETING THE TABLES

This document focuses on assessing the environmental impacts of spill response methods, and not on determining their effectiveness. However, since response method effectiveness is critical in determining the net impact of the spill and the response, effectiveness is not ignored. This document provides guidance in weighing impact against effectiveness. It assumes that an appropriate mix of environmental and operational expertise will be available to assess tradeoffs during spill response planning and, especially, during actual response operations. Response-method effectiveness was incorporated in the following three ways:

- First, types of response methods listed along the left hand column in the tables vary among the different groups of environments, e.g., on-water, shallow subtidal, shorelines, and ice. Some response methods are either ineffective or not applicable for that environment and, therefore, are not listed in the tables for that environment. For example, barriers/berms are not listed in the on-water matrices because it would not be feasible to use them there; nor are booms listed in the shoreline matrices because they are only used on-water and, therefore, they would not be applicable nor effective in those environments;
- Second, some methods (e.g., flooding) are feasible to use in certain habitats (e.g., sand beaches) within an environment but not in others (e.g., rocky shores) within that same environment. Where it is not feasible, a dash (–) is used all the way across the table, for every oil category; and
- Third, some methods are feasible and appropriate but may not be as effective for certain oil categories. The rating classification reflects this lower effectiveness, and the accompanying text provides an explanation on the rating. For example, low-pressure, ambient temperature flushing is given a lower rating for Category 5 oil compared with Categories 3 and 4 in all shoreline habitats because it is less effective in removing the oil. The adjacent text indicates how these ratings may change depending upon incident-specific conditions.

## RESTRICTIONS FOR USING RESPONSE METHODS

Restrictions related to safety, weather, spill size, or government regulations, among others, cover a wide spectrum of scenarios. It is impractical to discuss every possible situation or combination of factors which affects the feasibility of using these methods. Some of this information is included in the descriptions of each method (Section 3.3), in developing strategies for response (Chapter 4), or under each habitat (Chapter 5). Other considerations, such as aesthetic, social, and economic impacts, should be considered when making spill-specific response decisions, but are excluded from this relative assessment of environmental impacts. Specific safety issues regarding Category I products are reflected in the tables because of the increased degree of hazard from response. Safety must be a priority in the use of any response technique. Reliability of the ratings is less for countermeasures for which there is little operational experience, such as *in-situ* burning and Chemical

Countermeasure Products (CCPs)[1] other than dispersants. Readers are cautioned that using chemical, nutrient (to enhance biodegradation), and *in-situ* burning methods will require approvals from local, state, and/or Federal regulatory agencies.

## 3.3 RESPONSE TECHNIQUES

### INTRODUCTION

This section describes the most commonly-used techniques. For each, the following section includes a summary of:

- Objectives;
- General descriptions;
- Applicable habitat types preferred;
- Conditions for use (i.e., constraints commonly applied to protect sensitive biological resources);
- Environmental effects expected from proper use; and
- Waste generation.

Some of the methods listed require special government authorization for use during a spill. There are variations of the methods which have been used under specific spill conditions and some alternate technologies are rapidly evolving. Tables reflect the state of technology at the time of publication. Consideration of evolving techniques should occur during response planning.

The order of presentation for the response techniques is the same as their order in Tables 3 and 4.

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[1] Seven CCP categories (in addition to dispersants and bioremediation agents) were identified by Walker *et al.* (1993), including: herding agents, emulsion-treating agents, solidifiers, elasticity modifiers, shoreline cleaning agents, shoreline pre-treatment agents, and oxidation agents. This list of CCP categories available for use in the US has been further refined to include alternative sorbents and fire fighting foams (Walker *et al.*, 1999). **Note**: The category for Shoreline Cleaning Agents has been renamed "Surface Washing Agents" on the NCP Product Schedule; herding agents are presently referred to as "Surface Collecting Agents".

## Natural Recovery

### *Objective*

No attempt to remove any stranded oil in order to minimize impacts to the environment, or because there is no effective method for cleanup. Oil is left in place to degrade naturally.

### *Description*

No action is taken, although monitoring of contaminated areas may be required.

### *Applicable Habitat Types*

All habitat types.

### *When to Use*

When natural removal rates are fast (e.g., gasoline evaporation, high energy coastlines), when the degree of oiling is light, or when cleanup actions will do more harm than natural removal.

### *Biological Constraints*

This method may be inappropriate for areas used by high numbers of mobile animals (birds, marine mammals) or endangered species.

### *Environmental Effects*

Same as from the oil alone.

### *Waste Generation*

None.

## Booming

### *Objective*

To prevent oil from contacting resources at risk, and to facilitate oil removal.

### *Description*

A boom is specially designed for pollution response that is a floating, physical barrier, placed on the water to contain, divert, deflect, or exclude oil. *Containment* is deploying a boom to contain and concentrate the oil until it can be removed. *Deflection* is moving oil away from sensitive areas. *Diversion* is moving oil toward recovery sites that have slower flow, better access, etc. *Exclusion* is placing boom to prevent oil from reaching sensitive areas. Booms must be properly deployed and maintained, including removing accumulated debris.

### *Applicable Habitat Types*

Can be used on all water environments (weather permitting). Booms begin to fail by entrainment when the effective current or towing speed exceeds 0.7 knots perpendicular to the boom. Waves, wind, debris, and ice contribute to boom failure.

### *When to Use*

When preventing oil from contacting sensitive resources is important. Most responses to spills on water involve deploying boom to assist in removing floating oil. Containment booming of gasoline spills is usually not attempted, because of fire, explosion, and inhalation hazards. However, when public health is at risk, gasoline can be boomed if foam is applied and extreme safety procedures are used.

### *Biological Constraints*

Placing and maintaining boom and anchoring points should not cause excessive physical disruption to the environment, and both must be maintained so they do not fail or tangle and cause more damage. Vehicle and foot traffic to and from boom sites should not disturb wildlife unreasonably, and booms in very shallow water should be monitored so they do not trap wildlife (such as migrating turtles returning to sea or fish coming in at high tide).

### *Environmental Effects*

Minimal, if disturbance during deployment and maintenance is controlled.

### *Waste Generation*

Cleaning booms will generate contaminated wastewater that must be collected, treated, and disposed of appropriately. Discarded booms will need to be disposed of according to appropriate waste disposal regulations.

## SKIMMING

### *Objective*

To recover floating oil from the water surface using mechanized equipment. This includes specifically-designed pollution equipment called skimmers, and other mechanical equipment such as draglines and dredges which may be used in various situations.

### *Description*

There are numerous types of skimming devices, described in Schulze (1998), annually published "World Catalog of Oil Spill Response Products": weir, centrifugal, submersion plane, and oleophilic. They are placed at the oil/water interface to recover, or skim, oil from the water's surface and may be operated independently from shore, be mounted on vessels, or be completely self-propelled. Because large amounts of water are often simultaneously collected (incidental to skimmer operation) and treated, efficient operations require that floating oil be concentrated at the skimmer head, usually using booms. Adequate storage of recovered oil/water mixtures must be available, as must suitable transfer capability. Skimmers are often placed where oil naturally accumulates in pockets, pools, or eddies.

### *Applicable Habitat Types*

Can be used on all water environments (weather and visibility permitting). Waves, currents, debris, seaweed, kelp, ice, and viscous oils will reduce skimmer efficiency.

### *When to Use*

When sufficient amounts of floating oil can be accessed. Skimming spilled gasoline is usually not feasible because of fire, explosion, and inhalation hazards to responders. However, when public health is at risk, gasoline can be skimmed if foam is applied and extreme safety procedures used.

### *Biological Constraints*

Vehicle and foot traffic to and from skimming sites should not disturb wildlife unreasonably.

### *Environmental Effects*

Minimal, if surface disturbance by cleanup work force traffic is controlled.

### *Waste Generation*

Free floating oil can be recycled. Emulsions formed during the process must be treated (broken) before recycling. Oil-contaminated waste from the treatment phase should be treated as wastewater.

## Barriers/Berms

### *Objective*

To prevent entry of oil into a sensitive area or to divert oil to a collection area.

### *Description*

A physical barrier (other than a boom) is placed across an area to prevent oil from passing. Barriers can consist of earthen berms, trenching, or filter fences. When it is necessary for water to pass because of water volume, underflow or overflow dams are used.

### *Applicable Habitat Types*

At the mouths of creeks or streams to prevent oil from entering, or to prevent oil in the creek from being released into offshore waters. Also, on beaches where a berm can be built above the high-tide line to prevent oil from overwashing the beach and entering a sensitive back-beach habitat (e.g., lagoon).

### *When to Use*

When the oil threatens sensitive habitats and other barrier options are not feasible.

### *Biological Constraints*

Responders must minimize disturbance to bird nesting areas, beaver dams, or other sensitive areas. Placement of dams and filter fences could cause excessive physical disruptions, particularly in wetlands.

### *Environmental Effects*

May disrupt or contaminate sediments and adjacent vegetation. The natural beach (or shore) profile should be restored (may take weeks to months on gravel beaches). Trenching may enhance penetration of oil and quantity of contaminated sediments.

### *Waste Generation*

Sediment barriers will become contaminated on the oil side and filter fence materials will have to be disposed of as oily wastes.

## Physical Herding

### *Objective*

To free any oil trapped in debris or vegetation on water; to direct floating oil towards containment and recovery devices; or to divert oil from sensitive areas.

### *Description*

Plunging water jets, water or air hoses, and propeller wash can be used to dislodge trapped oil and divert or herd it to containment and recovery areas. May emulsify the oil. Mostly conducted from small boats.

### *Applicable Habitat Types*

In nearshore areas where there are little or no currents, and in and around man-made structures such as wharves and piers.

### *When to Use*

In low-current or stagnant water bodies, to herd oil toward recovery devices. In high-current situations to divert floating oil away from sensitive areas.

### *Biological Constraints*

When used near shore and in shallow water, must be careful not to disrupt bottom sediments or submerged aquatic vegetation.

### *Environmental Effects*

May generate high levels of suspended sediments and mix them with the oil, resulting in deposition of contaminated sediments in benthic habitats.

### *Waste Generation*

None.

## Manual Oil Removal/Cleaning

### *Objective*

To remove oil with hand tools and manual labor.

### *Description*

Removal of surface oil using hands, rakes, shovels, buckets, scrapers, sorbents, pitch forks, etc., and placing in containers. No mechanized equipment is used except for transport of collected oil and debris. Includes underwater recovery of submerged oil by divers, for example, with hand tools.

### *Applicable Habitat Types*

Can be used on all habitat types.

### *When to Use*

Light to moderate oiling conditions for stranded oil, or heavy oils on water or submerged on the bottom, that have formed semi-solid or solid masses and that can be picked up manually.

### *Biological Constraints*

Foot traffic over sensitive areas (wetlands, tidal pools, etc.) should be restricted or prevented. There may be periods when shoreline access should be avoided, such as during bird nesting.

### *Environmental Effects*

Minimal, if surface disturbance by responders and waste generation is controlled.

### *Waste Generation*

May generate significant quantities of oil mixed with sediment and debris which must be properly disposed of or treated. Decontamination of hand tools may produce oily wastewater that must be treated properly. Worker personal protective gear is usually disposed of daily or decontaminated and the resulting oily wastewater treated properly.

## MECHANICAL OIL REMOVAL

### *Objective*

To remove oil from shorelines, and bottom sediments using mechanical equipment.

### *Description*

Oil and oiled sediments are collected and removed using mechanical equipment not specifically designed for pollution response, such as backhoes, graders, bulldozers, dredges, draglines, etc. Requires systems for temporary storage, transportation, and final treatment and disposal.

### *Applicable Habitat Types*

On land, possible wherever surface sediments are both amenable to, and accessible by, heavy equipment. For submerged oil, used in sheltered areas where oil accumulates. On water, used on viscous or solid contained oil.

### *When to Use*

When large amounts of oiled materials must be removed. Care should be taken to remove sediments only to the depth of oil penetration, which can be difficult with heavy equipment. Should be used carefully where excessive sediment removal may erode the beach or shore. Buried oil lift-off consists of removing clean overburden and oiled sediments, and replacing them with clean overburden. Care is also needed to minimize further oil penetration from uncontrolled vehicle traffic.

### *Biological Constraints*

Heavy equipment use may be restricted in sensitive habitats (e.g., wetlands, soft substrates) or areas containing endangered species. Will need special permission to use in areas with known cultural resources. Dredging in seagrass beds or coral reef habitats may be prohibited. The noise generated by the mechanical equipment may present a constraint as well.

### *Environmental Effects*

The equipment is heavy, with many support personnel required. May be detrimental if excessive sediments are removed without replacement. All organisms in the sediments will be affected, although the need to remove the oil may make this response method the best overall alternative. Resuspension of exposed oil and fine-grained, oily sediments can affect adjacent bodies of water.

### *Waste Generation*

Can generate significant quantities of contaminated sediment and debris that must be cleaned or landfilled. The amount of waste generated by this cleanup option should be given careful consideration by response planners when reviewing potential environmental impacts of the oily wastes, debris, and residues.

## Sorbents

### *Objective*

To remove surface oil by using oleophilic (oil-attracting) material placed in water or at the waterline.

### *Description*

Sorbent material is placed *on the floating oil or water surface*, allowing it to sorb oil or is used to wipe or dab stranded oil. Forms include sausage booms, pads, rolls, sweeps, snares, and loose granules or particles. These products can be synthetically produced or be natural substances. Efficacy depends on the capacity of the particular sorbent, wave or tidal energy available for lifting the oil off the substrate, and oil type and stickiness. Recovery of all sorbent material is mandatory. Loose particulate sorbents must be contained in a mesh or other material.

### *Applicable Habitat Types*

Can be used on any habitat or environment type.

### *When to Use*

When oil is free-floating close to shore or stranded on shore. The oil must be able to be released from the substrate and sorbed by the sorbent. As a secondary treatment method after gross oil removal, and in sensitive areas where access is restricted. Selection of sorbent varies by oil type: heavy oils only coat surfaces, requiring use of sorbents with high surface areas to be effective (adsorbents); whereas, lighter oils can penetrate sorbent material (absorbents).

### *Biological Constraints*

Access for deploying and retrieving sorbents should not adversely affect wildlife or be through soft or sensitive habitats. Sorbents should not be used in a fashion that would endanger or trap wildlife. Sorbents left in place too long can break apart and present an ingestion hazard to wildlife.

### *Environmental Effects*

Physical disturbance of habitat during deployment and retrieval. Improperly deployed or tended sorbent material can crush or smother sensitive organisms.

### *Waste Generation*

Sorbents must eventually be collected for proper disposal; care should be taken to select and use sorbents properly, and prevent overuse and generation of large amounts of lightly-oiled sorbents. Because large amounts of waste may be generated, recycling should be emphasized rather than disposal.

## VACUUM

### *Objective*

To remove oil pooled on a shoreline substrate or subtidal sediments.

### *Description*

A vacuum unit is attached via a flexible hose to a suction head that recovers free oil. The equipment can range from small, portable units that fill individual 55-gallon drums to large supersuckers that are truck- or vessel-mounted and can generate enough suction to lift large rocks. Removal rates from substrates can be extremely slow.

### *Applicable Habitat Types*

Any accessible habitat type. May be mounted on vessels for water-based operations, on trucks driven to the recovery area, or hand-carried to remote sites.

### *When to Use*

When oil is stranded on the substrate, pooled against a shoreline, concentrated in trenches or trapped in vegetation. Usually requires shoreline access points.

### *Biological Constraints*

Special restrictions should be established for areas where foot traffic and equipment operation may be damaging, such as soft substrates. Operations in wetlands must be very closely monitored, and a site-specific list of procedures and restrictions developed to prevent damage to vegetation.

### *Environmental Effects*

Minimal, if foot and vehicular traffic are controlled and minimal substrate is damaged or removed.

### *Waste Generation*

Collected oil and or oil/water mix will need to be stored temporarily prior to recycling or disposal. Oil may be recyclable; if not, it will require disposal in accordance with local regulations. Large amounts of water are often recovered, requiring separation and treatment.

## Debris Removal

### *Objective*

To remove debris in path of spill prior to oiling and to remove contaminated debris from the shoreline and water surface.

### *Description*

Manual or mechanical removal of debris (driftwood, seaweed, trash, wreckage) from the shore or water surface. Can include cutting and removal of oiled logs.

### *Applicable Habitat Types*

Can be used on any habitat or environment type where access is safe.

### *When to Use*

When debris is heavily contaminated and provides a potential source of secondary oil release; an aesthetic problem; a source of contamination for other resources in the area is likely to clog skimmers; or likely to cause safety problems for responders. Used in areas of debris accumulation on beaches prior to oiling to minimize the amount of oiled debris to be handled.

### *Biological Constraints*

Foot traffic over sensitive areas (wetlands, spawning grounds) must be restricted. May be periods when entry should be denied (spawning periods, influx of large numbers of migratory waterbirds). Debris may also be a habitat.

### *Environmental Effects*

Physical disruption of substrate, especially when mechanized equipment must be deployed to recover a large quantity of debris.

### *Waste Generation*

Will generate contaminated debris (volume depends on what, and how much, is collected, e.g., logs, brush). Unless there is an approved hazardous waste incinerator that will take oily debris, burning will seldom be allowed, especially on-site burning. However, this option should still be explored, especially for remote locations, with the appropriate state or Federal agencies who must give approvals for burning.

The advantage of pre-spill debris collections is that waste disposal requirements will likely be less restrictive than if the debris is oiled. Once oiled, the debris is likely to be handled as a hazardous waste.

## SEDIMENT REWORKING/TILLING

### *Objective*

To break up oily sediments and surface oil deposits, increasing their surface area, and mixing deeper subsurface oil layers, thus enhancing the rate of degradation through aeration.

### *Description*

The oiled sediments are roto-tilled, disked, or otherwise mixed using mechanical equipment or manual tools. Along beaches, oiled sediments may also be pushed to the water's edge to enhance natural cleanup by wave activity (surf washing). The process may be aided with high-volume flushing of gravel.

### *Applicable Habitat Types*

On any sedimentary substrate that can support mechanical equipment or foot traffic and hand tilling.

### *When to Use*

On sand to gravel beaches with subsurface oil, where sediment removal is not feasible (due to erosion or disposal problems). On sand beaches where the sediment is stained or lightly oiled. Appropriate for sites where the oil is stranded above the normal high waterline.

### *Biological Constraints*

Avoid use on shores near sensitive wildlife habitats, such as fish-spawning areas or bird-nesting or concentration areas because of the potential for release of oil and oiled sediments into adjacent bodies of water. Should not be used in clam beds.

### *Environmental Effects*

Due to the mixing of oil into sediments, this method could further expose organisms that live below the original layer of oil. Repeated reworking could delay re-establishing of these organisms. Refloated oil from treated sites could contaminate adjacent areas.

### *Waste Generation*

None.

## Vegetation Cutting/Removal

### *Objective*

To remove portions of oiled vegetation or oil trapped in vegetation to prevent oiling of wildlife or secondary oil releases.

### *Description*

Oiled vegetation is cut with weed trimmers, blades, etc., and picked or raked up and bagged for disposal.

### *Applicable Habitat Types*

Habitats composed of vegetation, such as wetlands, sea grass beds, kelp beds, which contain emergent, herbaceous vegetation or floating, aquatic vegetation.

### *When to Use*

When the risk of oiled vegetation contaminating wildlife is greater than the value of the vegetation that is to be cut, and there is no less-destructive method that removes or reduces the risk to acceptable levels.

### *Biological Constraints*

Operations must be strictly monitored to minimize the degree of root destruction and mixing of oil deeper into the sediments. Access in bird-nesting areas should be restricted during nesting seasons. Cutting only the oiled portions of the plants and leaving roots and as much of the stem as possible minimizes impacts to plants.

### *Environmental Effects*

Vegetation removal will destroy habitat for many animals. Cut areas will have reduced plant growth and, in some instances, plants may be killed. Cutting at the base of the plant stem may allow oil to penetrate the substrate, causing sub-surface contamination. Along exposed sections of shoreline, the vegetation may not recover, resulting in erosion and habitat loss. Trampled areas will recover much more slowly.

### *Waste Generation*

Cut portions of oiled plants must be collected and disposed.

## FLOODING

### *Objective*

To wash oil stranded on land to the water's edge for collection.

### *Description*

A perforated header pipe or hose is placed above the oiled shore or bank. Ambient-temperature water is pumped through the header pipe at low pressure and flows downslope to the water where any oil released is trapped by booms and recovered by skimmers or other suitable equipment. On porous sediments, water flows through the substrate, pushing loose oil ahead of it. On saturated, fine-grained sediments, the technique becomes more of a surface flushing.

### *Applicable Habitat Types*

All shoreline types where the equipment can be effectively deployed. Not effective in steep intertidal areas.

### *When to Use*

In heavily-oiled areas when the oil is still fluid and adheres loosely to the substrate, and where oil has penetrated into gravel sediments. This method is frequently used with other washing techniques (low- or high-pressure, cold-to-hot-water flushing).

### *Biological Constraints*

Special care should be taken to recover oil where nearshore habitats contain rich biological communities. Not appropriate for muddy substrates.

### *Environmental Effects*

Habitat may be physically disturbed by foot traffic during operations and smothered by sediments washed down the slope. If containment methods are not sufficient, oil and oiled sediments may be flushed into adjacent areas. Flooding may cause sediment loss and erosion of the shoreline and shallow rooted vegetation. Oiled sediment may be transported to nearshore areas, contaminating them and burying benthic organisms.

### *Waste Generation*

Depends on the effectiveness of the collection method.

## LOW-PRESSURE, AMBIENT WATER FLUSHING

### *Objective*

To remove fluid oil that has adhered to the substrate or man-made structures, pooled on the surface, or become trapped in vegetation.

### *Description*

Ambient-temperature water is sprayed at low pressures (<10 psi), usually from hand-held hoses, to lift oil from the substrate and float it to the water's edge for recovery by skimmers, vacuums, or sorbents. Usually used with a flooding system to prevent released oil from re-adhering to the substrate downstream of the treatment area.

### *Applicable Habitat Types*

On substrates, riprap, and solid, man-made structures, where the oil is still fluid. In wetlands and along vegetated banks where oil is trapped in vegetation.

### *When to Use*

Where fluid oil is stranded onshore or floating on shallow intertidal areas.

### *Biological Constraints*

May need to restrict use so that the oil/water effluent does not drain across sensitive intertidal habitats, and that mobilized sediments do not affect rich subtidal communities. Use from boats will reduce the need for foot traffic in soft substrates and vegetation. Flushed oil must be recovered to prevent further oiling of adjacent areas.

### *Environmental Effects*

If containment methods are not sufficient, oil and oiled sediments may be flushed into adjacent areas. Flooding may cause sediment loss and erosion of the shoreline and shallow rooted vegetation. Some trampling of substrate and attached biota will occur.

### *Waste Generation*

Depends on the effectiveness of the collection method.

## High-pressure, Ambient Water Flushing

### *Objective*

To remove oil that has adhered to hard substrates or man-made structures.

### *Description*

Similar to low-pressure flushing, except that water pressure is 100-1,000 psi (720-7,200 kpa). High-pressure spray will more effectively remove sticky or viscous oils. If low water volumes are used, sorbents are placed directly below the treatment area to recover oil.

### *Applicable Habitat Types*

On bedrock, man-made structures, and gravel substrates.

### *When to Use*

When low-pressure flushing is not effective at removing adhered oil, which must be removed to prevent continued oil release or for aesthetic reasons. When a directed water jet can remove oil from hard-to-reach sites.

### *Biological Constraints*

May need to restrict flushing so that the oil does not drain across sensitive habitats. Flushed oil must be recovered to prevent further oiling of adjacent areas. Should not be used directly on attached algae or rich, intertidal areas.

### *Environmental Effects*

All attached animals and plants in the direct spray zone will be removed, even when used properly. May drive oil deeper into the substrate or erode fine sediments from shorelines if water jet is improperly applied. If containment methods are not sufficient, oil and oiled sediments may be flushed into adjacent areas. Some trampling of substrate and attached biota will occur.

### *Waste Generation*

Depends on the effectiveness of the collection method.

## Low-pressure, Hot Water Flushing

### *Objective*

To remove non-liquid/non-fluid oil that has adhered to the substrate or man-made structures, or pooled on the surface.

### *Description*

Hot water [90°F (32°C) up to 171°F (77°C)] is sprayed with hoses at low pressures [<10 psi (<72 kpa)] to liquefy and lift oil from the substrate and float it to the water's edge for recovery by skimmers, vacuums, or sorbents. Used with flooding to prevent released oil from re-adhering to the substrate.

### *Applicable Habitat Types*

On bedrock, sand to gravel substrates, and man-made structures.

### *When to Use*

Where heavy, but relatively fresh, oil is stranded onshore. The oil must be heated above its pour point so it will flow. Less effective on sticky oils.

### *Biological Constraints*

Avoid wetlands or rich intertidal communities so that the hot oil/water effluent does not contact sensitive habitats. Operations from boats will help reduce foot traffic in soft substrates and vegetation. Flushed oil must be recovered to prevent further oiling of adjacent areas. Should not be used directly on attached algae or in rich, intertidal areas.

### *Environmental Effects*

Hot water contact can kill attached animals and plants. If containment methods are not sufficient, oil may be flushed into adjacent areas. Flooding may cause sediment loss and erosion of the shoreline and shallow rooted vegetation. Some trampling of substrate and biota will occur.

### *Waste Generation*

Depends on the effectiveness of the collection method.

## HIGH-PRESSURE, HOT WATER FLUSHING

### *Objective*

To mobilize weathered and viscous oil strongly adhered to surfaces.

### *Description*

Hot water [90°F (32°C) up to 171°F (77°C)] is sprayed with hand-held wands at pressures greater than 100 psi (720 kpa). If used without water flooding, this procedure requires immediate use of vacuum or sorbents to recover the oil/water runoff. When used with a flooding system, the oil is flushed to the water surface for collection by skimmers, vacuums, or sorbents.

### *Applicable Habitat Types*

Gravel substrates, bedrock, and man-made structures.

### *When to Use*

When oil has weathered to the point that warm water at low pressure no longer effectively removes oil. To remove viscous oil from man-made structures for aesthetic reasons.

### *Biological Constraints*

Use should be restricted so that the oil/water effluent does not drain across sensitive habitats (damage can result from exposure to oil, oiled sediments, and hot water). Should not be used directly on attached algae nor rich, intertidal areas. Released oil must be recovered to prevent further oiling of adjacent areas.

### *Environmental Effects*

All attached animals and plants in the direct spray zone will be removed or killed, even when used properly. Oiled sediment may be transported to shallow nearshore areas, contaminating them and burying benthic organisms.

### *Waste Generation*

Depends on the effectiveness of the collection method.

## Steam Cleaning

### *Objective*

To remove heavy residual oil from solid substrates or man-made structures.

### *Description*

Steam or very hot water [171°F (77°C) to 212°F (100°C)] is sprayed with hand-held wands at high pressure [2,000+ psi (14,400 kpa)]. Water volumes are very low compared to flushing methods.

### *Applicable Habitat Types*

Man-made structures such as seawalls and riprap.

### *When to Use*

When heavy oil residue must be removed for aesthetic reasons, and when hot water flushing is not effective, and no living resources are present.

### *Biological Constraints*

Not to be used in areas of soft substrates, vegetation, or high biological abundance directly on, or below, the structure.

### *Environmental Effects*

Complete destruction of all organisms in the spray zone. Difficult to recover all released oil. If containment methods are not sufficient, oil may be flushed into nearshore areas.

### *Waste Generation*

Depends on the effectiveness of the collection method. Usually sorbents are used, generating significant waste volumes.

## SAND BLASTING

### *Objective*

To remove heavy residual oil from solid substrates or man-made structures.

### *Description*

Use of sandblasting equipment to remove oil from the substrate. May include recovery of used (oiled) sand.

### *Applicable Habitat Types*

On heavily oiled bedrock, artificial structures such as seawalls and riprap.

### *When to Use*

When heavy oil residue must be cleaned for aesthetic reasons, and even steam-cleaning is not effective.

### *Biological Constraints*

Not to be used in areas of soft substrates, vegetation, nor high biological abundance directly below, or adjacent to, the structures.

### *Environmental Effects*

Complete destruction of all organisms in the blast zone. Possible smothering of organisms in adjacent areas. Unrecovered, used sand will introduce oiled sediments into the adjacent habitat. Oiled sediment may be transported to shallow nearshore areas, contaminating them and burying benthic organisms.

### *Waste Generation*

Will need to recover and dispose of oiled sand used in blasting.

## DISPERSANTS

### *Objective*

To reduce impact to sensitive shoreline habitats and animals that use the water surface by chemically dispersing oil into the water column.

### *Description*

Dispersants reduce the oil/water interfacial tension, thereby decreasing the energy needed for the slick to break into small particles and mix into the water column. Specially-formulated products containing surface-active agents are sprayed (at concentrations of 1-5 percent by volume of the oil) from aircraft or boats onto the slicks. Some agitation is needed to achieve dispersion.

### *Applicable Habitat Types*

Water bodies with sufficient depth and volume for mixing and dilution.

### *When to Use*

When the impact of the floating oil has been determined to be greater than the impact of dispersed oil on the water-column community.

### *Biological Constraints*

Use in shallow water could affect benthic resources. Consideration should be made to avoid directly spraying any wildlife, especially birds or fur-bearing marine mammals.

### *Environmental Effects*

Until sufficiently diluted, the dispersed oil can adversely impact organisms in the upper 30 feet (10 meters) of the water column. Because dispersion may be only partially effective, some water-surface and shoreline impacts could occur.

### *Waste Generation*

None.

## EMULSION-TREATING AGENTS

### *Objective*

To break or destabilize emulsified oil into separate oil and water phases. Can be used to prevent emulsion formation, increasing oil recovery rates, extending the window for dispersant application, or making burning possible.

### *Description*

Emulsion-treating agents are surfactants that are applied to emulsified oil at low concentrations (0.1-2 percent). They can be injected into skimmer reservoirs to break the emulsion as it is skimmed from the water. They can be sprayed (similar to dispersants) directly onto slicks to break or prevent emulsions, although this type of application has not been successfully used operationally.

### *Applicable Habitat Types*

On all water environments where emulsified oil is present.

### *When to Use*

Where storage capacities are very limited, to separate the recovered, emulsified oil and water so that the water can be treated and discharged. On floating slicks, where emulsified oil can reduce skimmer efficiency and dispersant effectiveness.

### *Biological Constraints*

There is insufficient information to fully evaluate biological constraints. Use in shallow water could affect benthic resources. Consideration should be made to avoid directly spraying any wildlife, especially birds or fur-bearing marine mammals.

### *Environmental Effects*

Because this is a new method, there are few data available to evaluate environmental effects. Effective dosages are one to two orders of magnitude lower than dispersants. Environmental concerns include the potential for increased oil content of separated water; whether the oil will be more readily dispersed; and how the treated oil will behave upon contact with skimming equipment, birds, mammals, and shorelines.

### *Waste Generation*

May enable recycling of oil/water mixtures by breaking down emulsions.

## ELASTICITY MODIFIERS

### *Objective*

To impart visco-elastic properties to floating oil, thereby increasing skimming rates.

### *Description*

The product is applied as a liquid, slurry, or solid onto the oil. Some mixing is required and is usually provided by the water spray during application. Treated oil is rendered visco-elastic (gelatinous, or semi-solid), but still fluid; there is no chemical change in the oil. The primary purpose is to increase skimmer efficiency removal rates while minimizing water recovery amounts. Increases the efficiency of some skimmers, but may clog other skimmers and pumps.

### *Applicable Habitat Types*

On all water environments where oil can be contained for skimming. Not for use near wetlands or debris because of increased adhesive properties of the treated oil.

### *When to Use*

When skimmer efficiency is low. Must be used with booming or other physical containment. Not for use on heavy oils, which are already highly viscous.

### *Biological Constraints*

Not suitable for vegetated shores nor where there is extensive debris mixed in the oil. Should be avoided when birds or other wildlife cannot be kept away from the treated oil.

### *Environmental Effects*

May increase the smothering effect of oil on organisms; therefore, the treatment should be considered only where recovery of the treated oil is likely.

### *Waste Generation*

If skimming efficiency is increased, will reduce the volume of water in oil/water collections. Effects on recycling of oil treated with elasticity modifiers is unknown.

## Herding Agents

### *Objective*

To collect or herd oil into a smaller area and thicker slick in order to increase recovery. Can be used to herd oil away from sensitive areas or to help keep oil contained when it is necessary to move a boom.

### *Description*

These agents, which are insoluble surfactants and have a high spreading pressure, are applied in small quantities (1-2 gallons per lineal mile) to the clean water surrounding the edge of a fresh oil slick. They contain the oil, prevent spreading, but do not hold the spill in place. Hand-held or vessel-mounted systems can be used. Must be applied early in spill, when oil is still fluid.

### *Applicable Habitat Types*

On all still water environments.

### *When to Use*

Potential use for collection and protection. For collection, used to push slicks out from under docks and piers where it has become trapped, or in harbors where the equipment is readily accessible for use early in the spill. For protection in low-current areas, used to push slicks away from sensitive resources such as wetlands. Not effective in fast currents, rough seas, or rainfall.

### *Biological Constraints*

Not suitable for use in very shallow water or fish-spawning areas.

### *Environmental Effects*

Direct acute toxicity to surface-layer organisms possible, though available products vary greatly in their aquatic toxicity.

### *Waste Generation*

Same as for manual oil recovery.

## SOLIDIFIERS

### *Objective*

To change the physical state of spilled oil from a liquid to a solid.

### *Description*

Chemical agents (polymers) are applied to oil at rates of 10-45 percent or more, solidifying the oil in minutes to hours. Various broadcast systems, such as leaf blowers, water cannons, or fire suppression systems, can be modified to apply the product over large areas. Can be applied to both floating and stranded oil. Can be placed in sorbent booms and used like sorbents.

### *Applicable Habitat Types*

All water environments, bedrock, sediments, and artificial structures.

### *When to Use*

When immobilization of the oil is desired, to prevent refloating from a shoreline, penetration into the substrate, or further spreading. However, the oil may not fully solidify unless the product is well mixed with the oil, and may result in a mix of solid and untreated oil. Generally not used on heavy oil spills which are already viscous.

### *Biological Constraints*

Must be able to recover all treated material.

### *Environmental Effects*

Available products are insoluble and have very low aquatic toxicity. Unrecovered solidified oil may have longer impact because of slow weathering rates. Physical disturbance of habitat is likely during application and recovery.

### *Waste Generation*

If skimming efficiency is increased, solidifiers may reduce the volume of water collected during oil recovery. Oil treated with solidifiers is typically disposed of in landfills.

## Shoreline Cleaning Agents (Surface Washing Agents)

### *Objective*

To increase the efficiency of oil removal from contaminated substrates.

### *Description*

Special formulations are applied to the substrate, as a presoak and/or flushing solution, to soften or lift weathered or heavy oils from the substrate to enhance flushing methods. The intent is to lower the water temperature and pressure required to mobilize the oil from the substrate during flushing. Some agents will disperse the oil as it is washed off the beach, others will not.

### *Applicable Habitat Types*

On any habitat where water flooding and flushing procedures are applicable.

### *When to Use*

When the oil has weathered to the point where it cannot be removed using ambient water temperatures and low pressures. This approach may be most applicable where flushing effectiveness decreases as the oil weathers.

### *Biological Constraints*

When the product does not disperse the oil into the water column, the released oil must be recovered from the water surface. Use may be restricted where suspended sediment concentrations are high, near wetlands, and near sensitive nearshore resources.

### *Environmental Effects*

The toxicity and effects on dispersability of treated oil vary widely among products. Product toxicity should be taken into consideration during product selection.

### *Waste Generation*

Because treated oil must be recovered, waste generation is a function of recovery method, which often includes sorbents.

## Nutrient Enrichment (Biostimulation)

### *Objective*

To accelerate the rate of oil hydrocarbon degradation due to natural microbial processes by adding nutrients (generally nitrogen and phosphorus) that stimulate microbial growth.

### *Description*

If nutrients are a limiting factor (as measured using the interstitial pore water) in an area where shoreline oiling has occurred, water-soluble nutrients can be applied by a spray irrigation system. Nutrients should be applied daily if the impacted area gets completely submerged by tides and waves and if maximum biostimulation is desired. If the impacted area gets submerged only during spring tides, the frequency of nutrient addition will be determined by the intertidal zone water coverage. Using slow-release granular or encapsulated nutrients or oleophilic fertilizer (which adheres to the oil residue on the surface) should require less frequent addition, but time-series monitoring of interstitial pore water nutrient levels is needed to ensure target levels are being maintained, especially throughout the depth of the impacted intertidal zone.

### *Applicable Habitat Types*

Could be used on any shoreline habitat type where access is allowed and nutrients are deficient.

### *When to Use*

On moderate- to heavily-oiled substrates, after other techniques have been used to remove free product; on lightly-oiled shorelines, where other techniques are destructive or ineffective; and where nutrients limit natural attenuation. Most effective on light to medium crude oils and fuel oils (asphaltenes tend to inhibit rapid biodegradation). Less effective where oil residues are thick. Not considered for gasoline spills, which evaporate rapidly.

### *Biological Constraints*

Avoid using ammonia-based fertilizers at highly elevated concentrations because un-ionized ammonia is toxic to aquatic life. Nitrate is an equally good nitrogen source, minus the toxicity. Sodium tripolyphosphate is a better phosphorus source than orthophosphates because it is more soluble in seawater. If nutrients are applied properly with adequate monitoring, eutrophication should not be a problem. Only nutrient additives proven to be nontoxic and effective in either the laboratory or the field should be used in the environment. Contact toxicity of oleophilic nutrients may restrict their use, as other chemicals in the product could be more toxic to aquatic organisms in the presence of oil.

### *Environmental Effects*

Detrimental effects to shoreline from foot or vehicle traffic caused by workers applying nutrients (unless nutrients are sprayed from a vessel or aircraft).

### *Waste Generation*

None.

## Natural Microbe Seeding (Bioaugmentation)

### *Objective*

A form of bioremediation used to accelerate natural microbial degradation of oil by adding high numbers of oil-degrading microorganisms.

### *Description*

Formulations containing specific hydrocarbon-degrading microbes are added to the oiled area because indigenous hydrocarbon degraders are low in number, or, those that are present cannot degrade the oil effectively. Since microbes require nitrogen and phosphorus to convert hydrocarbons to biomass, formulations containing these oil degraders must also contain adequate nutrients.

Research studies conducted with bioengineered organisms or organisms enriched from different environments, grown in the laboratory to high numbers, and applied to an oiled beach to stimulate rapid biodegradation, have failed to prove conclusively that seeding is effective.

Bioaugmentation appears less effective than biostimulation because: 1) hydrocarbon degraders are ubiquitous in nature and, when an oil spill occurs at a given site, the influx of oil will cause an immediate increased response in the hydrocarbon degrading populations; but, 2) if nutrients are in limited supply, the rate of oil biodegradation will be less than optimal; thus, 3) supplying nutrients will enhance the process initiated by the spill, but adding microorganisms will not, because they still lack the necessary nitrogen and phosphorus to support growth.

The maximum number of microbial organisms achievable will determine the maximum biodegradation rate. If nutrient supplementation is sufficient to maximize that rate, bioaugmentation will not further increase the biodegradation rate.

### *Applicable Habitat Types*

There is insufficient information on impacts or effectiveness of this method to make a judgment on applicable habitat.

### *When to Use*

There is insufficient information on impacts or effectiveness of this method to make a judgment on when to use it.

### *Biological Constraints*

Avoid using products containing ammonia-based fertilizers at elevated concentrations because un-ionized ammonia is toxic to aquatic life. Nitrate is an equally good nitrogen source, minus the toxicity. If the product containing nutrients is applied properly with adequate monitoring, eutrophication should not be a problem; but toxicity tests should be evaluated carefully, as other chemicals in the product could be toxic to aquatic organisms.

### *Environmental Effects*

Detrimental physical effects to shoreline from foot or vehicle traffic caused by workers applying bioaugmentation products (unless nutrients are sprayed from a vessel or aircraft).

### *Waste Generation*

None.

## *IN-SITU* BURNING

### *Objective*

To remove oil from the water surface or habitat by burning it in place.

### *Description*

Oil floating on the water surface is collected into slicks at least 2-3 mm thick and ignited. The oil can be contained in fire-resistant booms, or by natural barriers such as ice or the shore. On land, oil can be burned when it is on a combustible substrate such as vegetation, logs, and other debris. Oil can be burned from non-flammable substrates using a burn promoter. On sedimentary substrates, it may be necessary to dig trenches for oil to accumulate in pools to a thickness that will sustain burning. Heavy oils are hard to ignite but can sustain a burn. Emulsified oils may not ignite nor sustain a burn when the water content is greater than 30 to 50 percent.

### *Applicable Habitat Types*

On most habitats, except dry, muddy substrates where heat may impact the biological productivity of the habitat. May increase oil penetration in permeable substrates. Not suitable for woody vegetation such as mangroves.

### *When to Use*

On floating slicks, early in the spill event when the oil can be kept thick enough (2-3 mm). On land, where there is heavy oil in sites neither amenable nor accessible to physical removal and the oil must be removed quickly. In wetlands and mud habitats, a water layer will minimize impacts to sediments and roots. Many potential applications for spills in ice. There are many operational and public health limitations.

### *Biological Constraints*

The possible effects of large volumes of smoke on nesting birds and populated areas should be evaluated.

### *Environmental Effects*

Temperature and air quality effects are likely to be localized and short-lived. Toxicological impacts from burn residues have not been evaluated. On water, burn residues may sink. On land, removal of burn residues is often necessary for crude and heavy oils. Residue removal can cause physical disruption to sensitive habitats such as wetlands. There are few studies on the relative effects of burning oiled wetlands compared to other techniques or natural recovery. Limited data indicate recovery of wetland vegetation will depend on season of burn, type of vegetation, and water level in the marsh at time of burn.

### *Waste Generation*

Any residues remaining after burning will need to be collected and landfilled, but with an efficient burn only a small fraction of the original oil volume will remain.

# CHAPTER 4.0

# GUIDELINES FOR DEVELOPING RESPONSE ACTIONS

This chapter provides information to help the reader understand the tradeoffs that were considered in developing the tables in Chapter 5. It reflects a consensus of extensive and technically-appropriate pre-spill decision processes regarding response:

- Goals (overall aims of the response, defined by government);
- Objectives (specified response outcomes, defined by response management);
- Strategies (plans used to carry out objectives, protect resources at risk);
- Tactics (specific actions taken to carry out a strategy); and
- Windows of opportunity (instances during which response actions are viable).

## GOALS

Generally, oil spill response goals, in order of priority, are:

1. Maintain safety of human life;
2. Stabilize the situation to preclude it from worsening; and
3. Minimize adverse environmental and socioeconomic impacts by coordinating all containment and removal activities to carry out a timely, effective response.

## OBJECTIVES

Responders should develop incident-specific objectives and strategies to address all three goals simultaneously. With the first two goals, responders must develop incident-specific response objectives which achieve the third goal, i.e., minimize further spill impacts and protect resources at risk. Objectives must be clearly articulated and be measurable and achievable, e.g., prevent oil from reaching a specific part of the shoreline from one point to another. These objectives must be prioritized because:

- Environmental impacts will be longer-lasting and more difficult to repair than socioeconomic impacts; and
- Effectively managing (planning, executing) a response requires a framework within which limited response resources (people, equipment, time) can be allocated to protect multiple resources at risk, not all of which can be protected; some will have higher priorities than others for protection.

## STRATEGIES

Strategies are the conceptual plans designed to achieve response objectives. For example, a combination of mechanical containment and recovery equipment, dispersants, and *in-situ* burning can be used to prevent oil from reaching the shoreline.

Initial spill conditions will play a large role in strategy development, and sufficient initial information must be gathered to determine:

- Type and amount of oil spilled;
- Spill location;
- Behavior of spilled oil;
- Spill trajectories and persistence;
- Locations and resources that may be impacted, and types of impacts; and
- Current and forecast weather.

As information is gathered, strategies can be developed (and revised) to minimize the risks to environmental resources. Though response strategies will vary according to incident-specific conditions, many can often be established in spill response plans (area contingency plans; owner/operator plans), consistent with response goals.

## TACTICS

Tactics are site-specific and individual activities taken to implement strategies, and can also be established in spill response plans, consistent with response goals. Specific tactics are usually developed for 12 to 24 hour time periods.

## WINDOWS OF OPPORTUNITY

Windows of opportunity (instances during which response actions are viable) are constrained or bounded by certain influences or conditions, and are available, or "open," for limited times.

Three primary windows exist following a marine oil spill; within each window, certain spill control measures can be implemented to minimize adverse environmental effects:

1. **Very early** - Oil is fresh and concentrated near the discharge source.
   - Window may be open for 1-2 days; and
   - Responders focus on source control, containment near the source, and removal (these offer the best opportunities to reduce adverse environmental impacts).
2. **Early** - Oil has spread, is no longer concentrated, and threatens sensitive resources and habitats.
   - Window may be open for several days to weeks;
   - Sensitive resources and habitats are threatened; and
   - Responders work to minimize the spread of oil, prevent it from contacting resources at risk, and protect resources and habitats most vulnerable to longer-term oil impacts.
3. **Later** - Oil has stranded.
   - Window may be open for days to months, or longer; and
   - Responders use habitat-appropriate shoreline cleanup options to minimize environmental effects and enhance natural recovery (in some cases, oil may be left to degrade naturally because physical removal would cause a greater negative impact than leaving it in place).

Options for reducing spill impacts during each of these windows are addressed later; but, because information regarding window 2 will be site-specific (and is addressed in area contingency plans), the emphasis here is on windows 1 and 3.

Figure 2 depicts the range of response possibilities for a generic, large marine oil spill (generalized response phases and windows illustrate the relative timing constraints of various response options).

| Incident start (window of opportunity) → | ...hours... (very early) → | ...hours/days/weeks... (early) → | ...months... (later) |
|---|---|---|---|
| PHASE / STRATEGY | STABILIZE/SECURE SOURCE | ON-WATER CONTAIN/ RECOVER/PROTECT | SHORELINE TREATMENT/CLEANUP |
| MECHANICAL | Close Valves<br>Patch<br>Pump/Offload | Manual Oil Removal<br>Boom, Skimmers<br>Sorbents<br>Mechanical Oil Removal<br>Vacuum<br>Barriers | Sorbents<br>Manual Oil Removal<br>Mechanical Oil Removal |
| CHEMICAL | | Shoreline Cleaning Agents<br>Dispersants<br>Emulsion Treating Agents<br>Solidifiers<br>Herding Agents<br>Elasticity Modifiers | Shoreline Cleaning Agents<br>Solidifiers |
| OTHER COUNTERMEASURES | | *In-situ* Burning | Bioremediation |
| WASTE MANAGEMENT | | On-site Storage<br>Recycle<br>Incineration | Stabilization<br>Recycle<br>Landfill<br>Incineration<br>Bioremediation |

**Figure 2.** Types of response options during a major oil spill (modified from Walker *et al.*, 1993).

## 4.1 INCIDENT-SPECIFIC FEASIBILITY ISSUES

After assessing the situation, defining goals, priorities, objectives, and identifying the possible response strategies, the next step is to consider the feasibility of field operations. Tables 5 and 6 summarize the issues (discussed in detail in the following sections) to be considered in developing incident-specific, on-water and shoreline operations.

**Table 5.** Incident-specific on-water strategy issues.

| Category | Issues |
|---|---|
| Nature and Amount of Oil | • Oil type spilled<br>• Oil volume and area and shape of slick(s)<br>• Average oil thickness and distribution<br>• Emulsification |
| Proximity | • Source considerations<br>• Water depths<br>• Shoreline and resources at risk<br>• Air and vessel traffic<br>• Equipment staging and support locations<br>• Exclusion zones |
| Timing | • Personnel and equipment availability<br>• Logistics support for sustained operations<br>• Time until impact<br>• Weathering |
| Environment | • Water depth<br>• Wind and waves<br>• Tides and currents<br>• Visibility<br>• Temperature<br>• Ice and floating debris<br>• Vulnerable species and habitats<br>• Human use |
| Authorization | • Approval to burn and/or apply CCPs*<br>• Approval to access restricted areas<br>• Transport and disposal of recovered oil or waste<br>• Permits |

* CCPs can include alternative sorbents, bioremediation agents, dispersants, elasticity modifiers, emulsion-treating agents, fire fighting foams, solidifiers, surface collecting agents, surface washing agents and shoreline pre-treatment agents.

**Table 6.** Incident-specific shoreline strategy issues.

| Category | Issues |
|---|---|
| Safety | • Slip and fall hazards<br>• Worker oil exposure hazards |
| Nature and Amount of Oil | • Oil type spilled<br>• Stranded oil amount<br>• Stranded oil distribution |
| Proximity | • Access from on-water and/or roads<br>• Worker support services<br>• Staging/deployment sites |
| Timing | • Timely strategy development<br>• Rapid cleanup to prevent oil re-mobilization |
| Environment | • Waves and breakers<br>• Tides<br>• Currents<br>• Weather<br>• Shoreline type<br>• Water depth and sea bottom character<br>• Vulnerable species and habitats<br>• Human use constraints<br>• Cultural constraints |
| Authorization | • Approval to burn and/or apply CCPs*<br>• Approval to access restricted areas<br>• Transport and disposal of recovered oil or waste<br>• Permits |

* CCPs can include alternative sorbents, bioremediation agents, dispersants, elasticity modifiers, emulsion-treating agents, fire fighting foams, solidifiers, surface collecting agents, surface washing agents and shoreline pre-treatment agents.

## ON-WATER FEASIBILITY ISSUES

On-water response strategies and procedures must address a broad range of site-, spill-, and environment-specific issues, including:

- Safety risks;
- Environmental effects; and
- Timing, spatial, and environmental limits.

These must be carefully considered in establishing response option performance levels. Safety is always paramount, but other priorities can be different for each spill.

### *Nature and Amount of Oil*

#### Oil Type

Identifying the type of oil spilled and being able to anticipate its changing physical and chemical character as it spreads and degrades (Section 2.1, Properties and Fate of Oil) will help responders:

- Conduct personnel safety assessments;
- Determine fire or explosion risks;
- Identify response option feasibility; and
- Determine windows of opportunity.

#### Oil Volume, Area, and Shape

Because on-water response equipment (Figure 3) has predictable, limited areal coverage rates, a slick's volume, changing area, and shape as it is transported and spread by wind and current will determine response option feasibility, effectiveness, and efficiency. Since mechanical recovery generally will remove a fraction of the oil spilled:

- Spills on water must be attacked early [a sudden release, even in a light surface current, can spread and be transported rapidly beyond any at-source containment; moderate- to large-volume spills on the order of 1,000 barrels or more can easily spread over 1 to 10 square miles (3 to 26 square kilometers) in a day or two]; and
- Response methods should be combined wherever possible (large spills can quickly exceed the holding capacity of most containment barriers).

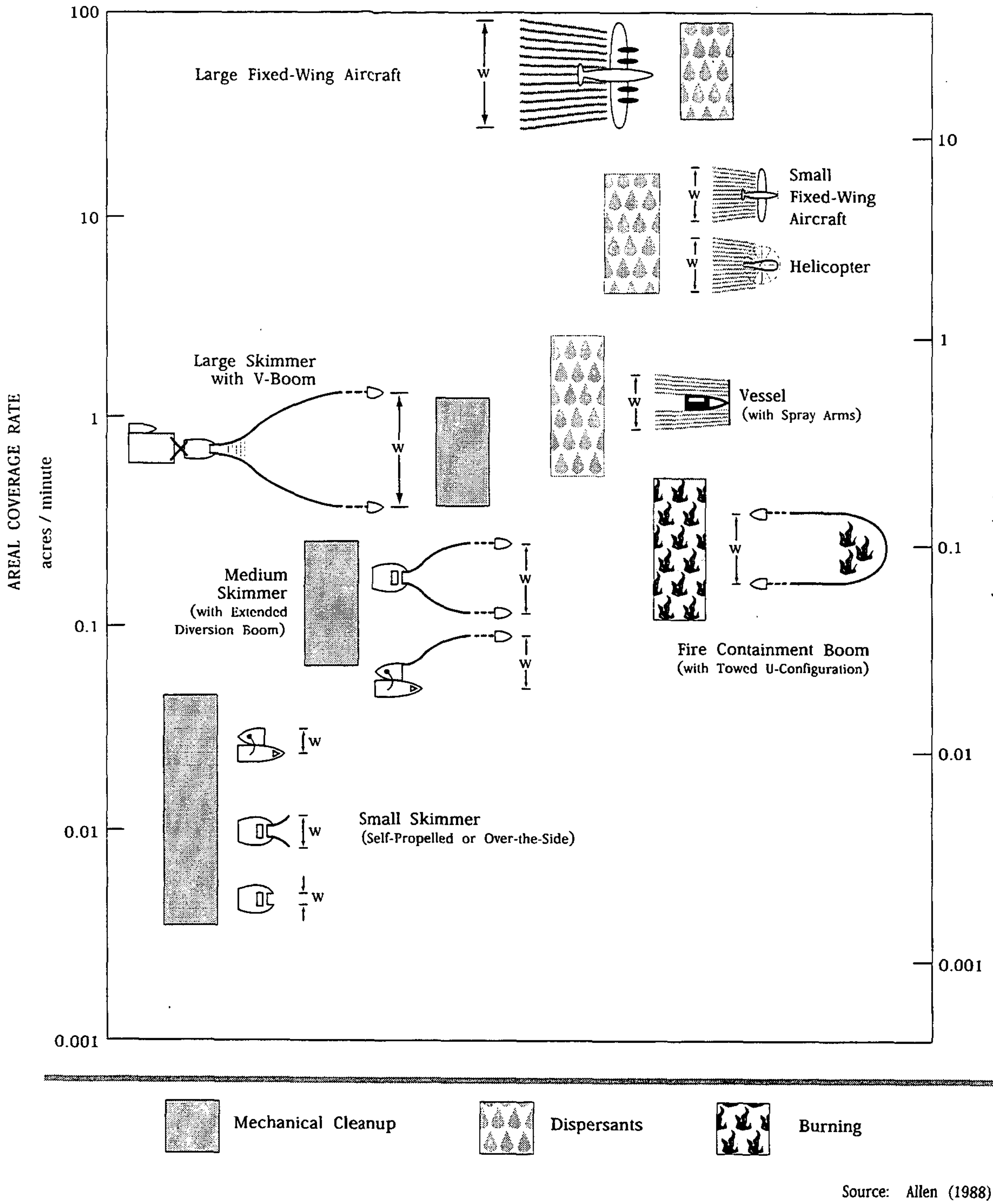



**Figure 3.** Schematic representation of areal coverage rates for selected spill response systems (Allen, 1988).

## Average Oil Thickness and Distribution

Though oil slick thickness can vary by orders of magnitude within different parts of a slick, average slick thickness and actual oil distribution are significant for determining response method feasibility. Figure 4 illustrates the general relationships between on-water response techniques and average slick thickness. Windrows, heavy oil patches, tarballs, etc., must also be considered, as they influence oil encounter rates, chemical dosages, and ignition potential.

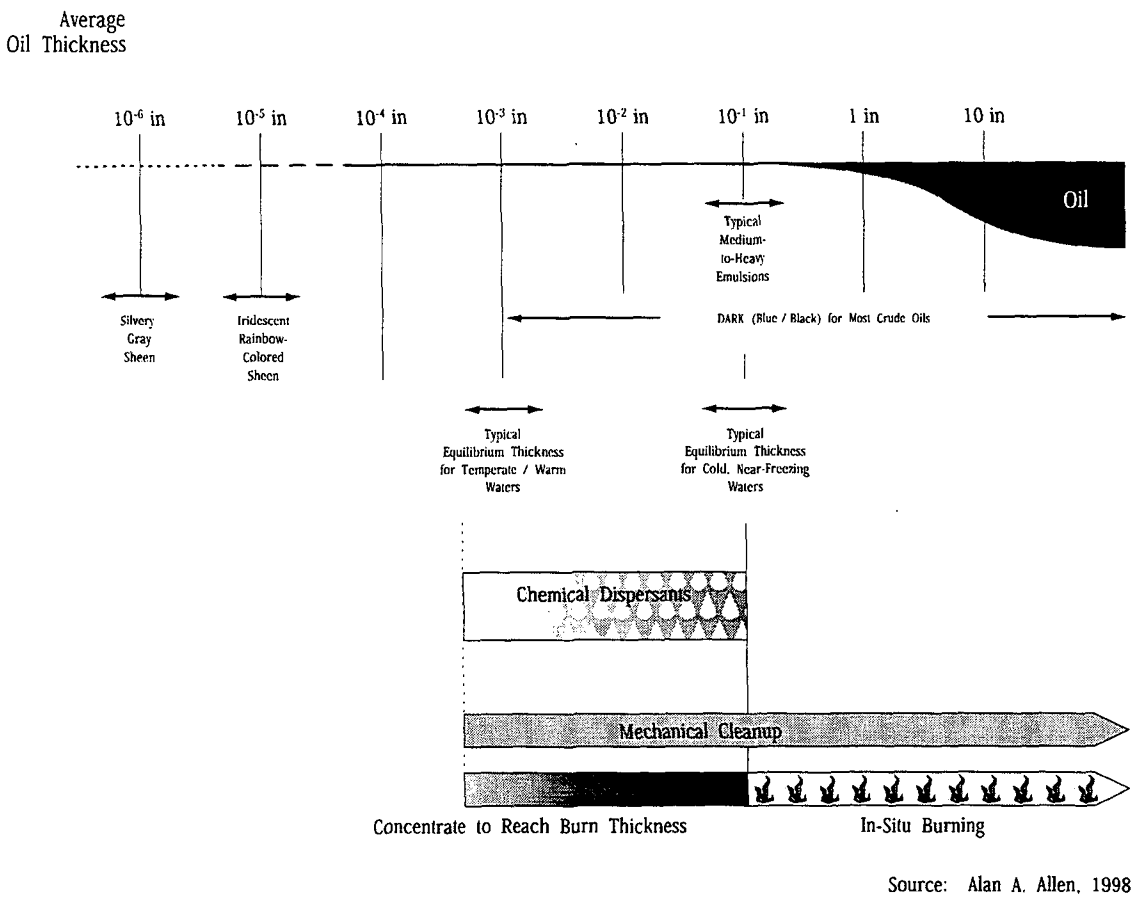



**Figure 4.** Average oil thickness versus potential response options (modified from Allen and Dale, 1996).

**Emulsification**

Weathering (Section 2.1) often involves water-in-oil emulsification, which can impair response operations by:

- Increasing overall oil volume and recovered fluid storage requirements;
- Decreasing oil's buoyancy (increasing its tendency to submerge);
- Increasing the oil's viscosity (or pumpability) and stickiness (complicating recovery operations);
- Decreasing the oil's affinity for surface tension modifiers (reducing its dispersibility);
- Decreasing the oils' ignitability (burning is difficult or impossible); and
- Decreasing available surface area for biodegradation (less biodegradable).

All of the above are important for understanding and estimating on-water response effectiveness, since some options may only be appropriate for a few hours under adverse conditions, or for several days during ideal conditions.

### *Proximity*

**Source Considerations**

Response operations must be conducted at safe distances from existing or potential spill sources, to reduce the risks of accidental ignition, exposure to harmful vapors, or changes in source characteristics that could endanger personnel or equipment.

**Shoreline and Resources at Risk**

Recovering or treating oil at sea can reduce the consequences to open-water and shoreline resources. Distance to shore is important because it will influence the type of vessels and equipment employed (size, draft, maneuverability, anchoring limitations) and the response countermeasures used. It is often more efficient and effective to recover or treat oil before it comes ashore.

**Air and Vessel Traffic**

On-water response and monitoring normally involve boats and/or aircraft, and activities of these vehicles must be carefully planned and controlled to prevent interference with other, ongoing (or planned) operations.

**Equipment Staging and Support Locations**

Response success will depend, in part, on the proximity of equipment and personnel staging locations to actual operations. Because response activities may interfere with each other (e.g., vessels transiting to and from staging areas) or with private or commercial activities, support operations will require careful planning.

**Designated Response Exclusion Zones**

Designating certain areas as public, private, or government exclusion zones may be necessary for conducting effective on-water operations. These zones may include national marine sanctuaries, archeological sites, military operations areas, or may be pre-designated chemical dispersant operations or *in-situ* burning areas. Some exclusion zones may have special activity or time requirements.

### *Timing*

**Personnel and Equipment Availability**

The time required to bring resources to the scene will be a significant factor in establishing an effective response. Because response operations are critically influenced by oil spreading, transport, and weathering, realistic estimates of time to arrive on scene must be established in response plans and re-evaluated as daily Incident Action Plans are developed.

**Logistics Support for Sustained Operations**

Effective, sustained response operations must be supported with:

- Trained, well-rested personnel for crew rotations (food, shelter);
- Spare parts and supplies (fuel, dispersants, PPE, boom, ignition systems, etc.) to keep equipment and personnel functioning;
- Secondary storage containers for recovered oil/water; and
- Sufficient, certified final disposal sites.

**Time Until Impact**

Responders must determine realistic oil encounter and recovery rates, to make maximum use of the time available before oil impacts sensitive resources. If estimates show that on-water, mechanical response systems cannot handle a sufficient portion of a spill, the environmental impact tradeoffs among containment and mechanical recovery, dispersant use, or *in-situ* burning must be carefully weighed against the impacts of that same oil reaching the shoreline. In some instances, it may be necessary to forego some on-water response in order to use those resources for shoreline protection and cleanup.

**Oil Weathering**

During the first 24 to 48 hours of open water exposure, most oil spills become difficult to recover, burn, or chemically disperse, because:

- Evaporation accelerates as oil spreads and thins, increasing its density, viscosity, and tendency to emulsify;
- Emulsification can produce oily fluids of greater volume and viscosity than the original spill; and
- Decreasing slick thickness makes removing oil increasingly difficult.

## *Environment*

**Water Depth**

Shallow-water response requires careful use of response equipment, since:

- Vessel size and/or draft will limit speed, maneuverability, and operating areas;
- Vessel or boom anchors can disturb benthic communities;
- Shallow-water locations with strong currents create unique problems:
  - Booms with a draft greater than 1/4 the water depth will lose significant amounts of oil from entrainment.
  - Vessel squat (settling of the stern as speed increases) may limit operating areas or parameters.
- Chemical dispersant use must not unnecessarily expose local biota to harmful concentrations of dispersed oil.

Water depth may be a consideration during *in-situ* burning deliberations because residues may sink; but heat transferred from a burning slick to the water is negligible and will not be a factor.

**Wind and Wave Energy**

All weather will affect spill response activities, and rising wind and waves will:

- Increase oil spreading, transport, evaporation, and emulsification;
- Increase responder fatigue due to vessel and equipment handling difficulties; and
- Reduce containment boom effectiveness.

While there are exceptions for certain types and conditions of oil, and specific types of equipment or dispersant, Figure 5 illustrates wind and wave influences on response operations feasibility over a broad range of average oil film thicknesses:

- **Mechanical Cleanup:** Effectiveness drops significantly because of entrainment and/or splash-over as short-period waves develop beyond 2 to 3 feet (0.6 to 0.9 meters) in height. Containment and recovery decrease rapidly as slick thicknesses drop below a thousandth of an inch (i.e., very low oil encounter rates).
- **Dispersants:** Effective dispersion requires a threshold amount of surface mixing energy (typically a few knots of wind and a light chop) to be effective. At higher wind and sea conditions, dispersant evaporation and wind-drift will limit chemical dispersion application effectiveness; and, there is a point [~25 kt winds, 10 feet (3 meter) waves] where natural dispersion forces become greater, particularly for light oils. Because of droplet size versus slick thickness constraints and application dose-rate limitations, dispersants work best on slick thicknesses of a few thousandths to hundredths of an inch. Improved dispersants, higher dose rates, and multiple-pass techniques may extend the thickness limitation to 0.1 inch (0.25 centimeters) or more.
- **Burning:** Fire boom is affected by the same entrainment and splash-over problems as most conventional booms in 2 to 3 feet (0.6 to 0.9 meters), short-period waves.

  During calm conditions, sustained burning is easier and normally requires a minimum oil thickness of about 0.1 inch (0.25 centimeters) of oil; for heavier and emulsified oils, this thickness will be greater. When oil has spread and thinned, it may sometimes be possible to collect and concentrate to minimum combustion thickness.

  Fresh, volatile oil slicks cannot be ignited in winds greater than 20 knots.
- **Surveillance:** Remote sensing technologies may be helpful for locating floating oil, depending on environmental conditions.

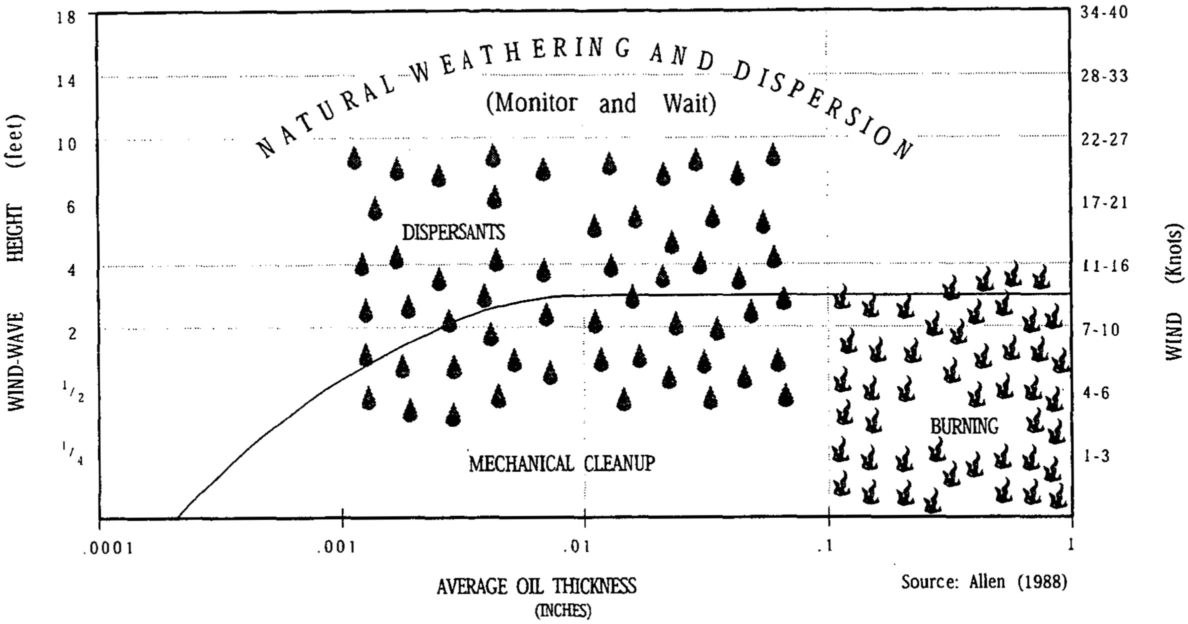



**Figure 5.** Primary spill response options under various wind/sea conditions and oil film thicknesses (modified from Allen, 1988).

## Tides and Currents

Tides can:

- Change or reverse the direction and speed of water flow; and
- Change water depth.

Currents can:

- Reduce containment equipment effectiveness. Most booms are effective in currents less than 1.0 knot, although fast-water booming techniques and equipment can enhance containment effectiveness.

Tides and currents can:

- Operate in conjunction with wind to transport surface and subsurface oil over great distances.

Thus, tide and current will dictate vessel size and power requirements; anchor size, type, and placement; towed boom drift distances; the time and location of possible sensitive resource impacts; and the amount of oil loss from entrainment (particularly with high viscosity oils and oils of density near 1.0). Booming and skimming while drifting with the current will help minimize such losses.

**Visibility**

If response activities are conducted in low visibility, artificial light, or bright moonlight it will be difficult to find the heaviest oil concentrations or to monitor oil losses from booms and skimmers. Depending upon incident specifics, it may be feasible to conduct on-water operations in static or on-station modes during low visibility, allowing oil to come to recovery sites.

**Temperature**

Low temperatures will generally increase oil viscosity (requiring viscous-oil recovery system use), inhibit spreading, evaporation, and emulsification, and may extend response windows of opportunity (but some oils may form stable emulsions in low temperatures).

During extreme cold weather, ice may limit the spread of oil and improve the chances of recovery or burning. Extreme cold will also:

- Increase hypothermia potential, requiring responders to use special, cold-weather personnel protection equipment, machinery, and procedures.

In high temperature and humidity situations, the above constraints will usually be reversed: oil will spread and evaporate faster, increasing fire and explosion potential, accelerating weathering processes, reducing response windows, and impacting equipment deployment times (equipment that works better on thicker oils which have retained their lighter ends must be deployed quickly). Extreme heat and humidity will also:

- Increase hyperthermia potential, requiring use of warm-weather personnel protection procedures, equipment, and machinery.

**Ice and Floating Debris**

In some situations, ice or other floating debris may actually help contain oil and enhance *in-situ* burning; but heavy concentrations, particularly in strong currents, will clog, overload, or destroy most interception barriers. Debris will also tend to keep oil thick, dampen waves, and reduce dispersant effectiveness.

Frequent surveillance, and assigning resources to keep debris clear of recovery operations, will be necessary. If the debris is not too large, responders may be able to use interception barriers or screens with relatively narrow oil interception swaths.

### *Authorization*

**Approval to Burn and/or Apply Dispersants**

*In-situ* burning or dispersant use requires government authorization, (generally requested by the party responsible for the spill). Because safety, environmental impact, wildlife, and public concern issues are involved, a number of formal, pre-spill agreements have been signed which allow an On-Scene Coordinator (OSC) to authorize dispersant use or *in-situ* burning. Specific constraints are usually applied regarding:

- Zone and boundary designations;
- Distances from shore;
- Water depths;
- Weather; and
- Time (daylight, season).

Some states and regions may consider these requests only on a case-by-case basis, which delays response activity and may force responders to miss particular windows of opportunity. Such delay must be factored into the response planning process.

**Approval to Access Restricted Areas**

As noted earlier, vessels and/or aircraft response operations may require special clearances or approvals, particularly near shore, where residential, commercial, industrial, recreational, or environmentally sensitive areas may be directly or indirectly impacted. Permission from government or owners/operators may be necessary before responders can enter or use these areas.

**Transport and Disposal of Recovered Oil or Waste**

Response planners must assess the time, cost, and effectiveness of storing, transporting, and disposing of recovered oil/oily wastes including the effects that such operations will have on available resources, (e.g., the length of time that response systems may be suspended due to lack of storage space). Disposal of recovered oil and oily wastes must comply with government regulations. Planners must also address:

- Temporary storage (onshore, offshore) of oil and oily debris, or sorbent materials;
- Decanting and discharging free water from recovered fluids;
- Transfer of waste from vessels/barges to onshore facilities;
- Handling waste from offshore equipment/vessel cleaning operations;
- Disposing of waste, burn residue, and debris at approved sites; and
- Product sampling and analyzing.

## SHORELINE FEASIBILITY ISSUES

Shoreline response strategies may be constrained by safety, physical, or environmental considerations.

### *Safety*

The dangers or risks inherent in land-based operations involving mechanized equipment are similar to those of on-water activities, and weather-related hazards from high winds, waves, currents, and tides, though less critical on land, still exist near and on the shoreline.

Stranded oil and near-shore oil has usually weathered, and the threat of harmful exposures or accidental ignition is lower than at, or near, its source; however, some oils may still contain enough light ends to make exposure, inhalation, or ingestion risky (except for asphalt-type oils).

### *Nature and Amount of Oil*

Understanding how a particular spill has weathered will help responders select appropriate treatment or cleanup options. Such information can be gathered by shoreline assessment surveys; these involve systematically collecting data to describe (using standard terms and definitions) the location, amount, distribution, and character of stranded or nearshore oil.

### *Proximity*

Responders must consider shoreline proximity issues so that inshore on-water operations can be safely conducted. Considerations may include distance(s) to:

- Safe or sheltered anchorage;
- Support services (e.g., medical, food, lodging, maintenance and repair, and communications);

- Suitable staging or deployment sites; and
- Shoal waters; uncharted, underwater obstacles, etc.

### *Timing*

Shoreline assessments must be conducted as soon as practicable so that planners can incorporate the information into developing response strategies, selecting response options, and provide sufficient resources to remove the oil and prevent it from refloating and impacting other areas.

### *Environment*

Evaluating the operating environment for shoreline protection and cleanup involves a number of issues, including: waves and breakers, tides, currents, water depths, weather, shoreline features, ecological constraints, human use or cultural resource constraints, and public or government requirements or perceptions.

#### Waves and Breaker Energy

Small boats operating near shore, or responders working near the water's edge, are directly exposed to hazards from nearshore waves and breakers. Although these can usually be easily seen and activities adjusted to account for them, unexpected or unpredictable conditions can occur, since:

- Vessel wakes can travel several miles, and produce unexpected, steep, breaking waves 3 or 4 feet (0.9 or 1.2 meters) high;
- Wave and breaker heights can vary unexpectedly (and rare, but dangerous, "sneaker" waves can occur on open ocean coasts); and
- Dangerous wave backwash and rip currents are common along open ocean coasts.

Most shallow- or calm-water booms are ineffective in waves over two feet because they cannot follow short, choppy waves. Although specifically designed for use at the water's edge, shoreline or intertidal booms can be easily rolled or twisted by wave action.

#### Tides

Though tides and currents are predictable, rapid changes in water levels can isolate and strand unwary personnel, particularly in areas with high tidal ranges, or on wide, flat intertidal areas. Tidal changes from storm surges or wind setups are not as readily predictable, but must also be considered.

## Currents

Nearshore currents may be strong (particularly tidal inlet currents, longshore currents, or rip currents), and booms must be regularly redeployed or reconfigured to account for changing water flow.

## Weather

Coastal weather can change rapidly and responders must consider the risks from:

- High wind – violent winds (wind shear/microbursts) in electrical storms;
- Remote access – isolation of responders;
- Low visibility – fog, rain, snow, smoke, darkness, or extreme light intensity;
- Ice formation – rafting, damming, or breakup – vessel or equipment icing; sea/river ice floes;
- Intense precipitation – flooding, ground destabilization (mudslides/sinkholes); and
- Extreme temperature/humidity – hypothermia/hyperthermia.

## Shoreline Condition

Not all response methods are appropriate for every shoreline type; some may be impractical, unfeasible, environmentally intrusive, or damaging. Shoreline conditions to be evaluated, so responders can select proper response methods, will include:

- Rock falls or slides from backshore cliffs;
- Slippery rock surfaces;
- Presence of ice;
- Limited bearing capacity on mud flats, sand flats, beaches, backshore areas;
- Beach or backshore width and accessibility; and
- Surface mat stability in floating marshes (bogs).

## Water Depths and Sea Bottom Character

Nearshore operational safety depends, in part, on responders' knowledge of bottom configuration and navigation conditions (e.g., bottom conditions will dictate which anchors or mooring systems will work; generally, rock bottoms provide poor anchorage). Keys to success include local knowledge, and the scale, accuracy, and availability of:

- Nautical charts; and
- Sailing directions and Notices to Mariners.

**Environmental (Ecological) Constraints**

Response strategies must allow responders to meet defined response objectives without causing more damage than the oil itself. If, after initially removing gross oil amounts, the level of intrusion necessary to remove any residual oil may cause unacceptable changes, damage, or become inefficient, response activities should be modified. This concept is discussed in Section 2.3.

Certain animals, plants, or insects may be hazardous to shore-zone responders, and response managers must make full use of local knowledge to help reduce such risks (during the *Exxon Valdez* response, armed guards were used to protect responders from Kodiak brown bears).

**Human Use Constraints**

Day-to-day human activities can affect responder safety afloat or ashore:

- Small boats, commercial traffic, ocean-going vessels, or ferries may transit areas where response activities are planned or underway;
- Vehicle traffic on piers, wharves, docks, or backshore roads may be dangerous; and
- Backshore residential, commercial, industrial, or recreational activities may conflict with response operations.

**Cultural Constraints**

Historically-, archaeologically-, or culturally-significant sites or resources are found on all coasts, but are more likely in areas remote from, or undisturbed by, recent human activity (e.g., much of the Pacific Northwest coast). Even if these sites are not directly affected by oil, shoreline activities may result in contact with these resources.

If such sites are present within response areas, special permission will normally be required from cognizant tribal, government, cultural, historic, or archeological organizations prior to commencing cleanup activities.

### *Authorization*

In addition to shoreline access, which may require permission from outside the response organization, government organizations:

- May restrict use of non-mechanical countermeasures listed on the National Contingency Plan Product Schedule (e.g., dispersants, surface washing agents, bioremediation agents, or burning); and
- Will require specific authorization and permits to transport and dispose (including temporary storage of recovered oily materials) of recovered oily wastes.

## 4.2 PROCESS FOR DEVELOPING INCIDENT- SPECIFIC STRATEGIES

Spill response management follows a general sequence of steps for each spill, spill phase, and response location:

1. Gather information and assess the situation.
2. Define response goals and priorities.
3. Define response objective(s).
4. Develop strategies to meet the objectives, based on windows of opportunity.
5. Evaluate the feasibility of the options and strategies in view of the environmental conditions and spill specifics.
6. Select response options and tactical arrangements to implement identified strategies (begin process to obtain necessary approvals, permission, permits).
7. Prepare an Incident Action Plan for carrying out the identified strategies.
8. Implement field response operations plans for each strategy.

While certain objectives, strategies, and tactics can be identified prior to an incident, and will usually be included in both owner/operator response plans and area contingency plans, responders must develop incident-specific response strategies (step 4, above) at the time of the incident. Steps 4, 5, and 6 are related to the incident response objectives, and are subject to a variety of incident-specific conditions, such as those discussed in detail in the remainder of this section. The remaining steps will be sufficiently incident-specific that discussing them further in this manual is not possible.

### INTEGRATION OF ON-WATER RESPONSE OPTIONS

If a response objective is to minimize or prevent shoreline impact, using multiple, integrated on-water countermeasures offers the best chance of success. Thus, if "very early" window of opportunity options are to be used, decision-making, strategic plan development and approvals, and implementation must be rapid.

Each response tool has advantages, disadvantages, and limitations in its effectiveness requiring decision-makers to weigh various tradeoffs when considering and comparing response options. Since there is no single, perfect response option, the best solution is to use all the "tools in the toolbox" in combined (integrated) operations to achieve response objectives. In general, these tools include:

- Monitor and wait. No active response to remove oil;
- Physical containment and mechanical recovery. Removes oil from the water, with few environmental impacts, but involves operational limitations associated with weather, visibility, physics, etc.;
- Dispersant application. Protects waterfowl and shoreline habitats, but increases oil in the water column and exposure of water column organisms;
- *In-situ* burning. Protects sensitive shoreline habitats by removing floating, burnable oil, but heavy, black smoke is unsightly, alarming, and can be a respiratory hazard for humans and animals. Removal of burn residue may be technologically difficult and may further damage the environment; and
- Shoreline cleanup will not disrupt water column species, but allowing oil to reach shore means that intertidal and shore-based species will have already been impacted.

## *Temporal Considerations*

Mechanical recovery, dispersant application, and *in-situ* burning operations can be used singly, or in combination, to improve efficiency and effectiveness.

- Mechanical Recovery: oil that escapes containment or recovery will still be available for subsequent mechanical removal, treatment with dispersants, or for burning;
- Dispersants: some of the dispersant-treated slick may actually be missed and be available for additional dispersant operations, burning, or mechanical containment and recovery (except oleophilic skimmers for a few hours). Also, containing and burning a partially-treated slick should remain viable, since dispersant application may decrease the slick's tendency to emulsify and prolong or re-open the window of opportunity for burning;
- Burning: most (>90%) of the oil burned will be converted to carbon dioxide, water vapor, and soot. Any oil that escapes the fire boom will be available downstream for re-collection and burning, mechanical recovery, or dispersant treatment; and
- The residues from a successful burn or partially-burned Categories III and IV oils, on the other hand, are not suitable for chemical dispersion; however, physical removal will be possible using viscous-oil recovery systems, or nets

and hand tools. If partially burned oil/residue sinks, then the environmental consequences of leaving the submerged oil must be compared to the consequences of removing the submerged material.

### *Spatial Considerations*

Integrating response options also includes spatial considerations (Figure 6). For safety reasons, combined, simultaneous operations should be conducted only in specific safe operating zones which are based upon the following (taking into account spill and site specifics):

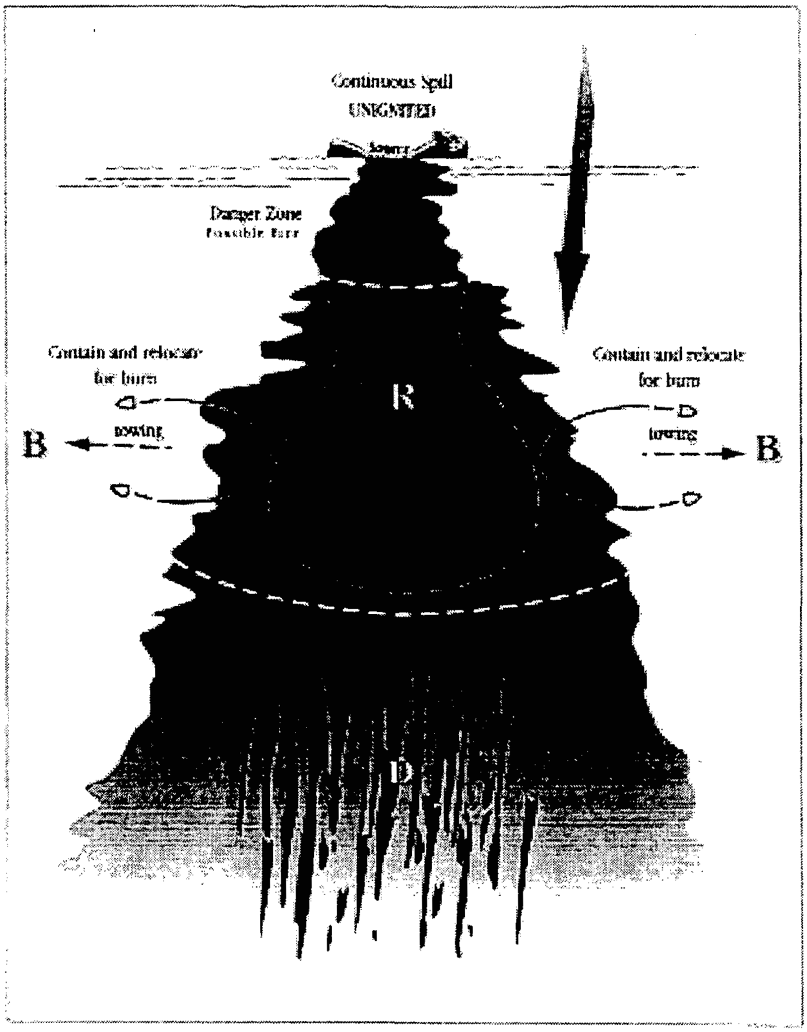
- Response vessels must always be sufficiently separated from each other to preclude near misses, collisions, or other disruptions of operations;
- Aircraft operations must be coordinated through a single air-traffic control system with specific directives for allowable altitudes, air-space, air and surface radio frequencies, emergency procedures, etc.;
- Mechanical cleanup and *in-situ* burning operations should be positioned in the thickest layers of oil, consistent with safety and environmental constraints;
- Burning should be positioned and conducted to: 1) avoid ignition of source; 2) avoid endangering personnel, facilities, vessels, or equipment downstream/downwind; 3) prevent accidental ignition of nearby contained or uncontained slicks or vapors; and
- Dispersants should be used on slicks that are sufficiently downstream/downwind from other operations that wind or current will not carry dispersant into those operating areas. Safe operating distances will be spill-specific.

## SHORELINE STRATEGIES

Shoreline response strategies differ from on-water response strategies because:

- Stranded oil generally remains in place or is slow-moving; and
- Land-based operations usually are less weather-dependent than water-based activities, and there are different safety and feasibility factors to consider.

Since shoreline response can be a long-term operation (days-weeks-months), integrating multiple shoreline protection and cleanup options into strategies which are implemented simultaneously is common practice (nearshore containment and




Source: Alan A. Allen, 1998

**Figure 6.** Spatial considerations for integrated operations on a continuous release spill. R=recovery; D-dispersant; B=*in-situ* burning

recovery often take place alongside various types of shoreline cleanup).

The following discussion includes all options operated from shore.

### *Shoreline Protection*

The basic shoreline protection objective is to:

- Prevent, or minimize, contact between oil and the shore zone (or a resource at risk in the zone).

This can be done by combining activities, techniques, and equipment to:

- Remove shoreline debris before the oil is washed ashore;
- Contain and recover floating oil prior to shoreline impact;
- Deflect oil away from shore;
- Trap or contain and collect oil at the shoreline;
- Prevent stranded oil from refloating and affecting adjacent areas; and
- Prevent oil being washed over a beach into a lagoon or backshore area.

### *Shoreline Treatment and Cleanup*

For an impacted shoreline, the main treatment objective is often to restore the oiled shore zone to a pre-spill "clean" condition. But defining a specific level of "clean" will be different for each spill (or even different for different phases of a single response) and, although promoting recovery usually includes removing some portion of the oil and allowing the rest of the oil or residue to degrade naturally, the best course of action may be to let all the oil degrade naturally. Final levels of allowable oil concentrations can, and should, be determined by consensus (considering overall environmental consequences) during contingency planning and sensitivity mapping prior to any spill. This process should balance conflicting environmental and socioeconomic concerns.

Reducing overall environmental consequences in an effective and efficient manner usually requires a combination of techniques, including:

- Natural recovery;
- Physical washing;
- Physical removal;
- Physical *in-situ* treatment (including burning); and
- Chemical or biological treatment.

# CHAPTER 5.0

# EVALUATION OF RESPONSE OPTIONS IN VARIOUS HABITATS

## 5.1 INTRODUCTION

This chapter presents the predicted environmental impacts of the various response methods in 1) on-water, 2) shallow subtidal, 3) shoreline intertidal, and 4) ice habitats, with each of the five oil groups.

**The reader is cautioned to use the information from the tables in the context of the accompanying text, which is intended to clarify and enhance their usefulness.**

Four environment categories have been selected to provide convenient groupings of the habitats. They do not encompass all marine habitats, and category titles alone are not uniquely descriptive of the habitats addressed.

- The **On-water** environment includes marine water column and surface habitats, without specific reference to potentially overlapping benthic or intertidal habitats. The two habitats discussed in Section 5.2 are:
  - Offshore
  - Bays and estuaries
- **Shallow Subtidal** environments are of particular interest because they are susceptible to damaging exposure from the soluble and/or dispersed fractions of spilled oil, to oily runoff from beach cleaning, and to physical damage by on-water response forces (vessels, anchors, booms, etc.). The five habitats discussed in Section 5.3 include three sensitive benthic areas, and two general bottom types:
  - Coral
  - Seagrasses
  - Kelp
  - Soft bottom
  - Mixed and hard bottom

The **Shoreline Intertidal** environment includes those impacted when floating oil strands at the shoreline. The impact of oil and of cleanup methods on these habitats is generally highly visible and has been relatively well documented and understood for some time. Intertidal habitats addressed in Section 5.4 are:

- Exposed rocky shores
- Exposed, solid, man-made structures
- Exposed, wave-cut platforms
- Sand beaches/tundra cliffs
- Mixed sand and gravel beaches
- Gravel beaches
- Riprap
- Exposed tidal flats
- Sheltered rocky shores
- Sheltered, solid, man-made structures
- Peat shores
- Sheltered tidal flats
- Marshes (salt to brackish)
- Mangroves, and
- Inundated lowland tundra

- **Ice** environments, Section 5.5, address:
  - Accessible ice and
  - Inaccessible ice

For each of the four environment categories above, analysis of the environmental impact information is presented in tables and text. The presentation format (tables and text) differs somewhat among environment categories to allow the authors to best address unique aspects of the respective categories. Nevertheless, habitat description, sensitivity, and response methods are addressed for each habitat, and summary tables predict relative environmental impact for each response method with each oil group. The reader is reminded to refer to Chapter 3.3 for a detailed description of the scoring used in the tables.

## 5.2 ON-WATER HABITATS

Information for on-water response is presented separately from subtidal or shoreline habitats and is divided into two habitats: 1) offshore; and 2) bays and estuaries. For the on-water habitats, it is often true that: 1) spill response is not conducted from a shoreline, but from water-based vessels or aircraft; and 2) response activities are focused on removing oil from the water surface. Since oil slicks are mobile and can be driven by wind or water currents onto shorelines or into sensitive nearshore habitats (e.g., coral reefs, and mangroves), an important response performance consideration is the degree to which oil on the water can be either recovered, contained, or modified to reduce oil exposure in other habitats.

The ability of *on-water* response methods to prevent oil from stranding on a shoreline or reaching sensitive benthic or water column resources, can influence the need for any nearshore or shoreline response activities. Therefore, on-water spill response objectives include:

- Reducing impacts to organisms that live on or in the sea surface;
- Reducing the extent of impacts to sensitive nearshore subtidal or intertidal habitats; and
- Increasing the degradation rate of any unrecovered oil to reduce negative long-term environmental effects.

In addition to the amount of spilled oil removed, on-water spill response performance is often measured by the level of impacts which occur in addition to those caused by the spilled oil. Refer to Table 3 for a comparison of the environmental impact from on-water response options in the absence of oil. Because no single response option can accomplish all three on-water response objectives completely, a response strategy should include reasonable combinations of methods to obtain a high oil encounter rate (area/time).

Eliminating spilled oil from an on-water habitat lessens the potential for oil to reach and impact other habitats. Response performance, measured via the likelihood of spilled oil from on-water habitats being transported elsewhere, is explicitly considered in this Section, in contrast to determination of relative environmental impact to nearshore and shoreline habitats addressed in Sections 5.3 and 5.4.

The range of response options suitable for use in open waters is less than that for shorelines. The primary response tools are containment booms and skimmers (mechanical), dispersants (chemical), and *in-situ* burning. If there is little chance of shoreline impact, and the spilled oil readily weathers, natural recovery may be the best option.

Chemical countermeasure products (CCPs), other than dispersants, such as elasticity modifiers, have not been adequately developed nor demonstrated for an informed assessment of potential environmental impact. Excluding dispersants, CCPs are not usually stand-alone response options; their main function is to modify oil properties to improve the performance of other response methods. For example, elasticity modifiers give the oil cohesive properties which enhance mechanical skimming operations, but they do not remove oil from the water surface. Emulsion-treating agents could be used as an initial step for each of the primary response methods.

## FEASIBILITY AND EFFECTIVENESS

For a specific spill, advice from responders with local knowledge and expertise can be critical for assessing feasibility and expected relative effectiveness of response methods. Feasibility is the *ability* to employ a response method. Relative effectiveness is a measure of the *quantity* of oil recovered or removed, and then prevented from impacting another habitat.

The dominant factors which influence response effectiveness for a particular spill are: 1) weather conditions; 2) oil properties; and 3) equipment limitations. Factors favoring feasibility and effectiveness for each method class are summarized in Table 7 and are discussed in more detail in Chapter 4 (Section 4.2). The greater the number of favorable factors, the greater the quantity of oil removed, dispersed, or burned. An integrated response using two or more methods should be considered to reduce the quantity of this remaining fraction of oil and, therefore, potential impacts. The elapsed time to respond is an indicator of how rapidly actions can be taken to minimize the potential damage to adjacent shoreline habitats. Any of the three types of methods has the potential to minimize environmental effects if it can be successfully implemented in the earliest stages of a spill. Implementation is dependent on a variety of factors, most notably the ability to deliver and deploy necessary equipment material.

**Table 7.** Factors favoring feasibility and effectiveness of on-water spill response.

| Response Options | Factors |
|---|---|
| Mechanical (containment and recovery) | • Low wind and sea state (wind ≤ 12 kt; Beaufort Force 3 seas, or below)<br>• Thick oil layer (> 1 mm)<br>• Sufficient storage for recovered oil and water mixture<br>• Availability of equipment and short travel time to spill<br>• Oil not highly viscous<br>• For Category V oils, special mechanical equipment (dredges, vacuum systems, and nets)<br>• Generally not appropriate for Category I oils |
| Dispersant | • Calm to moderate sea state *for application* (wind ≤ 24 kt; Beaufort Force 5 seas, or below)<br>• Moderate to high sea state *after application* (wind >25 kt; approximately Beaufort Force 6 seas)<br>• Oil has not formed a highly stable emulsion ("mousse")<br>• Average oil thickness 0.1-0.2 mm<br>• Effective dispersant formulation<br>• Availability of equipment and short travel time to spill<br>• Oil type must be dispersible |
| Burning (containment and recovery) | • Low wind and sea state (wind ≤ 12 kt; Beaufort Force 3 seas or below)<br>• Thick oil layer (> 2 to 3 mm after containment)<br>• Oil has not significantly emulsified (< 20-30% water)<br>• Oil contains sufficient light ends to ignite<br>• Availability of equipment and short travel time to spill |

The two most influential sea state factors for on-water spill response are wind speed and wave height. Responders cannot control these conditions and must adjust their activities appropriately. The influence of these factors on response feasibility and effectiveness is presented in Table 8. At winds ≥ 15 knots, waves begin overpowering the ability of booms to hold or deflect oil. Spilled oil disperses more readily at higher wave heights, but application can become more difficult. For example,

- At high wind conditions (i.e., > 15 knots), the feasibility/relative effectiveness of dispersant is ranked low (L) because of potential difficulties in application and targeting accuracy. With satisfactory application, this rating can be upgraded to high (H). Large, multi-engine airplanes such as Hercules C-130s, DC-4s, and DC-3s can apply dispersant in winds up to ≈ 35 knots. Slick targeting is less critical with high sea energy because that energy can drive physical dispersion. Dispersants have a medium (M) relative effectiveness

**Table 8.** Estimate of wind speed and sea height influences on effectiveness and feasibility of on-water response options by oil type.

| Method | Feasibility of Response/Relative Effectiveness (for a moderate sized spill of 500-5,000 bbls) Wind Speed (knots)[1] | | |
|---|---|---|---|
| | **0 – 5 (wave height 0-0.5 ft)** | **5 – 15 (wave height 0.5-5 ft)** | **>15 (wave height >5 ft)** |
| Mechanical | | | |
| Category I[2] | M | L | NF |
| Category II | M | L | NF |
| Category III | M | L | NF |
| Category IV | M | L | NF |
| Category V | L | NF | NF |
| Dispersants | | | |
| Category I | M | H | L |
| Category II | M | H | L[3] |
| Category III | M | H | L[3] |
| Category IV | L | M | NF |
| Category V | – | – | – |
| Burning | | | |
| Category I[2] | – | – | – |
| Category II | H | M | NF |
| Category III | H | M | NF |
| Category IV | M | L | NF |
| Category V | – | – | – |

NF = Generally not feasible; L = Low feasibility and low relative effectiveness; M = Feasible and moderate relative effectiveness
H = Very feasible and high relative effectiveness; – = Not applicable for this type oil

1 Wind speed categories are relative to the speed of wind that results in boom failure (≅ 15 knots).
2 Concerns about responder safety will limit response activities with Category I oil spills.
3 With good mixing conditions at high winds, dispersant use can be quite effective if application is successful.

rating at low wind speeds because, although application conditions are ideal, the mixing energy is low; and

- For Category IV oils, the medium (M) ranking for mechanical response options at low sea heights is based on use of special skimmers (i.e., belt or brush-type) which work better on thicker oil films. Because of the greater thickness and viscosity of Category IV oil films, dispersant application rates higher than normal may be needed (i.e., > 5-10 gal per acre and > 1:20 dispersant:oil ratio).

## Relative Environmental Impacts for On-Water Response Options

The principal on-water response options which offer the best opportunities for oil removal are mechanical, dispersants, and burning. Other response options, e.g., CCPs, may offer opportunities for treatment of an oil slick, but most CCPs have not been adequately developed nor field tested for an informed assessment of their effectiveness or potential environmental impact. Excluding dispersants, CCPs are not usually stand-alone response options; their main function is to modify oil properties to improve the performance of other response methods.

The relative environmental impact for on-water response methods is presented in Tables 9 and 10. Information is provided by habitat according to the five representative oil types (Category I - V), as described in Section 2.1. Rankings are given for the relative environmental impact of the response methods in the on-water habitat where the spill is considered *to have occurred,* and does not include any subsequent impacts to adjacent habitats. Refer to the descriptions of the response options and their function(s) in Chapter 3. If interested in relative impacts to benthic organisms in nearshore habitats, refer to Tables 11 - 15 for specific shallow subtidal bottom habitats.

## OFFSHORE

### *Habitat Description*

Offshore waters are those where the water depth is > 30 feet (10 meters) and there is no surrounding land. Spilled oil transport is more controlled by wind and ocean currents than by tides or mixing with freshwater outflows.

Animals which use this habitat include marine mammals, sea turtles, pelagic birds, and many commercially and recreationally important fish and pelagic invertebrates (e.g., squid). Although organism densities in this habitat are generally low, there are times of localized high densities. For example, upwelling of nutrient-rich, deep waters rapidly increases the productivity of warmer surface waters. Evaluation of environmental impacts to open water habitats is focused on water column organisms and those which inhabit or use the sea surface.

### *Sensitivity*

Biological resources in the water column are less vulnerable to spills than nearshore resources. Although the sea surface microlayer is an important zone for many biochemical processes, data indicates that most oil spills would not affect a sufficiently large area to be of ecological importance. In the top few meters where dissolved or dispersed oil concentrations are likely to be greatest, the organisms most vulnerable to exposure are poor or passive swimmers (planktonic forms). The potential for adverse impacts to water column organisms declines within hours and days post-spill because most of the soluble and toxic components of the spilled oil evaporate.

Pelagic birds are at greatest risk from surface slicks since large numbers are concentrated in various areas at different times for feeding, migration, overwintering, or breeding. Even direct contact with very low concentrations of oil can adversely impact birds through direct ingestion during preening, or by lessening the waterproof and insulation qualities of feathers. Little is known, however, about the impacts of oil on some other animals, such as whales and turtles.

**Table 9.** Relative environmental impact from response methods for OFFSHORE. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Booming-Containment | – | A | A | A | – |
| **Booming-Deflection/Exclusion** | A | A | A | A | – |
| Skimming | – | A | A | A | – |
| **Physical Herding** | B | B | B | B | – |
| Manual Oil Removal/Cleaning | – | – | – | – | – |
| **Sorbents** | – | B | B | B | – |
| Debris Removal | – | A | A | A | – |
| **Dispersants** | B | A | A | A | – |
| Emulsion-treating Agents | – | B | B | B | – |
| **Elasticity Modifiers** | – | B | B | – | – |
| Herding Agents | – | B | B | – | – |
| **Solidifiers** | – | B | B | – | – |
| *In-situ* Burning | – | A | A | A | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Offshore*

Category V oils are likely to submerge, and since most response methods can only be used on the surface of the water, most methods are labeled not applicable for Category V oils. Special equipment may be needed for some products (e.g., containment booms which extend at least 3 m below the surface and air-injected recirculation pumps to coagulate emulsified particles). If submerged, Category V oils will have little impact to water column organisms but may smother benthic organisms.

**Natural Recovery**

- Low impact except for Category III to Category V oils which are persistent and may eventually strand on shorelines.
- May have some adverse impacts to pelagic birds, particularly off the continental shelf, from contact with surface oil.

**Booming - Containment**

- Not applicable for Category I oils because of safety concerns.
- Most effective in low-wave conditions and slow currents.
- No impact in deep waters.
- Should be used in combination with recovery or removal methods (e.g., skimmers, burning).

**Booming - Deflection/Exclusion**

- Most effective in low-wave conditions and slow currents.
- No impact in deep waters.

**Skimming**

- Effectiveness limited by widely-spread, thin oil slicks.
- Not applicable to Category I oils because of safety concerns.

**Physical Herding**

- May be needed under calm conditions to move oil toward recovery devices.
- Water spray onto gasoline likely to mix the product into the water column.

**Manual Oil Removal/Cleaning**

- Manual labor with hand tools is rarely used offshore.

Mechanical Oil Removal

Sorbents

- Not a stand-alone technique except for very small spills.
- Inhibit the evaporation of gasoline spills.

Debris Removal

- Debris removal is rarely used offshore.

Dispersants

- Inhibit the evaporation of Category I spills.
- Less effective on heavy or weathered oils.
- Use requires comparing the impact of dispersed versus undispersed oil.
- Concentrations of dispersed oil will initially increase near the surface but will rapidly decline due to mixing and dilution.

Emulsion-treating Agents

- Not applicable to Category I oils that do not form stable emulsions.

Elasticity Modifiers

- Not appropriate to Category I oils because of safety concerns during application and inhibition of evaporation.
- Not appropriate on Category IV and V oils because they are already viscous.

Herding Agents

- Most effective under calm conditions and with low viscosity oils.

Solidifiers

- Not appropriate to Category I oils because of safety concerns during application and inhibition of evaporation.
- Not appropriate on Category IV and V oils because they are already viscous.
- Recovery of treated oil must be considered.

*In-situ* Burning

- More difficult to ignite emulsified and heavy oils and to sustain the burn.
- Safety issues for workers, vessels, and aircraft must be addressed.
- Not applicable to Category I spills due to safety concerns.

- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.

## Bays and Estuaries

### *Habitat Description*

Bays and estuaries are near-coastal waters partially surrounded by land, are more sheltered than the offshore habitats, and have more limited circulation and flushing offshore. Depths for this habitat are frequently <30 feet (10 meters), and because of the likelihood of shallower depths, bottom habitats (benthic organisms) can be impacted. Tides and freshwater mixing influence the distribution of species and have a substantial effect on spilled oil. Flushing and dilution rates vary greatly and suspended sediment concentrations can be high.

Estuaries and bays are used by commercially or recreationally important finfish, shellfish, and other organisms which migrate seasonally into estuaries or use these habitats for breeding and nursery areas only or live there exclusively. Because of the shallow depths and access to food, this habitat is used by large numbers of migratory or wintering waterfowl, wading, and diving birds. Bays and estuaries are also home to marine mammals and sea turtles.

### *Sensitivity*

Bays and estuaries can be highly sensitive to oil spills, particularly where flushing rates are low and the probability of contact increases, because early life stages of many organisms tend to concentrate in bays and estuaries. These habitats have the greatest potential for impact to: 1) biological resources in the water column (lower water volumes for dilution); 2) benthic organisms (proximity of water bottom and high depositional areas that may concentrate oil); 3) marine mammals; and 4) colonies of water fowl and wading birds. Stranded oil on nearby shorelines can become a prolonged source of oil re-released to the water column.

To protect biological resources, use of certain response options is seasonally limited. Examine the life histories of important species for the specific area to be protected to determine localized and temporal restrictions or preferences. Bays and estuaries provide shelter for many bird species, and adverse effects would be greatest during migration and overwintering when the birds form large flocks. Many species spawn in these habitats during spring, and their sensitive early life stages may persist in shallow waters. Notable examples include: herring, spawning horseshoe crabs; juvenile shrimp and crabs; and salmon smolt.

**Table 10.** Relative environmental impact from response methods for BAYS AND ESTUARIES. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* *I* | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | B | B | C | C |
| Booming-Containment | – | A | A | B | – |
| **Booming-Deflection/Exclusion** | A | A | A | B | – |
| Skimming | – | A | A | A | – |
| **Physical Herding** | B | B | B | B | – |
| Manual Oil Removal/Cleaning | – | – | C | B | B |
| **Sorbents** | – | B | B | B | – |
| Debris Removal | – | A | A | A | B |
| **Dispersants** | B | B | B | B | – |
| Emulsion-treating Agents | – | B | B | B | – |
| **Elasticity Modifiers** | – | B | B | – | – |
| Herding Agents | – | B | B | – | – |
| **Solidifiers** | – | B | B | – | – |
| *In-situ* Burning | – | A | A | B | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

### *Response Methods: Bays and Estuaries*

Since Category V oils are likely to submerge, many methods are not applicable. Special equipment may be needed for some products [e.g., containment booms which extend at least 9 feet (3 meters) below the surface and air-injected recirculation pumps to coagulate emulsified particles]. If submerged, Category V oils will have little impact to water column organisms but may smother benthic organisms.

**Natural Recovery**

- Heavier oils are more persistent and may affect shorelines.
- Category I oils tend to be less persistent.

**Booming - Containment**

- Most effective in low-wave conditions and slow currents.
- Should be used in combination with recovery or removal methods (e.g., skimmers, burning).
- Safety concerns limit the containment of gasoline spills; however, booms can be used to exclude or deflect the spill away from sensitive resources.

**Booming - Deflection/Exclusion**

- Most effective in low-wave conditions and slow currents.

**Skimming**

- Effectiveness limited by widely spread, thin sheets of oil.
- Safety concerns limit the containment and skimmer recovery of gasoline spills.

**Physical Herding**

- May be needed under calm conditions to move oil toward recovery devices.
- Care should be taken not to mix the oil into the water column or sediment.

**Manual Oil Removal/Cleaning**

- May be needed where heavier, more persistent oils have heavily contaminated bottom sediments.
- Usually requires large crews and repeated entries which disrupt substrate and wildlife.
- Not applicable to Category I oils because of safety concerns.

- Not applicable to Category II oils because hand tools tend to be ineffective on these more fluid oils.

Mechanical Oil Removal Sorbents

- Not a stand-alone technique except for very small spills.
- Inhibit the evaporation of gasoline spills.
- Overuse generates excess waste.

Debris Removal

- Operate from small boats to minimize substrate disruption.

Dispersants

- Inhibit the evaporation of Category I spills.
- May reduce fire and explosion hazards of Category I oils, but the dispersed oil may cause impacts on water column and benthic organisms.
- Less effective on heavy or weathered oils.
- Use requires comparing the impact of dispersed versus undispersed oil.
- Shallow water depths and lower dilution rates can result in high aquatic toxicity from oil/dispersant mixtures.

Emulsion-treating Agents

- Not applicable to Category I oils that do not form stable emulsions.

Elasticity Modifiers

- Not appropriate to Category I oils because of safety concerns during application and inhibition of evaporation.
- Not appropriate on Category IV and V oils because they are already viscous.

Herding Agents

- Most effective under calm conditions and for low viscosity oils.
- Should be coupled with recovery when used to protect sensitive habitats.

Solidifiers

- Not appropriate to Category I oils because of safety concerns during application and inhibition of evaporation.
- Not appropriate on Category IV and V oils because they are already viscous.
- Recovery of treated oil must be considered.

***In-situ* Burning**

- More difficult to ignite emulsified and heavy oils and to sustain the burn.
- Safety issues must be addressed.
- Smoke can have a temporary effect on air quality.
- Not applicable to Category I spills due to safety concerns.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.

## 5.3 SHALLOW SUBTIDAL

Whereas the previous section dealt with nearshore on-water habitats, the focus in this section is on specific subtidal habitats and their associated benthic communities. The shallow subtidal environment extends seaward from the low spring tidal level to a water depth of about 30 feet (10 meters). This environment supports an extremely varied community of animals and plants. The exact community of animals and plants present in any one area will be a function of distance from shore, water depth, water temperature, turbidity, sediment grain size, water movement, wave energy, and freshwater influences. The shallow subtidal habitat may have a high total productivity and is often very important to nearshore and offshore fisheries.

Concerns about seafood contamination from dispersed oil or oiled sediments can become a significant issue. Real, potential, or perceived contamination can disrupt seafood harvesting, distribution, and sales activities.

The habitats that are addressed include:

- Coral reefs;
- Seagrasses;
- Kelp beds;
- Soft bottom; and
- Mixed and hard bottom.

The response options for shallow subtidal habitats are discussed from two perspectives. The first is for response actions implemented within the habitat to protect the habitat and associated communities. An example would be removal of sunken tarballs from a seagrass bed. Response actions can also cause physical injury to shallow water habitats (e.g., from propellers, anchors, wading). The second perspective is for response actions implemented in, or adjacent to, the habitat to reduce impacts to more sensitive resources. An example would be use of *in-situ* burning in the vicinity of seagrass beds to reduce impacts along a mangrove-dominated shoreline. The categories of impact listed in the tables reflect the potential impact of each response option on the subtidal habitat, without considering the tradeoffs of impacts between at-risk habitats if one option is selected over another. Responders should use the information in the following tables and text to predict the potential impacts to subtidal resources for each possible response option. For the examples cited, impacts to seagrasses from *in-situ* burning and sunken residues would be compared against those predicted under the spill conditions to mangroves if *in-situ* burning was not used. The tables will help responders compare the relative environmental impacts of possible options for each resource at risk and make such tradeoff decisions.

It is important to reiterate that the impacts associated with Category V oils are subtidal and occur when these types of oil sink. Also, many Category IV oils have the same potential for sinking under certain conditions, e.g., when they pick up sediment, which makes them heavier. The impacts to subtidal resources considered in the tables and text for Category V oils are those resulting from the deposition of oil as tarballs and mats, rather than contaminated sediments.

## CORAL REEFS

### *Habitat Description*

Coral reefs are structures created and maintained by the establishment and growth of populations of stony coral and coralline algae. Coral reefs are mostly subtidal in nature, although the most shallow portions of some reefs can be exposed during very low tides. The four major reef categories are:

- Fringing reefs – long, narrow bands of reefs parallel to, and near, the shore.
- Barrier reefs – similar to fringing reefs except that they occur farther offshore, are broader, and have a lagoon between the reef and land.
- Atoll reefs – circular reefs that form a central, shallow lagoon.
- Patch reefs – small, irregularly-shaped coral reefs that occur in isolated patches. They can occur in conjunction with any of the types of above reefs.

Of special concern are reef flats which are broad, pavement-like platforms formed by reefs when they reach sea level. Some reef flats are also formed by submergence or erosion of carbonate rock. Most of the surface of reef flats is generally in the intertidal and shallow subtidal zone.

Coral reefs support extremely diverse and complex communities. Recent studies have shown that many coral species throughout the world spawn simultaneously over a very short time period (days), a behavior which makes the entire recruitment class very vulnerable.

### *Sensitivity*

Coral reefs vary widely in sensitivity to spilled oil, depending on the water depth, oil type, and duration of exposure. There are three primary exposure pathways: direct contact with floating oil; exposure to dissolved and dispersed oil in the water column; and contamination of the substrate by oil deposited on the seafloor. Floating oil could directly coat reef communities where:

- The landward border of fringing reef platforms is exposed at low tide;
- High coral heads growing on reef flats or shallow patch reefs are exposed; and
- The outer, seaward part of reef-flat platforms (the reef crest) is slightly elevated and exposed at low tide.

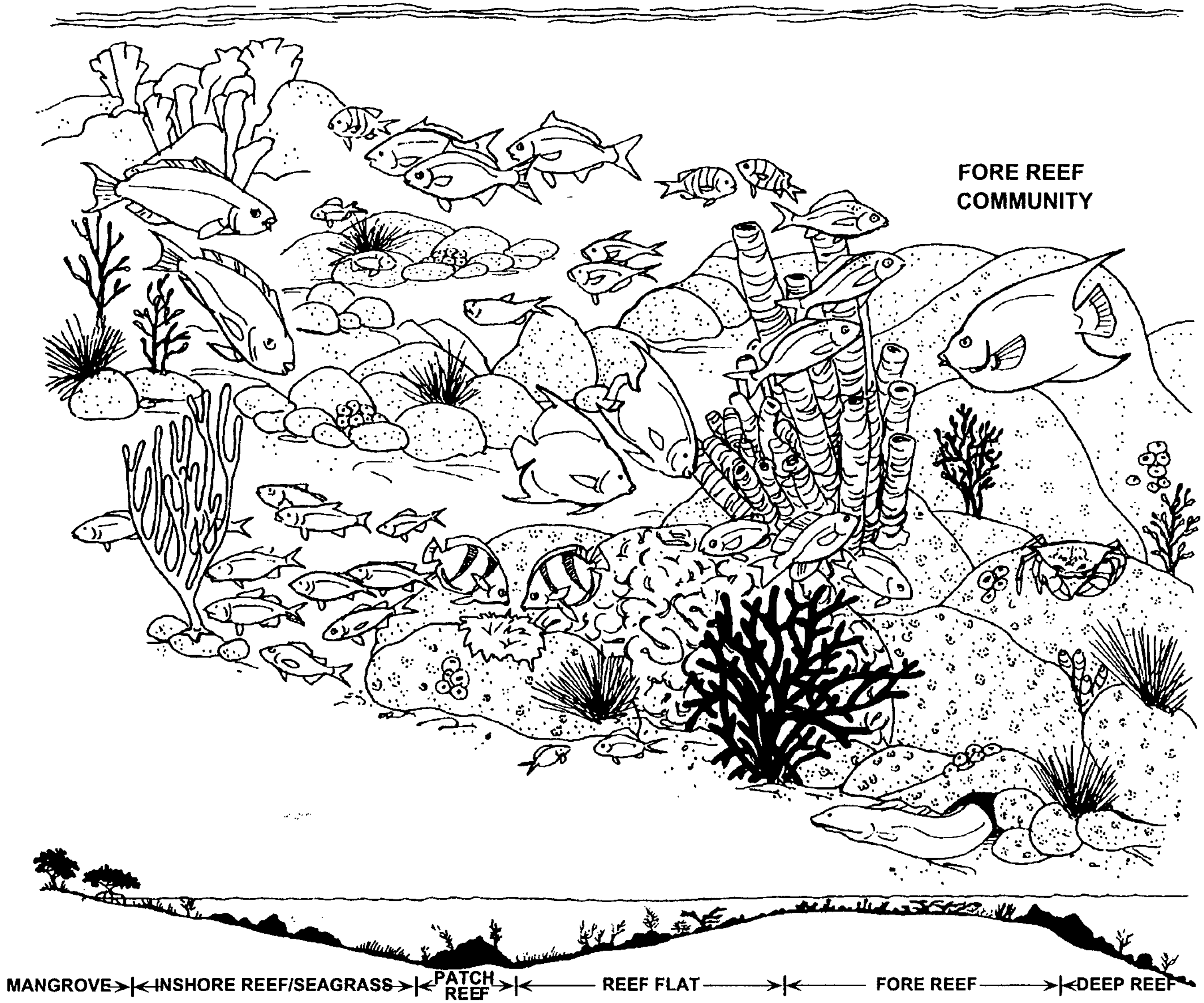
Liquid oil is readily lifted from intertidal reef areas with the rising tide, except under extremely heavy oil concentrations. This is especially true of the outer reef platform, which is heavily washed by waves. Oil can coat elevated coral heads which are dead and dry out at low water, and tarballs can become trapped in the crevices on the rough coral surface.

Oil slicks usually pass over subtidal reefs with no direct contamination, though corals can be affected by exposure to oil dissolved or dispersed in the water. Exposures are generally short-term (hours to days) and recovery usually occurs quickly. However, the reef-associated community of fish crustaceans, sea urchins, etc., can experience significant mortality. Greatest impact would result from spills of light, refined products directly into shallow waters overlying reefs; or spills during coral spawning events, which could affect the larvae of all coral species. There is little documentation of long-term impacts to coral reefs from oil spills, except where the exposure is chronic, such as from oil-handling operations, or where intertidal sediments are a long-term source of re-mobilized oil. It should be noted that there are concerns for coral reef health because coral bleaching unrelated to oil spills is occurring in many reefs, and additional impacts from oiling or response actions would add to the stress experienced by these communities.

The currents around reefs are usually strong enough to prevent large-scale smothering of subtidal reefs by submerged oil. However, oil that is heavier than seawater can become trapped in wave and current shadows, particularly on the landward side of reefs. Floating oil stranded on adjacent beaches can pick up sediment which then get eroded and deposited on the bottom in wave shadows (areas that are relatively unaffected by wave action where oil tends to accumulate) around reefs. In both cases, the oil generally forms tarballs and mats rather than continuous oil layers. The accumulations can be centimeters thick, and the oil can adhere to rock outcrops and coral debris, even underwater. Sometimes the sunken oil can separate from the sediments and re-float, increasing the time of exposure for water-column resources, such as territorial fish and invertebrates.

Figure 7 is an illustration of the coral reef habitat. Table 11 shows the relative impact from various response methods on coral reef habitat.

# CORAL REEF




Source: NOAA, 1998

Figure 7

**Table 11.** Relative environmental impact from response methods for CORAL habitats.
This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* I | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | A | B |
| Booming | – | B | B | B | – |
| **Skimming** | – | B | B | B | – |
| Physical Herding | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | – | D | D |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | B | B | B | C | C |
| Dispersants | – | C | C | C | – |
| ***In-situ* Burning** | – | B | B | B | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Coral Reefs*

**Natural Recovery**

- Removal may be needed where significant amounts of oil have sunk.

**Booming**

- Booming of Category V oils, which are assumed not to float, is not effective.

**Skimming**

- Caution is needed when deploying and anchoring skimmers near reefs to prevent physical damage to the reef.
- Skimming of gasoline is generally not appropriate due to safety concerns.
- Skimming of Category V oils is not effective.

**Physical Herding**

- Not effective in open-water areas with currents and waves.

**Manual Oil Removal/Cleaning**

- Can be used for oil adhered to sheltered nooks on intertidal platforms. Foot and vehicular traffic should not be allowed across the reef flat; thus, access must be from the seaward side via boats.
- Divers can pick up sunken tarballs and mats around reefs without disturbing the coralline community.

**Mechanical Oil Removal**

- Dredging in coral reefs would cause excessive physical disturbances.

**Sorbents**

- Sorbents can be used to recover oil being re-mobilized from adjacent shorelines, though no foot traffic on the reef flat should be allowed.
- Only use sorbents that are contained and can be recovered.
- Can be effective in recovering sunken oil if it re-floats.

**Vacuum**

- Only appropriate for use at high tide where the oil naturally collects against the shoreline or is concentrated by booms. No vehicular nor foot traffic should be allowed on the reef flat.
- Thick oil accumulations on the substrate around subtidal reefs could be removed by diver-directed vacuum pumping. Usually not appropriate for oil-contaminated sediments.

**Debris Removal**

- Oiled debris is not expected to accumulate in coral reef habitats.

**Vegetation Cutting**

- Not applicable to coral reef habitats.

**Low-pressure, Ambient Water Flushing**

- Only flush exposed reefs.
- Use on heavy oils is likely to leave residual oil.

**Dispersants**

- The use of dispersants directly over shallow reefs is likely to have significant impacts to the reef community. However, their use in offshore areas may reduce impacts to highly sensitive intertidal environments.

***In-situ* Burning**

- *In-situ* burning may be considered outside of the immediate vicinity of reefs to protect sensitive intertidal environments.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.
- Category V oils are assumed to be non-floating; thus, burning is not applicable.

## SEAGRASSES

### *Description*

Seagrasses are highly productive habitats that occur on intertidal flats and in shallow coastal waters worldwide from arctic to tropical climates. Distribution of subtidal seagrasses is limited by light penetration (a function of turbidity and water depth), sediment type, salinity, and wave or current energy.

Seagrasses are important to the coastal marine environment because they:

- Help stabilize sediments (their leaves decrease current velocities and their roots bind sediments).
- Produce detritus, which provides a major basis of food chains, although the bulk of the biomass is in the roots (in the rhizomes).
- Support a highly productive community that lives on the surface of the leaves, with a total biomass that can exceed that of the plants themselves.
- Are used as a direct food source by those organisms that graze on seagrasses, namely green turtles, manatees, and waterfowl.
- Provide a habitat which is used by fish and invertebrates as nursery areas.
- Play a key role in nutrient cycling of nitrogen, phosphorous, and sulfur.

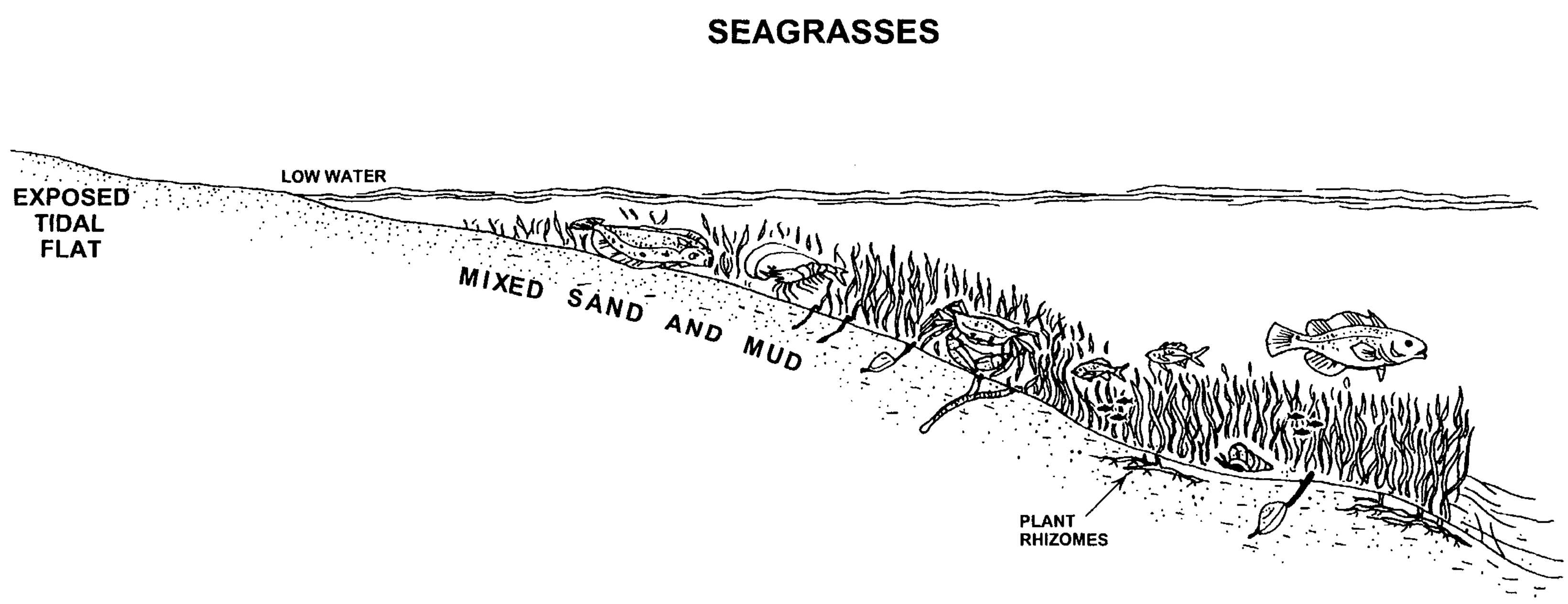
### *Sensitivity*

The sensitivity of seagrasses to oil spills depends on the amount and type of oil, the tidal elevation of the beds, and the degree of exposure to wave and tidal energy. Oil readily adheres to seagrass, and the oiled blades or leaves are quickly defoliated. But, unless the sediments are heavily oiled (which is not common), the plants have the capacity to grow new leaves.

Oil will usually pass over subtidal seagrass beds, resulting in no direct contamination. The plants are not generally affected by short durations of exposure to dissolved/dispersed oil typical of most spills. However, the epiphytic community and the juvenile organisms using the grass beds as a nursery can be highly sensitive to both the water-soluble fraction of the oil and oil that physically coats the vegetation and sediments.

Subtidal seagrass beds are susceptible to contamination by sunken oil or disruption by a response option. The currents in seagrass beds are not always strong enough to prevent the accumulation of submerged oil. Oil that is heavier than seawater can become trapped in the beds, coating the leaves and sediments. Floating oil stranded on adjacent beaches can pick up sediment and then get eroded from the beach face and deposited in adjacent seagrass beds. Refloating of submerged oil can also create a chronic source of exposure. Also, there are concerns about increased susceptibility of seagrasses to other stresses if the sediments become contaminated.

Figure 8 illustrates the seagrass habitat. Table 12 shows the relative impacts from various response methods on seagrass habitat.




Source: NOAA, 1998

Figure 8

**Table 12.** Relative environmental impact from response methods for SEAGRASS habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | B | B |
| Booming | B | B | B | B | – |
| **Skimming** | – | B | B | B | – |
| Physical Herding | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | D | D | D |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | – | B | B | B |
| Vegetation Cutting/Removal | – | – | C | C | C |
| **Low-pressure, Ambient Water Flushing** | – | – | – | – | – |
| Dispersants | – | C | C | C | – |
| ***In-situ* Burning** | – | B | B | B | – |

Category Descriptions

I – Gasoline products

II – Diesel-like products and light crude oils

III – Medium grade crude oils and intermediate products

IV – Heavy crude oils and residual products

V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Seagrasses*

**Natural Recovery**

- Natural recovery minimizes sediment disturbance. Natural cleansing is most effective in areas of moderate to high tidal and wave energy.
- Removal may be needed where significant amounts of oil have sunk.

**Booming**

- Boom can be deployed in seagrass areas to protect intertidal beds and adjacent shoreline habitats. Caution is needed when deploying and anchoring boom to prevent physical damage to seagrass beds.
- Safety concerns limit the containment of gasoline spills; however, boom can be used to exclude or deflect the spill away from sensitive resources.
- Booming of Category V oils is not effective.

**Skimming**

- Caution is needed when deploying and anchoring skimmers near seagrass beds to prevent physical damage to the seagrass bed.
- Skimming of gasoline is generally not appropriate due to safety concerns.
- Skimming of Category V oils, which are assumed not to float, is not effective.

**Physical Herding**

- Possible use where persistent oil is trapped by leaves and flowers growing all the way to the water surface (mostly in brackish areas with very small tidal range).
- Care is needed to prevent sediment suspension and mixing with the oil, and disturbance of roots and vegetation by boat activity.

**Manual Oil Removal/Cleaning**

- Tarballs and mats can be picked up by workers on intertidal beds (preferably from small boats to avoid trampling and driving oil into sediment) or by divers in subtidal beds.
- Caution is needed to prevent physical disturbance of sediments and roots by foot traffic, which should only be allowed on firm substrates and with close monitoring.

**Mechanical Oil Removal**

- Dredging in seagrass beds would cause excessive physical disturbances.

## Sorbents

- Sorbents can be used to recover oil being re-mobilized from adjacent shorelines. Only use sorbents that are contained and can be recovered.
- Can be effective in recovering sunken oil if it re-floats.
- Physical removal rates of heavy oils will be slow, so less oil will be mobilized for recovery by sorbents, particularly for sheltered areas.
- Use of sorbent snare by divers to "scrub" oiled vegetation and sediments will not improve recovery of the seagrass bed itself. This method may be considered necessary to reduce exposure to organisms using the seagrass beds (e.g., turtles, manatees) and to reduce widespread contamination when blades are sloughed off.

## Vacuum

- For intertidal beds, vacuuming is appropriate only at high tide where the oil naturally collects against the shoreline or is concentrated by booms. No vehicular traffic should be allowed in the seagrass beds.
- Thick oil accumulations on the substrate in seagrass beds could be removed by diver-directed vacuum pumping. Not appropriate for oil-contaminated sediments.
- Care should be taken to prevent excessive sediment removal or disturbance of the roots during vacuuming.

## Debris Removal

- Oiled seagrass wrack or plant debris on adjacent beaches should be removed quickly, to prevent transport of oiled detritus into the seagrass beds.

## Vegetation Removal

- Cutting of seagrass is not recommended unless important species, i.e., sea turtles, manatees, or waterfowl, are at significant risk from contact with or ingestion of, oil.
- The oiled blades are naturally sloughed off in days to weeks.
- Seagrass roots should be left intact so that regeneration can occur.

## Low-pressure, Ambient Water Flushing

- Not applicable.

**Dispersants**

- Use of dispersants directly over subtidal seagrass beds can impact the highly sensitive communities. However, use in offshore areas may reduce impacts to highly sensitive intertidal environments.

***In-situ* Burning**

- *In-situ* burning may be considered outside the immediate vicinity of seagrass beds to protect sensitive intertidal environments.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.

## KELP

### *Description*

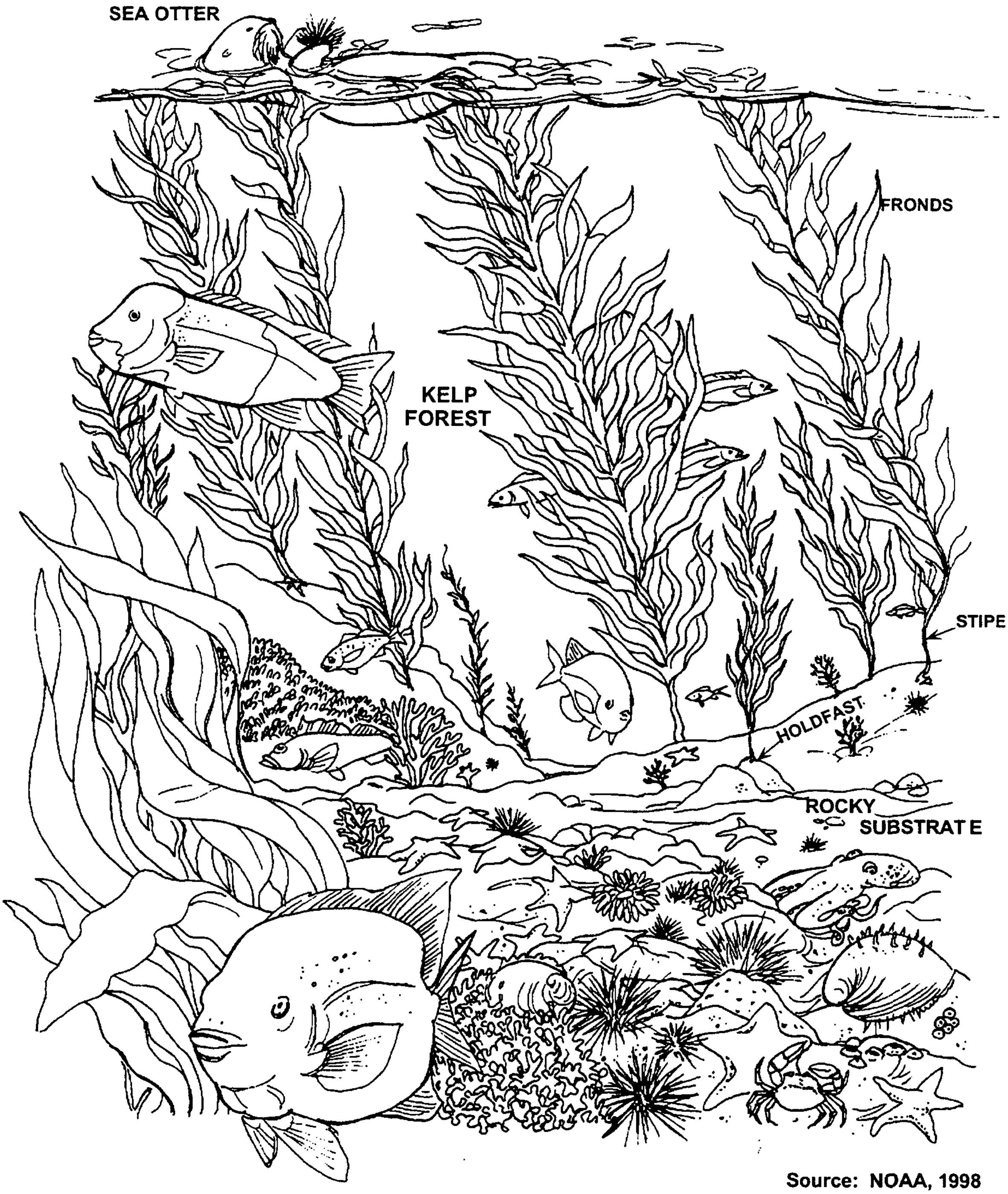
Kelp are very large brown algae which grow on hard subtidal substrates in cold temperate regions. Kelp have a holdfast which attaches to the substrate, a stem-like or trunk-like stipe, and large flattened leaf-like blades called fronds. The upper part of the plant is maintained near or at the surface by the buoyancy of hollow floats. Where there is a floating surface canopy, they are called kelp forests; without a surface canopy, they are called kelp beds. Giant kelp can grow up to about 98 feet (30 meters) in length. Kelp require constant water motion to provide nutrients, thus they are found in relatively high energy settings. With multiple layers of habitats, the kelp forests support a diverse animal community of fish, invertebrates, and marine mammals as well as important algal communities. Kelp are a very important component of the food web and is also commercially harvested (*Macrocystis*).

### *Sensitivity*

Kelp itself is not considered to be very sensitive to spilled oil. It has a mucous coating which prevents oil from adhering directly to the vegetation. Studies with No. 2 fuel oil have shown sublethal responses, but they are usually temporary. The main response issue is often removal of oil which has become trapped in the dense surface canopy, increasing the persistence of oil within the kelp environment. Because many fish and protected marine mammals (e.g., sea otters) are concentrated in kelp forest habitats, oil persistence in kelp increases the risks of exposure of these organisms. Cleanup efforts are often hampered by the difficulty of recovering oil from the dense canopy.

Figure 9 illustrates a kelp habitat. Table 13 shows the relative impacts from various response methods on kelp habitat.

KELP




Source: NOAA, 1998

Figure 9

**Table 13.** Relative environmental impact from response methods for KELP habitats.
This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* *I* | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | B | B |
| Booming | – | B | B | B | – |
| **Skimming** | – | B | B | B | – |
| Physical Herding | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | – | – | – | – | – |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | A | A | A | – |
| Vacuum | – | – | – | – | – |
| **Debris Removal** | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | B | B | – |
| **Low-pressure, Ambient Water Flushing** | – | – | – | – | – |
| Dispersants | – | C | C | C | – |
| ***In-situ* Burning** | – | B | B | B | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Kelp*

<u>Natural Recovery</u>

- Persistence and slow release of medium and heavy oils in the canopy will increase the risk of exposure to organisms in and around the kelp.
- Heavy oils could accumulate in sheltered pockets on the bottom, re-floating during storms and re-exposing resources to the oil.

<u>Booming</u>

- Booms can be used around the perimeter of the kelp. Use caution when anchoring vessels and boom to minimize damage to the kelp.
- Safety concerns limit the containment of gasoline spills; however, booms can be used to exclude or deflect the spill away from sensitive resources.

<u>Skimming</u>

- Generally not feasible in the kelp canopy.
- Some specialized systems, e.g., fox tails, may be useful.
- Skimming of gasoline is generally not appropriate due to safety concerns.
- Skimming of Category V oils is not effective.

<u>Physical Herding</u>

- Directional herding can be used to move oil from the canopy as long as it does not physically damage the plants.
- Minimize boat activity in the kelp canopy.

<u>Manual Oil Removal/Cleaning</u>

- Difficult access to offshore kelp beds makes this option ineffective.

<u>Mechanical Oil Removal</u>

- Kelp generally grows on rocky substrates without significant sediments, so traditional mechanical methods are not applicable.

<u>Sorbents</u>

- Sorbents can be placed at the kelp edge to recover oil being re-mobilized from the canopy. The canopy is usually too thick for pulling sorbents through the canopy.
- Only use sorbents that are contained and can be recovered.

Vacuum

- Difficult access to offshore kelp beds makes this option ineffective.

Vegetation Removal

- Seek expert advice before cutting oiled kelp.
  - Cutting kelp abruptly increases sunlight to the seafloor below.
  - Consider secondary impacts to the associated animal community.
  - Due to different reproductive mechanisms, cutting may be more appropriate for some kelp (*Macrocystis* and *Cystoseria*) but not for others (*Nereocystis*).
- Kelp holdfasts should be left intact so that regeneration can occur.

Low-pressure, Ambient Water Flushing

- Not applicable.

Dispersants

- Little is known about the impacts of dispersants on kelp vegetation.
- The impact of dispersed oil is likely to be greater on the community of organisms associated with the kelp habitat than on the kelp itself.

*In-situ* Burning

- *In-situ* burning in the kelp canopy would likely affect the fronds, but with impacts no greater than cutting.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.
- Use would be conditional on the absence or removal of mammals and birds in the immediate vicinity.

## Soft Bottom

### *Description*

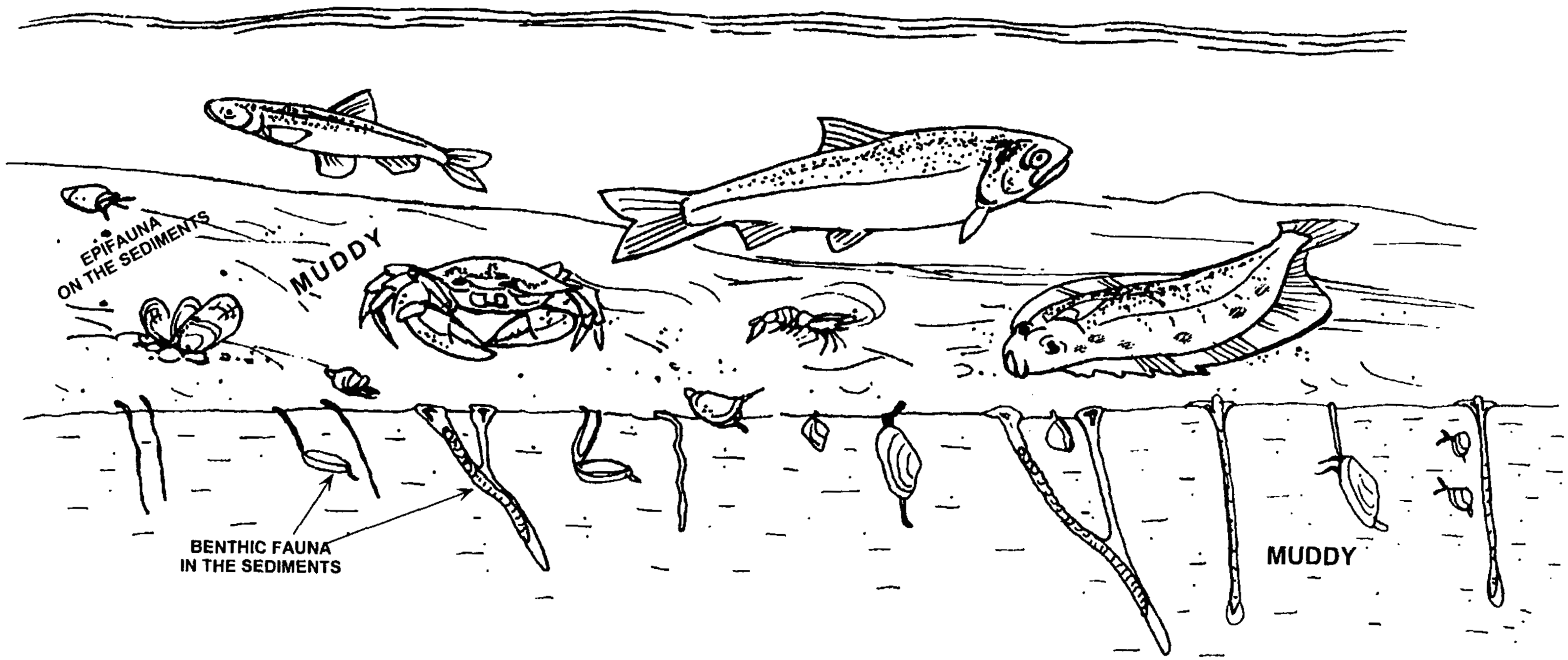
The sediments of soft bottom subtidal habitats consist of various percentages of sand, silt, and clay. Soft bottoms can occur in sheltered bays and estuaries, as well as in deeper offshore areas. The presence of fine-grained sediments is an indicator that the substrate is not exposed to significant wave nor tidal energy. These habitats are likely areas of sediment and contaminant accumulation. They generally support a rich community of organisms that live on, or in, the bottom—shrimp, crabs, clams, fish, and the pelagic and benthic communities that support them (e.g., plankton, worms, amphipods, isopods, etc.).

### *Sensitivity*

Soft subtidal habitats are highly sensitive to oil spill impacts because of the rich biological communities and slow natural removal rates in muddy sediments. However, they are not often exposed to spilled oil. The greatest risk of exposure is from sinking oils which are heavier than the overlying water, or sorption of dispersed oil onto suspended sediments which are then deposited on the bottom. Significant natural dispersion of oil and sediments into the water column occurs only during large storms and nearshore oil spills. Shoreline cleanup can also suspend oil and fine-grained sediments, causing deposition of oily sediments in nearshore habitats. Because of the relatively low energy setting, physical removal rates of oil deposited on the bottom will be slow. Oil persistence will be a function of the degradability of the oil and the depths to which the oil is mixed into the substrate. Benthic organisms may be exposed to 1) dissolved/dispersed oil that mixes in shallow water down to the bottom, and 2) oiled sediments via oil dissolution to the pore or interstitial water in the sediments. Impacts can be both acute and chronic, depending on the oil type, sensitivity of the biota, life stages present, reproductive rates, etc.

Figure 10 illustrates a soft bottom habitat. Table 14 shows the relative impacts from various response methods on soft bottom habitats.

## SOFT BOTTOM




Source: NOAA, 1998

Figure 10

**Table 14.** Relative environmental impact from response methods for SOFT BOTTOM habitats. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | B | B |
| Booming | A | A | A | A | – |
| **Skimming** | – | A | A | A | – |
| Physical Herding | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | – | C | C |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | – | – | – | – | – |
| Dispersants | – | C | C | C | – |
| ***In-situ* Burning** | – | B | B | B | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Soft Bottom*

### Natural Recovery

- Removal may be needed where significant amounts of oil have sunk and formed mats or concentrations of tarballs on the bottom.

### Booming

- Booms can be deployed in soft bottom areas with minimal damage to the substrate.
- Specialized booms can be deployed above the low tide line to protect sheltered tidal flats and marshes.
- Safety concerns limit the containment of gasoline spills; however, booms can be used to exclude or deflect the spill away from sensitive resources.

### Skimming

- Skimming of gasoline is generally not appropriate due to safety concerns.
- Skimming of Category V oils is not effective.

### Physical Herding

- In shallow water, there is some risk of disrupting bottom sediments, suspending sediments, and mixing oil and sediments together.

### Manual Oil Removal/Cleaning

- Divers may pick up sunken tarballs and mats from the bottom, although finding the oil can be very difficult, and significant amounts of oil may be left behind.

### Mechanical Oil Removal

- Dredging may be appropriate for removing thick oil deposits in soft subtidal habitats, particularly in harbors where natural flushing is slow.
- Special efforts will be needed to control suspended sediments and re-suspended oil during recovery operations.

### Sorbents

- Sorbents can be used to recover oil being re-mobilized from adjacent shorelines, although natural removal rates will be slow.
- May be effective in recovering sunken oil if it refloats.

Vacuum

- Thick oil accumulations on muddy substrates could be removed by diver-directed vacuum pumping, though it is likely that not all of the oil can be found and recovered.
- Will result in some sediment disturbance and removal.

Debris Removal

- Most soft subtidal habitats do not contain significant amounts of debris.

Vegetation Removal

- Not appropriate for most muddy habitats because they lack vegetation.

Low-pressure, Ambient Water Flushing

- Not applicable.

Dispersants

- Dispersants can be used over soft subtidal habitats in order to protect more sensitive intertidal environments. Effects on biota are less for applications in deep water and/or high dilution rates.

*In-situ* Burning

- *In-situ* burning can be used to protect sensitive intertidal habitats.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.

## Mixed and Hard Bottom

### *Description*

This habitat includes subtidal substrates composed of rock, boulders, or cobbles, although there may be patches of sand veneer covering a base of hard bottom. Silt- and clay-sized sediments are generally lacking, because the high energy environment sweeps them away or there is no local source of these sediment sizes. Examples of these habitats include the rocky subtidal off California, Oregon, Washington, Alaska, and Maine, carbonate reefs such as in Florida, and live bottom areas on bedrock outcrops in an otherwise soft bottom region. These habitats can have rich and diverse communities of attached and associated algae and animals; oftentimes there is little, if any, open space. Some of these habitats form a relief several meters high (reef or bank) which attracts a diversity of fish. Some hard bottom habitats are dominated by kelp beds; however, they are discussed above under "Kelp".

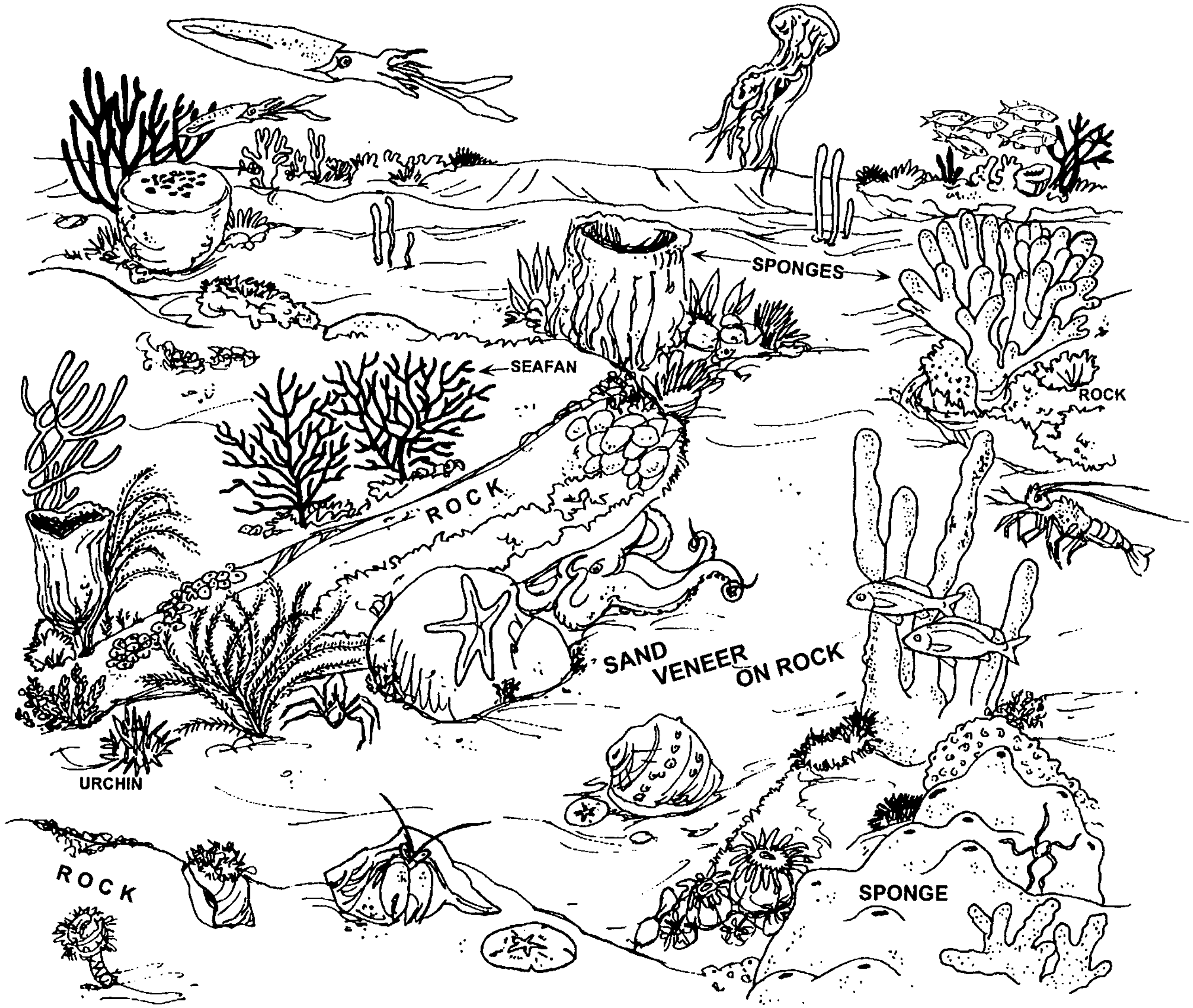
### *Sensitivity*

Mixed and hard bottom habitats are usually considered to have low vulnerability to oil spills. Because of the relatively high dilution rates, oil in the water column seldom reaches toxic levels and benthic organisms have little exposure. The exception would be where large amounts of a light oil are physically dispersed into the nearshore surf zone shortly after release. Under these conditions, and with a rich benthic community, there can be significant toxic effects to bottom organisms that cannot escape the dispersed oil plume. There is little risk of deposition of oil or oiled sediments in these habitats. Currents are usually strong enough in nearshore areas to keep non-floating oil and contaminated sediments suspended in the water column. There could be a short-term exposure as oiled sediments are transported through the habitat into deeper areas.

Concerns about seafood contamination from dispersed oil or oiled sediments can become a significant issue. Real, potential, or the fear of, contamination may result in closure of seafood harvesting activities.

Figure 11 illustrates mixed and hard bottom habitats. Table 15 shows the relative impacts from various response methods on mixed and hard bottom habitats.

MIXED AND HARD BOTTOM




Source: NOAA, 1998

Figure 11

**Table 15.** Relative environmental impact from response methods for MIXED AND HARD BOTTOM habitats. *This table should not be used without the accompanying text in the document.*

| *Response Method* | *Category* I | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | B | B |
| Booming | – | B | B | B | – |
| **Skimming** | – | A | A | A | – |
| Physical Herding | – | A | A | A | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | – | – | B | B |
| Vegetation Cutting/Removal | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | – | – | – | – | – |
| Dispersants | – | B | B | B | – |
| ***In-situ* Burning** | – | B | B | B | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Mixed and Hard Bottom*

Natural Recovery

- Natural cleansing is expected to occur quickly, especially in the higher energy environments.
- The only exception may be where large amounts of oil have sunk and accumulated in current shadows.

Booming

- Avoid anchoring booms in known sensitive areas, such as unique live bottom areas.
- Safety concerns limit the containment of gasoline spills; however, booms can be used to exclude or deflect the spill away from sensitive resources.

Skimming

- Caution is needed when deploying and anchoring skimmers near live bottoms to prevent physical damage to the live bottoms.
- Skimming of gasoline is generally not appropriate due to safety concerns.
- Skimming of Category V oils is not effective.

Physical Herding

- May be needed under calm conditions to move oil toward recovery devices.

Manual Oil Removal/Cleaning

- Divers may pick up sunken tarballs and mats in areas of special concern, or where natural removal is expected to be slow.
- Finding and recovering the oil can be very difficult, and significant amounts of oil may be left behind.

Mechanical Oil Removal

- Dredging would not be appropriate for this subtidal habitat.

Sorbents

- Sorbents can be used to recover oil being re-mobilized from adjacent shorelines.
- Can be effective in recovering sunken oil if it refloats.

Vacuum

- Thick oil accumulations on persistent pockets on hard substrates could be removed by diver-directed vacuum pumping, although it is likely that not all of the oil can be found and recovered.

Debris Removal

- May be needed where large amounts of oil are trapped by debris on the seafloor.

Low-pressure, Ambient Water Flushing

- Not applicable.

Vegetation Removal

- Not appropriate because oil is not expected to adhere to algae underwater, the dominant type of vegetation in this habitat.

Dispersants

- Dispersants can be used directly over these habitats to protect sensitive intertidal habitats. The deeper the water, the greater the dilution, and the less effect a dipsersant will have on the mixed and hard bottom habitats.

*In-situ* Burning

- *In-situ* burning can be used directly over these habitats to protect sensitive intertidal habitats.
- Some Category III oils and all Category IV oils can produce higher amounts of burn residues which can sink, affecting benthic resources.

## 5.4 SHORELINE INTERTIDAL

The recommendations in this section are grouped according to habitat, based on shoreline habitat sensitivity, as reflected by the NOAA Environmental Sensitivity Index (ESI) ranking. ESI rankings are controlled by the following four factors:

- Relative exposure to wave and tidal energy;
- Shoreline slope;
- Substrate type (grain size, mobility, penetration, and trafficability); and
- Biological productivity and sensitivity.

An understanding of the relationships among the physical processes, substrate types, and associated biota is critical to the development and proper interpretation of ESI ratings. This document focuses on one element of environmental sensitivity, namely, the sensitivity of habitats to impacts resulting from oil removal operations. Rankings of "10B" and "10C" are not included in this document because they relate to freshwater habitats.

Sensitivity issues of special concern to marine areas include strong seasonal variations in biological productivity and exposure to physical processes, urban areas with extensive man-made structures along the shoreline, and populated areas that are very near shorelines and bodies of water when human-health concerns can dominate cleanup issues. Important seasonal considerations include presence of ice in winter; variations in water level, which greatly influence habitats likely to be exposed to oil; flooding of stranded oil, and natural removal rates; sensitivity of vegetation to direct oiling impact; and use of habitats by migratory birds.

The habitats discussed in this section include the following (ESI rankings are included in parentheses):

- Exposed, Rocky Shores (1A)
- Exposed, Solid, Man-made Structures (1B)
- Exposed, Wave-cut Platforms (2)
- Sand Beaches (3/4)
- Tundra Cliffs (3/4)
- Mixed Sand and Gravel Beaches (5)
- Gravel Beaches (6A)
- Riprap (6B)

- Exposed Tidal Flats (7)
- Sheltered, Rocky Shores (8A)
- Sheltered, Solid, Man-made Structures (8B)
- Peat Shores (8C)
- Sheltered Tidal Flats (9)
- Marshes (salt to brackish) (10A)
- Mangroves (10D)
- Inundated, Lowland Tundra (10E)

## EXPOSED, ROCKY SHORES

### *Habitat Description*

This shoreline type is characterized by an impermeable rocky substrate. The bedrock slope is very steep (>45°), thus the intertidal zone is very narrow. The rock surface can be highly irregular, with numerous crevices. Although boulder-sized debris can occur at the base of exposed, rocky cliffs, sediment accumulations are uncommon and usually temporary because of rapid erosion. The shoreline is exposed to high wave and tidal energy on a regular basis. Exposed, rocky shores seldom occur in combination with other shoreline types. They are most common on exposed headlands with deep water nearshore.

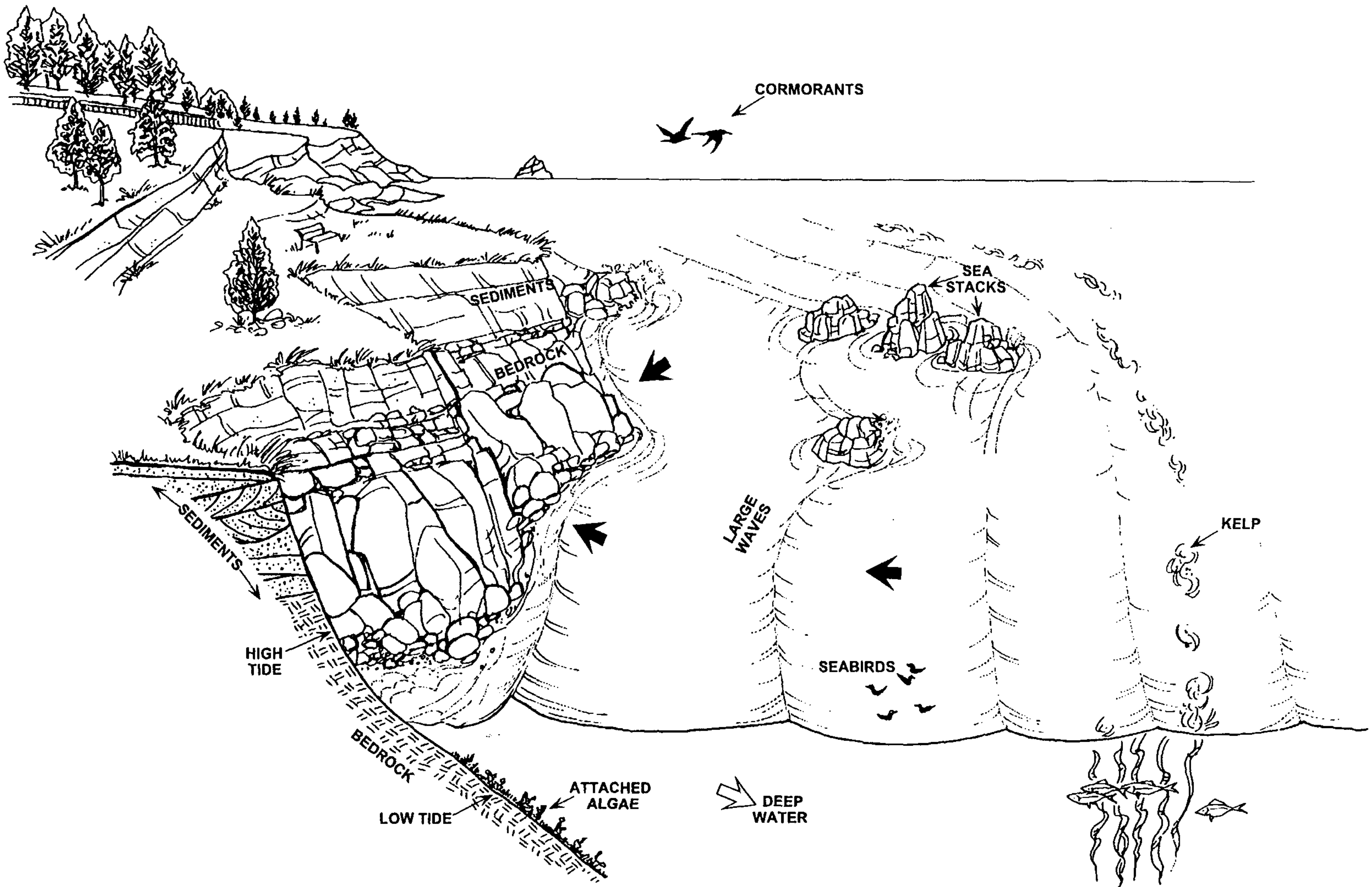
### *Sensitivity*

Except when marine mammal habitats or rookeries are present, exposed, rocky shores are considered to be the least sensitive of marine shoreline habitats to oil spills. The substrate may be colonized by a rich intertidal community, which can exhibit strong vertical zonation in species assemblages. The mid- and lower-intertidal zone can be heavily covered with attached algae and a high diversity of animals living attached to the bedrock and sheltered under the algal cover. Species density and diversity vary greatly, but barnacles, snails, mussels, seastars, limpets, sea anemones, and shore crabs are often abundant. By the nature of the high-energy setting, attached organisms are hardy and accustomed to high hydraulic impacts and pressures. Isolated cliffs provide nesting sites for birds, which can be present in large numbers in nearshore waters. Tide pools can be found in this habitat.

Spilled oil is usually held offshore by waves reflected from steep cliffs. Any oil that is deposited remains on the surface where natural processes quickly remove the oil from exposed faces, although oil persistence on any specific shoreline segment is related to the incoming wave energy during, and shortly after, a spill. Thus, many response options are not necessary. The most persistent oil would occur as a band at the high-water line or splash zone, or patches of thicker oil deposits in sheltered wave shadows such as in crevices or the lee of larger boulders. Impacts to intertidal communities are expected to be of short-term duration, except where heavy concentrations of a light refined product come ashore very quickly.

Figure 12 illustrates an exposed, rocky shores habitat (ESI classification 1A). Table 16 shows the relative impacts from various response methods on exposed, rocky shores.

# EXPOSED ROCKY SHORES




Source: NOAA, 1998

Figure 12

**Table 16.** Relative environmental impact from response methods for EXPOSED, ROCKY SHORES. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | B | A | A | A |
| Vacuum | – | A | A | A | A |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | – | A | A | B | B |
| High-pressure, Ambient Water Flushing | – | B | B | B | B |
| **Low-pressure, Hot Water Flushing** | – | – | C | C | C |
| High-pressure, Hot Water Flushing | – | – | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | – | – | – | – |
| Surface Washing Agents | – | – | C | C | C |
| **Nutrient Enrichment** | – | – | – | – | – |
| Natural Microbe Seeding | – | – | – | – | – |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Exposed, Rocky Shores*

<u>Natural Recovery</u>

- Cleanup of larger spills may be necessary because of the amount of oil present.
- Oil persisting in wave shadows, particularly heavier oils, may require removal.

<u>Barriers/Berms</u>

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

<u>Manual Oil Removal/Cleaning</u>

- Useful for heavy oils in patches or crevices and persistent oil along the high tide line, although residues will likely remain.

<u>Mechanical Oil Removal</u>

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

<u>Sorbents</u>

- Overuse generates excess waste.
- Less effective with low viscosity oils which spread into thin sheens and are rapidly dispersed in higher energy environments.
- In exposed environments, sorbents are likely to be torn away from anchoring points and stranded on adjacent shorelines.
- Specialized sorbents can be used effectively for lighter oils.

<u>Vacuum</u>

- Vacuuming will be effective on any pooled oil.

<u>Debris Removal</u>

- Degree of oiling that warrants debris removal and disposal depends on human and sensitive resource use of the site.

<u>Sediment Reworking/Tilling</u>

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Vegetation Cutting/Removal**

- Not appropriate because removing oiled vegetation would do more harm than leaving it.

**Flooding**

- Cannot be used effectively on steep habitats.

**Low-pressure, Ambient Water Flushing**

- Most effective on fresh, fluid oils; heavy oils likely to leave residues or require longer treatment.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

**High-pressure, Ambient Water Flushing**

- Most effective on fresh, fluid oils.
- Can be effective in removing oil from bedrock crevices.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

**Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing**

- Any organisms in the application area would be adversely affected.
- Most effective on heavy crudes where heat would make oil more fluid.
- Use is appropriate in limited areas only when heavy amounts of oil persist and pose risks to biota using the habitat or adjacent waters.
- To reduce risk of transporting oil and hot water to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

**Steam Cleaning and Sand Blasting**

- Highly intrusive techniques that will kill any organisms present.
- Use only for aesthetic reasons in very limited areas.

**Solidifiers**

- Not appropriate due to the rough characteristics of this substrate.

**Surface Washing Agents**

- Can be used to reduce the need for high temperature or high pressure to remove persistent oils.
- Individual products vary in their toxicity and ability to remove the treated oil.

**Nutrient Enrichment**

- Products likely to be washed away and less effective in high-energy setting.

**Natural Microbe Seeding**

- Products likely to be washed away and less effective in high-energy setting.

***In-situ* Burning**

- Oil is not expected to accumulate sufficiently to burn.

## Exposed, Solid, Man-made Structures

### *Habitat Description*

This habitat includes structures built for shore protection such as seawalls, piers, and bulkheads. These structures can be constructed of concrete, wood, stone, or corrugated metal. They usually extend below the water surface, although seawalls can have beaches or riprap in front of them. These structures are common along developed shores, particularly in harbors, marinas, and residential areas. They are exposed in varying degrees and frequencies to waves and currents, and they are exposed to significant areas of open water or strong river currents.

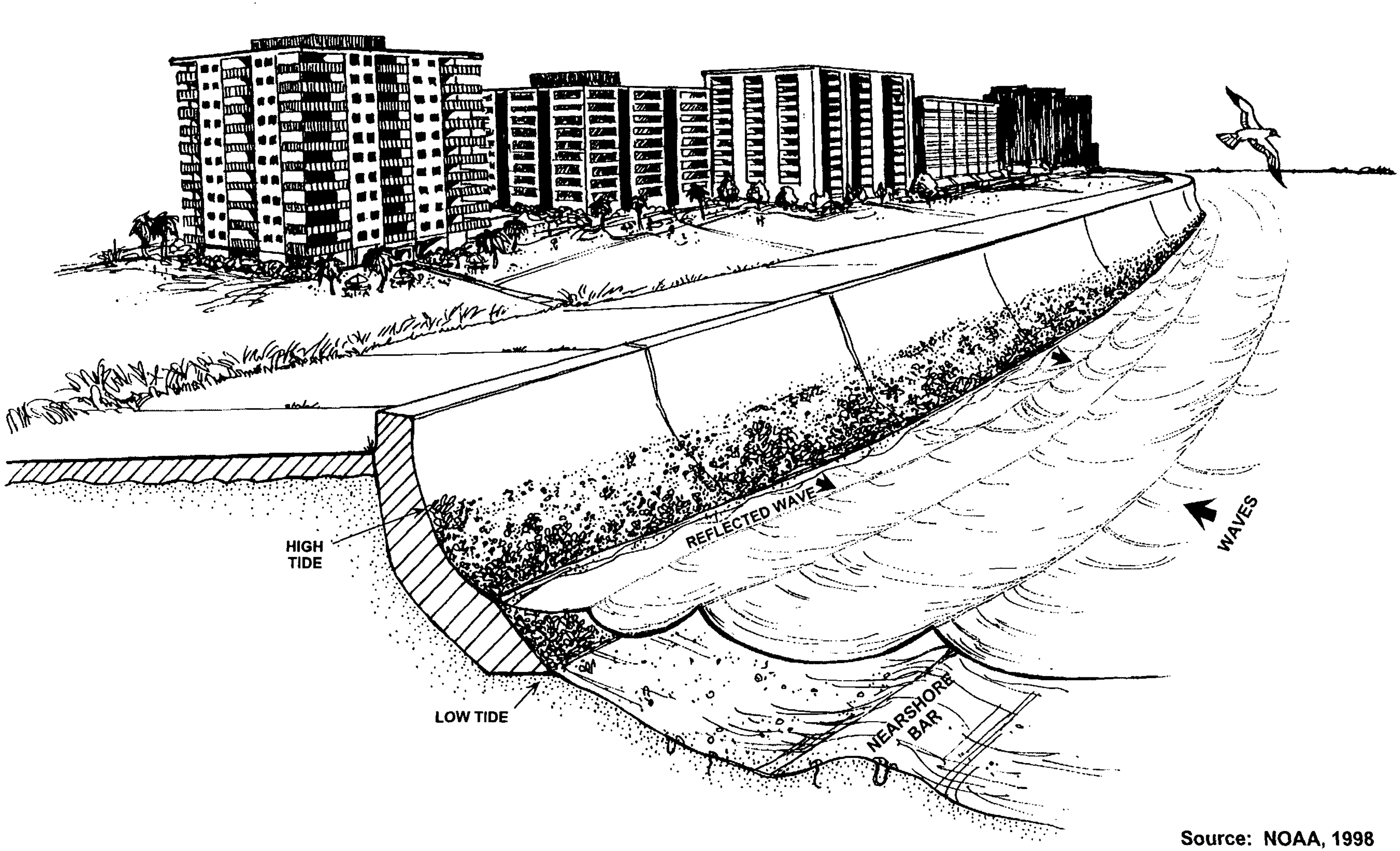
### *Sensitivity*

Exposed, solid, man-made structures are ranked low in sensitivity to oil spills. The intertidal portion can be covered with attached algae and organisms, particularly the middle and lower portions. In some areas, such as the southeastern United States, they provide the only hard, intertidal substrate and can be heavily colonized.

Solid seawalls are generally impermeable to oil penetration, but oil can heavily coat rough surfaces, forming a band at the water line. During storms, oil can splash over the top and contaminate terrestrial habitats. Oil usually does not adhere to the middle to lower portions. Instead, stranded oil often forms a band at the high-tide line, above the zone of attached algae and organisms. Often, there are sources of pollutants or habitat degradation nearby. More intrusive cleanup techniques are often used due to the structure's lower biological importance, higher public demand for oil removal for aesthetic reasons, and need to minimize human exposure to oil in populated areas. Furthermore, it is expected that the artificial substrates will be rapidly recolonized.

Figure 13 illustrates exposed, solid, man-made structures (ESI classification 1B). Table 17 shows the relative impacts from various response methods on exposed rocky shores.

# EXPOSED, SOLID, MAN-MADE STRUCTURES




Source: NOAA, 1998

Figure 13

**Table 17.** Relative environmental impact from response methods for EXPOSED, SOLID, MAN-MADE STRUCTURES. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | B | A | A | A |
| Vacuum | – | – | – | – | – |
| **Debris Removal** | – | – | – | – | – |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | – | A | A | B | B |
| High-pressure, Ambient Water Flushing | – | B | B | B | B |
| **Low-pressure, Hot Water Flushing** | – | – | C | C | C |
| High-pressure, Hot Water Flushing | – | – | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | – | – | – | – |
| Surface Washing Agents | – | – | B | B | B |
| **Nutrient Enrichment** | – | – | – | – | – |
| Natural Microbe Seeding | – | – | – | – | – |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Exposed, Solid, Man-made Structures*

**Natural Recovery**

- Most effective for lighter oils and more exposed settings.
- Heavier oils may necessitate removing persistent residues.

**Barriers / Berms**

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Manual Oil Removal/Cleaning**

- Heavy residues will likely remain on rough surfaces.

**Mechanical Oil Removal**

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Sorbents**

- Less effective with low viscosity oils that spread into thin sheens and are rapidly dispersed by wave energy.
- Physical removal rates of heavy oils will be slow, so less oil will be mobilized for recovery by sorbents.
- Overuse results in excess waste generation.
- Specialized sorbents can be used effectively for lighter oils.

**Vacuum**

- Oil is not likely to pool in sufficient quantities to use this technique.

**Debris Removal**

- Little debris is expected to be present.

**Sediment Reworking/Tilling**

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Vegetation Cutting/Removal**

- Little vegetation is usually present in this habitat.

**Flooding**

- Cannot be used effectively on steep habitats.

Low-pressure, Ambient Water Flushing

- Only effective when the oil is fluid.
- Use on heavy oils is likely to leave large amounts of residual oil in the environment.

High-pressure, Ambient Water Flushing

- Effective for removing sticky oils from solid surfaces.
- Use on heavy oils is likely to leave large amounts of residual oil in the environment.

Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing

- High water temperatures are often needed to liquefy heavy oils.
- High water pressures are often needed to remove weathered oils from solid substrates.

Steam Cleaning and Sand Blasting

- Highly intrusive; will kill any organisms present.
- Used when removing persistent oil is required for aesthetic reasons.

Solidifiers

- Not appropriate due to the vertical characteristics of this substrate.

Surface Washing Agents

- Can be used to reduce the need for high temperature or high pressure to remove persistent oils.
- Individual products vary in their toxicity and ability to recover the treated oil.

Nutrient Enrichment

- Products likely to be washed away and less effective in high-energy setting.

Natural Microbe Seeding

- Products likely to be washed away and less effective in high-energy setting.

*In-situ* Burning

- Oil is not expected to accumulate sufficiently to burn.

## EXPOSED, WAVE-CUT PLATFORMS

### *Habitat Description*

This shoreline type is characterized by an impermeable rocky or clayey substrate that has been cut by waves into flat platforms. The slope of the shoreline is less than 30°, and usually it is very flat, less than 5°. Thus, the intertidal zone can be up to hundreds of meters wide. The platforms are exposed to strong wave-generated currents and wave-reflection patterns. There can be a thin veneer of sand and gravel sediments on the rock platform and at the base of the cliff, although storm waves will regularly mobilize them. Along exposed marshes, waves erode the shoreline, creating a scarp and narrow platform in hard-packed and stiff clay.

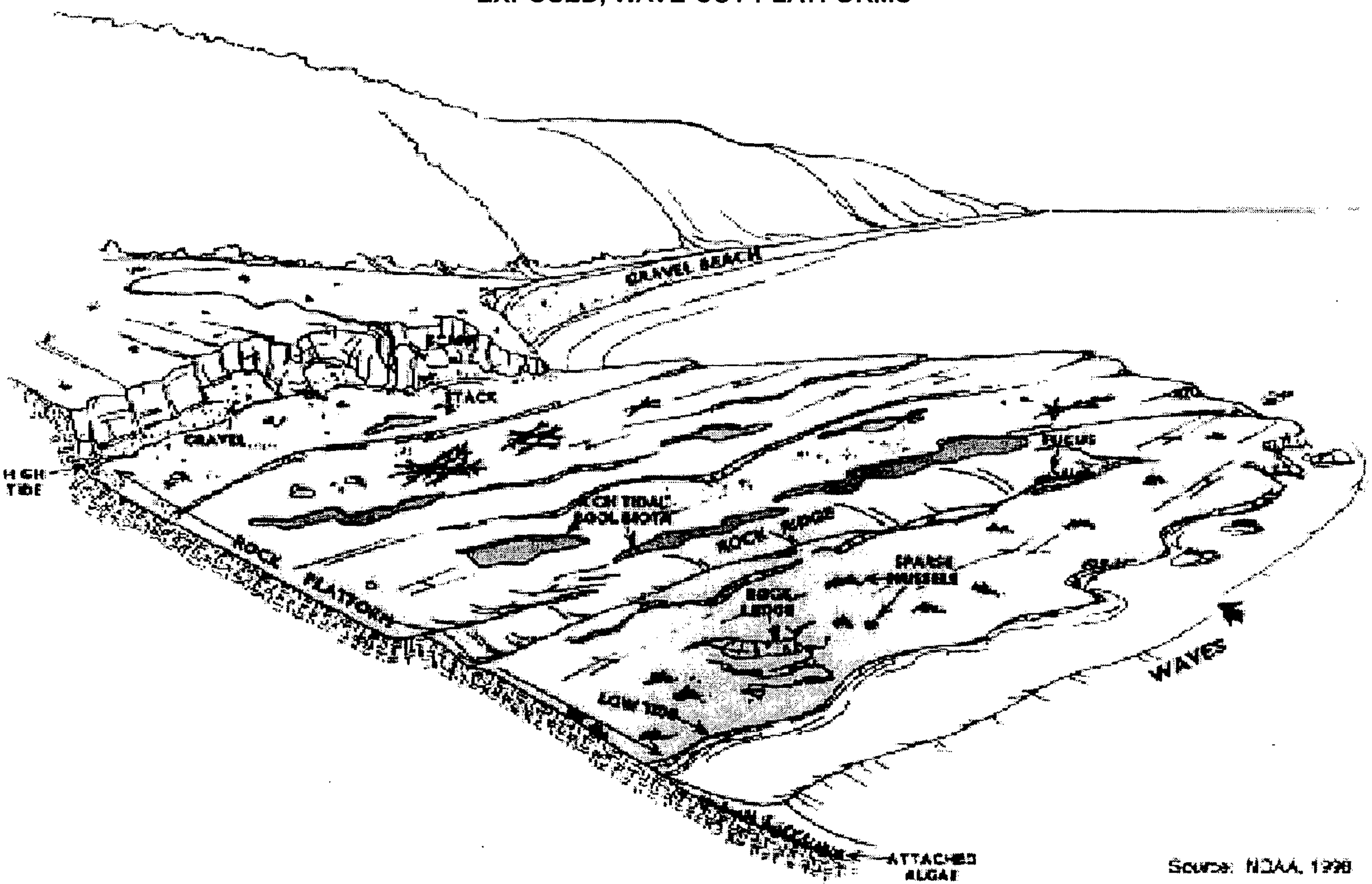
### *Sensitivity*

Wave-cut platforms are ranked low in oil spill sensitivity because of their exposure to high wave and current energy. By the nature of the exposed setting, attached organisms are hardy and used to high hydraulic impacts and pressures. On rocky platforms, cover of algae can be very dense, and tidal pool communities can be particularly rich. The platforms are often used by birds and marine mammals for feeding and resting during low tide. Wave-cut clay platform and scarps can have burrowing animals in the mud.

Oil may be partially held offshore by wave reflection from the platforms. Oil generally will not adhere to the platform, but will be transported across the platform and accumulate along the high-tide line. Any oil that is deposited will be rapidly removed; however, with a flatter and wider intertidal zone, the oil could spread over the platform at low tide and have greater biological impacts. Persistence of oiled sediments is usually short-term, except in wave shadows or large sediment accumulations.

Figure 14 illustrates an exposed, wave-cut platform (ESI classification 2). Table 18 shows the relative impacts from various response methods on exposed, wave-cut platforms.

## EXPOSED, WAVE-CUT PLATFORMS




Source: NOAA, 1998

Figure 14

**Table 18.** Relative environmental impact from response methods for EXPOSED, WAVE-CUT PLATFORMS. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | B | B | B | B |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | B | A | A | A |
| Vacuum | – | A | A | A | A |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | – | A | A | B | B |
| **Low-pressure, Ambient Water Flushing** | – | A | A | B | B |
| High-pressure, Ambient Water Flushing | – | B | B | B | B |
| **Low-pressure, Hot Water Flushing** | – | D | C | C | C |
| High-pressure, Hot Water Flushing | – | D | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | C | C | C |
| **Nutrient Enrichment** | – | – | – | – | – |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | D | D | D | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Exposed, Wave-cut Platforms*

Natural Recovery

- Cleanup of larger spills may be necessary because of the amount of oil present.
- Oils persisting in wave shadows and sediment pockets may require removal.

Barriers/Berms

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate, particularly on clay platforms.

Manual Oil Removal/Cleaning

- Expect significant residues of diesel and medium oils to remain when using only manual removal because of their fluidity and difficulty of manual pickup.
- Useful for heavy oils and oiled sediments in patches or crevices.
- On clay platforms, foot traffic should be restricted so as not to disturb the muddy, though cohesive, substrate.

Mechanical Oil Removal

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate, particularly on clay platforms.

Sorbents

- Overuse generates excess waste.
- Less effective with low viscosity oils which spread into thin sheens and are rapidly dispersed in higher energy settings.
- In exposed settings, sorbents are likely to be torn away from anchoring points and stranded on adjacent shorelines.
- Specialized sorbents can be used effectively for lighter oils.

Vacuum

- The wide, flat intertidal zone and tidal pools may hold oil at low tide, making it recoverable.

Debris Removal

- Degree of oiling that warrants debris removal and disposal depends on human and sensitive resource use of the site.

**Sediment Reworking/Tilling**

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Vegetation Cutting/Removal**

- Little vegetation is usually present in this habitat.

**Flooding and Low-pressure, Ambient Water Flushing**

- Most effective on fresh, fluid oils.
- Use on heavy oils is likely to leave large amounts of residual oil in the environment.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

**High-pressure, Ambient Water Flushing**

- Most effective on fluid oils.
- Can be effective in removing oil from crevices and pockets of sediment on bedrock.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.
- On clay platforms, high pressure may erode the substrate.

**Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing**

- Any organisms in the application area would be adversely affected by hot water.
- Use is appropriate in limited areas on rocky platforms only when oil removal is needed to protect special species of concern or for aesthetic reasons in high-use areas.
- To reduce risk of transporting oil and hot water to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

**Steam Cleaning and Sand Blasting**

- Highly intrusive technique; will kill any organisms present.
- Use only for aesthetic reasons in very limited areas on bedrock.

Solidifiers

- Use to prevent concentrations of stranded oil from being refloated and transported to more sensitive habitats.
- Not generally applicable for Category I oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.

Surface Washing Agents

- Shallow water depths nearshore could slow dilution of released oil and/or product, increasing exposure to water column and benthic organisms.
- Individual products vary in their toxicity and recoverability of the treated oil.
- Can be used to reduce the need for high temperature or high pressure to remove persistent oils.

Nutrient Enrichment

- Concerns about nutrient toxicity, especially ammonia, in rich nearshore waters.
- Nutrients likely to be rapidly diluted and less effective in high-energy setting.

Natural Microbe Seeding

- There is insufficient information on impact and effectiveness.

*In-situ* Burning

- Can effectively remove thick oil accumulations on tidal pools, but there would be a limited time period between tides during which burning could be conducted. Can result in physical residues and long-term impacts to biota.
- Category I oils are not expected to accumulate sufficiently to burn.

## SAND BEACHES

### *Habitat Description*

Sand beaches have a substrate composed of sediments that are predominantly finer than 0.08 inches (2 millimeters) but greater than silt or clay-sized material (see Appendix C for grain sizes). Fine-grained sand beaches tend to be wide and flat, hard packed, and able to support vehicular traffic. Coarse-grained sand, 0.09-0.08 inches (0.5-2 millimeters), forms beaches which usually are steeper and narrower than finer-grained sand, and the sediments are soft with low trafficability. Exposed sand beaches can undergo rapid erosional or depositional changes during storms, with coarse-grained sand beaches likely to change the most; deposition of up to 8 inches (20 centimeters) can occur in a single tidal cycle. Sheltered sand beaches, occurring along inland waterways and bays, tend to be narrow and less likely to undergo rapid erosion/deposition cycles. In developed areas, sand beaches can be artificially created by man and are commonly used for recreation.

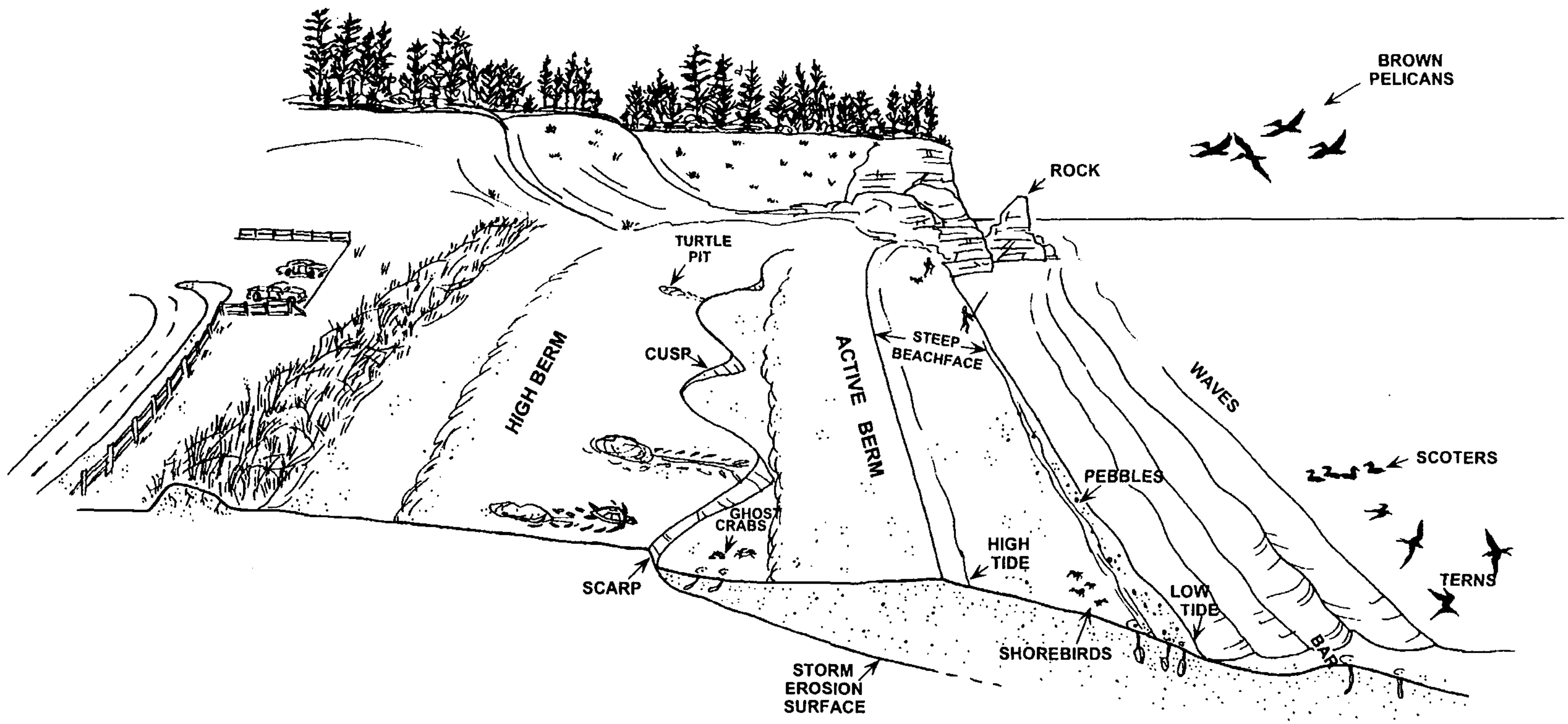
### *Sensitivity*

Sand beaches have low to medium sensitivity to oil spills. Biological use by infauna is highly variable. Spilled oil may cause temporary declines in infaunal populations, which can affect shorebirds which feed on them. Back beach areas can be important nesting areas for birds, and there are special concerns for beaches where sea turtles deposit eggs. In developed areas, sand beaches are considered sensitive because of their high recreational use.

During small spills, oil will concentrate in a band along the swash line. Maximum penetration into fine- to medium-grained sand will be less than 6 inches (15 centimeters), and into coarse-grained sand will be up to 12 inches (30 centimeters). Heavy oil accumulations will cover the entire beach surface at low tide, but the oil will be lifted off the lower beach with the rising tide. Fine-grained sand beaches are relatively easy to clean because the oil mostly remains close to the surface and either manual or mechanical removal can be effective. Burial of oiled layers by clean sand within the first two weeks will be less than 12 inches (30 centimeters) along the upper beach face, unless the oil is deposited right after an erosional storm. Coarse-grained sand beaches have the potential for rapid burial of oil, even after one tidal cycle. Maximum burial may be up to 3 feet (1 meter) if the oil strands at the start of a depositional period. Cleanup is more difficult, as equipment tends to grind oil into the substrate because of the loose packing of the sediment. Responders often have to deal with multiple layers of oiled and clean sediments. On heavily used recreational beaches, extensive cleanup is usually required to remove as much of the oil as quickly as possible. When large amounts of sediment must be removed, it may be necessary to replace these sediments with clean material.

Figure 15 illustrates a sand beach (ESI classification 3/4). Table 19 shows the relative impacts from various response methods on sand beaches.

## SAND BEACHES




Source: NOAA, 1998

Figure 15

**Table 19.** Relative environmental impact from response methods for SAND BEACHES. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* *I* | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | B | B | C | D |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | D | B | A | A | A |
| Mechanical Oil Removal | D | B | B | B | B |
| **Sorbents** | – | B | A | A | B |
| Vacuum | – | – | B | A | A |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | D | B | B | B | B |
| **Vegetation Cutting/Removal** | – | C | C | C | C |
| Flooding (deluge) | A | A | A | B | C |
| **Low-pressure, Ambient Water Flushing** | B | B | B | B | C |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | C | C | C |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | – | B | – | – |
| Surface Washing Agents | – | – | C | C | C |
| **Nutrient Enrichment** | – | A | A | B | C |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | C | C | C |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Sand Beaches*

**Natural Recovery**

- Lower impact for small spills, lighter oil types.

**Barriers/Berms**

- Only considered to build up low spots to protect back shore areas.
- Berms built with sand from the beach can disrupt beach and dune habitat.

**Manual Oil Removal/Cleaning**

- Minimizes sediment removal and problems of erosion and waste disposal.
- Effective when oil is mostly on the surface, not buried beneath clean sand.
- Gasoline tends to evaporate quickly; therefore habitat disruption, worker safety concerns, and waste generated by manual cleanup are not balanced by benefits in removing oil; similar, but lesser, concerns for diesel-like oils.
- Safety is of concern to workers in areas of cliff failure, slumping, slides, and mudflow. These often are large-scale (tens to hundreds of meters) events that usually are unpredictable.

**Mechanical Oil Removal**

- Tends to remove large amounts of clean sand with the oiled sand.
- Appropriate on high-use beaches where rapid removal of oil is required, or where long stretches of shoreline are heavily oiled or the oil is deeply buried.
- Gasoline tends to evaporate quickly; therefore habitat disruption, worker safety concerns, and waste generated from mechanical cleanup are not balanced by benefits in removing oil; similar, but lesser, concerns for diesel-like oils.

**Sorbents**

- Less effective for low viscosity oils which spread into thin sheens.
- Heavy oils are released from the shoreline at a slow rate, so less oil will be mobilized for recovery by sorbents.
- Overuse results in excess waste generation.

**Vacuum**

- Not applicable to gasoline and diesel-like spills because the oil quickly soaks in rather than remaining on the sediment surface.
- Early use of vacuum on pooled oil can prevent deeper penetration.

- Will minimize amount of sorbent waste when used with flushing efforts.
- Can remove heavy, non-sticky oil from sand substrates completely, but slowly.
- Trenches can be used to collect oil in order to increase the effectiveness of vacuum recovery. Trenching should be used with restraint as it often increases sediment contamination without increasing the effectiveness of vacuum recovery.

Debris Removal

- Degree of oiling that warrants debris removal depends on use by humans and sensitive animals.

Sediment Reworking/Tilling

- Appropriate for lightly oiled and stained sediments, to speed removal rates, and to polish recreational beaches.
- Gasoline evaporates quickly; habitat disruption and worker safety concerns from sediment reworking are not balanced by benefits in removing oil.

Vegetation Cutting/Removal

- Removal of dune vegetation could cause destabilization and erosion problems.

Flooding

- For Category I and II oil spills, may speed flushing of subsurface oil.
- For heavier oils, only effective when the oil is fluid and on the sand surface, rather than subsurface.
- Use on heavy oils is likely to leave large amounts of residual oil.

Low-pressure, Ambient Water Flushing

- Only effective when the oil is fluid and adheres loosely to the sediments.
- Requires pressure adjustments to minimize the amount of sand washed downslope.

High-pressure, Ambient Water Flushing

- High-pressure is not appropriate for sand substrates because of excessive sediment flushing.

Low-pressure, Hot Water Flushing

- Can be needed to soften and lift sticky oil off the sand surface.
- Any organisms present will be adversely affected by hot water.

**High-pressure, Hot Water Flushing**

- High-pressure is not appropriate because of excessive sediment flushing.

**Steam Cleaning**

- High-pressure is not appropriate because of excessive sediment flushing.

**Sand Blasting**

- High-pressure is not appropriate because of excessive sediment flushing.

**Solidifiers**

- Not generally applicable for Category I light oils which usually quickly penetrate the substrate, nor for heavy oils which are too viscous.
- Early use may prevent pooled oil from penetrating deeper.

**Surface Washing Agents**

- Individual products vary in their toxicity and ability to recover the treated oil.
- Can be used to reduce the need for high temperatures or high pressure to remove persistent oils.

**Nutrient Enrichment**

- More effective for lighter oils that leave thin residues; less effective for thick, weathered oil residues.
- Best used as a polishing technique after gross oil removal.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness in intertidal habitats.

***In-situ* Burning**

- Can result in physical residues and long-term impacts to biota.
- Category I and II oils are not expected to accumulate sufficiently to burn.
- Most oils when ignited will penetrate the sand, leaving insufficient surface thickness to burn.

## TUNDRA CLIFFS

### *Habitat Description*

Tundra cliffs are an erosional feature composed of tundra vegetation that usually overlies peat and exposed ground ice or permafrost. They are distinct and different from eroding unconsolidated sediment cliffs, which may have peat or exposed ice in the upper sections, but that are predominantly exposed sediments, such as sands and silts. Cliff heights range from less than 3 feet (1 meter) to as much as 15 to 30 feet (5 or 10 meters). As the face of a tundra cliff retreats, due to wave action or to thermal erosion that melts the ground ice, the tundra and peat materials fall to the base of the cliff. Initially this material falls as fragmented and irregular blocks until it is reworked by wave action. Erosion rates vary considerably depending on exposure to waves during the open-water season and the height of the cliff. Low erosion rates are on the order of 0.5 m/year (i.e., less than 0.2 m/month during the open-water season), with high rates in excess of 4.0 m/year (1.0 to 1.5 m/open-water month). Despite often rapid erosion rates, relatively little beach-forming material is supplied to the intertidal zone so that beaches usually are either narrow or absent in many areas. Eroded peat commonly accumulates at the base of a tundra cliff or may be transported along shore.

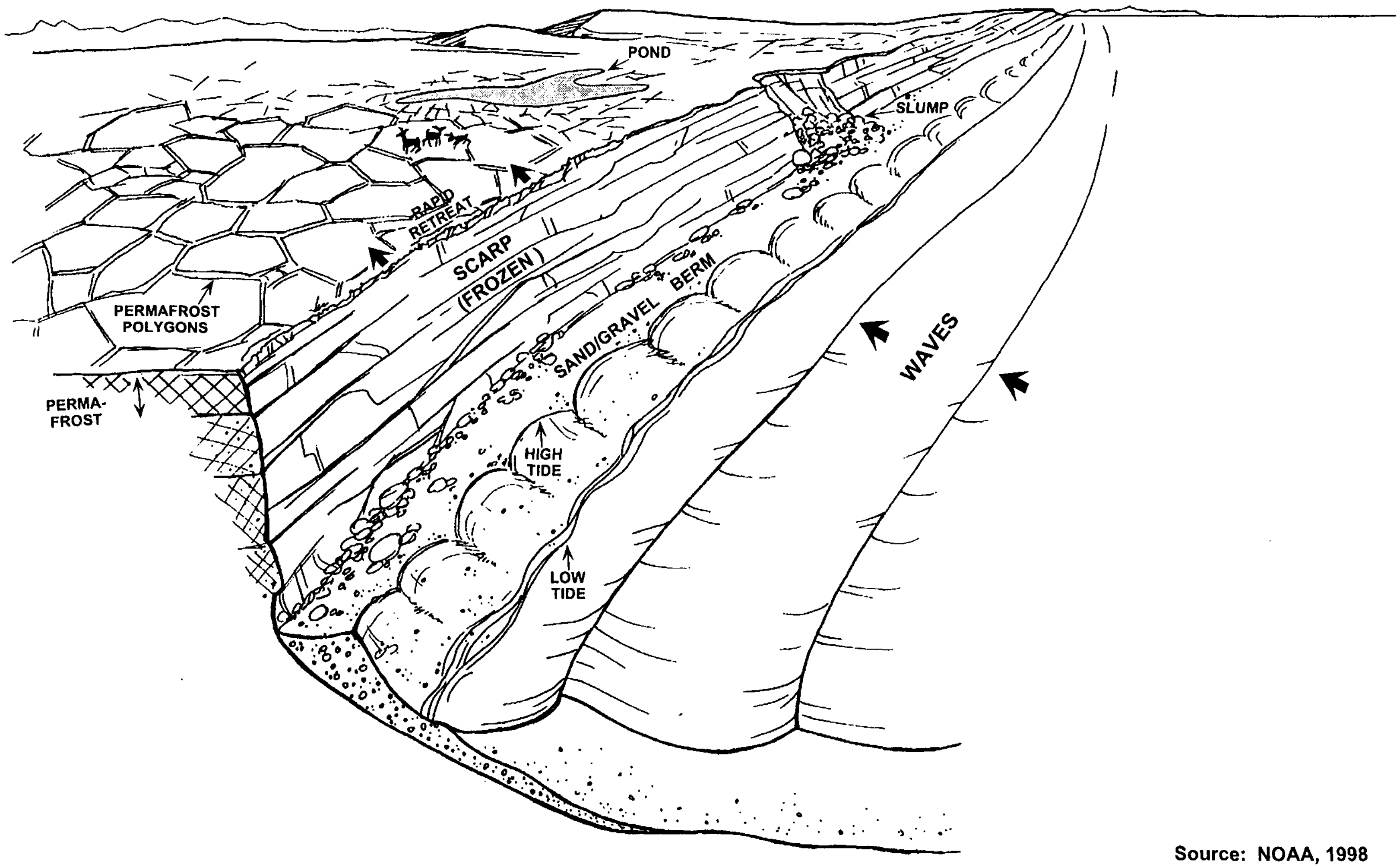
### *Sensitivity*

Tundra cliffs have a low sensitivity to oil spills. Although the level of biological activity usually is low, these Arctic shores have high populations of migratory birds during summer months. Oil could be stranded only during the ice-free summer season but, if mixed with peat, the oil could leach out over long time periods. Oil that is washed up onto exposed ground ice is unlikely to stick, unless air temperatures are below freezing, and will flow back down onto the beach. Persistence usually would be short due to natural cliff retreat. Oil on the cliff or the slumped tundra blocks, that also erode rapidly, would be reworked and remobilized by wave action.

Tundra cliffs often are undercut and are naturally unstable, so that safety is a primary concern during operations on these shorelines, even if cliff height is low [6 feet (2 meters)]. Cliff failure, slumping, and mud flows are unpredictable and can be sudden, large-scale events, involving many tons or tens of cubic yards of materials.

Figure 16 illustrates a tundra cliff (ESI classification 3/4). Table 20 shows the relative impacts from various response methods on tundra cliffs.

# TUNDRA CLIFFS




Source: NOAA, 1998

Figure 16

**Table 20.** Relative environmental impact from response methods for TUNDRA CLIFFS*. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | B | B | B | B |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | D | B | B | B | B |
| Mechanical Oil Removal | C | C | C | C | C |
| **Sorbents** | – | B | A | A | B |
| Vacuum | – | – | B | A | A |
| **Debris Removal** | – | B | B | B | B |
| Sediment Reworking/Tilling | D | B | B | B | C |
| **Vegetation Cutting/Removal** | D | D | D | D | D |
| Flooding (deluge) | A | A | A | B | C |
| **Low-pressure, Ambient Water Flushing** | C | B | B | B | C |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | – | B | – | – |
| Surface Washing Agents | – | – | – | – | – |
| **Nutrient Enrichment** | – | B | B | C | C |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

*Cleanup occurs only in the short arctic summer, a very limited window of intense ecological activity.

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Tundra Cliffs*

### Natural Recovery

- Impacts to migratory birds are of concern because of high summer populations.
- Oil on the cliff face, or in the tundra and peat deposits at the base of a cliff, likely will be naturally removed within a very short time (weeks), provided that the oil is not stranded at the onset of freeze-up.

### Barriers/Berms

- During periods of little wave action in the open-water season, cliff retreat is a result of warm air melting the exposed ice. At these times, oil removed from an eroding cliff by ice melting could be contained at the base of a cliff by a barrier or berm or by sorbents.

### Manual Oil Removal/Cleaning

- Manual removal of oil or oiled tundra/peat at the base of a cliff is practical only for small amounts of material.
- Safety is a primary concern during manual cleaning operations as these shorelines are naturally unstable.
- Not advisable for volatile oils. This oil type may evaporate more slowly than in lower latitudes due to lower summer air temperatures.

### Mechanical Oil Removal

- Can accelerate erosion by removal of the protective beach at the base of the cliff.

### Sorbents

- Less effective for low viscosity oils.
- Natural peats are common on this shoreline type and can be used as a sorbent, provided that they are not taken from the living tundra but from beach peat deposits.
- Overuse can cause waste management and disposal problems.

### Vacuum

- May have some application if oil has pooled between slumped blocks.
- Not applicable for very light (Category I or II) oils as these will penetrate the sediments rapidly.

Debris Removal

- Arctic beaches frequently have debris lines at the high-water level, but this option may be impractical as most shorelines are in remote locations.

Sediment Reworking/Tilling

- Appropriate for lightly oiled and stained sediments at the base of the cliff. This *in-situ* method does not involve the transfer and disposal of material.

Vegetation Cutting/Removal

- The vegetation on the tundra is a living community and cutting should be limited to plants that would not recover due to the continued presence of the oil.

Flooding

- Appropriate for all but the heavier oils. Can accelerate flushing of light oils from the beach sediments or from peat.

Low-pressure, Ambient Water Flushing

- Oil could be washed from the cliff face and contained and collected at the base of a cliff by a berm or by sorbents.
- Tundra cliffs are an eroding and often unstable coastal feature. Flushing or washing activities may trigger unexpected block falls, slumping, or mud flows.

High-pressure, Ambient Water Flushing

- High-pressure flushing or washing activities are not appropriate because they can trigger unexpected block falls, slumping, or mud flows.

Low-pressure, Hot Water Flushing

- High-temperature water flushing or washing activities are not appropriate because they can accelerate thermal erosion of the ice in the cliff face and trigger unexpected block falls, slumping, or mud flows.

High-pressure, Hot Water Flushing

- High-temperature or pressure water flushing or washing activities are not appropriate because they can accelerate thermal and mechanical erosion of the ice in the cliff face and trigger unexpected block falls, slumping, or mud flows.

## <u>Steam Cleaning</u>

- High-temperature water flushing or washing activities are not appropriate because they can accelerate thermal erosion of the ice in the cliff face and trigger unexpected block falls, slumping, or mud flows.

## <u>Sand Blasting</u>

- High-pressure sand blasting can accelerate erosion of the cliff face and trigger unexpected block falls, slumping, or mud flows.

## <u>Solidifiers</u>

- Not generally applicable for light oils, which usually quickly penetrate the sediments, nor for heavy oils which are viscous.

## <u>Surface Washing Agents</u>

- Not appropriate because oil and cleaner would penetrate the substrate.

## <u>Nutrient Enrichment</u>

- Experience in site remediation with petroleum contaminated sites has shown that nutrient enrichment could be beneficial.

## <u>Natural Microbe Seeding</u>

- Applicability not well understood for Arctic shores.

## <u>*In-situ* Burning</u>

- Burning of oil on the beach can induce thermal erosion of ice in the cliff face and possibly cause mud flows, or slumping, or block failure.
- Not appropriate because of potential for long-term, hard to extinguish fires.

## MIXED SAND AND GRAVEL BEACHES

### *Habitat Description*

Mixed sand and gravel beaches are characterized by a substrate that is composed predominantly of a mixture of sand- to cobble-sized sediments (see Appendix C for grain sizes). On some beaches, the pebble- to cobble-sized fractions of the sediment may be represented by shells and shell fragments. Typically, well-sorted beaches are exposed to some wave or current action that separates the finer-grained fraction; finer-grained sediments (sand to pebbles) occur at the high-tide line and coarser sediments (cobbles to boulders) occur in the storm berm and on the lower beach face. There can be large-scale seasonal changes in the sediment distribution patterns because of the transport of the sand fraction offshore during storms. On depositional beaches, multiple berms can be formed at the different water levels generated during storms. There can be patches of gravel forming cusps at regular spacing along the beach. However, the sediment distribution does not necessarily indicate the energy at a particular shoreline. The presence of attached algae, mussels, and barnacles indicates beaches which are relatively sheltered, with the more stable gravel supporting a richer biota. In glaciated areas, the gravel component can include large boulders; in other areas the gravel is composed of shell. Natural replenishment rates are slow for gravel, compared to sand.

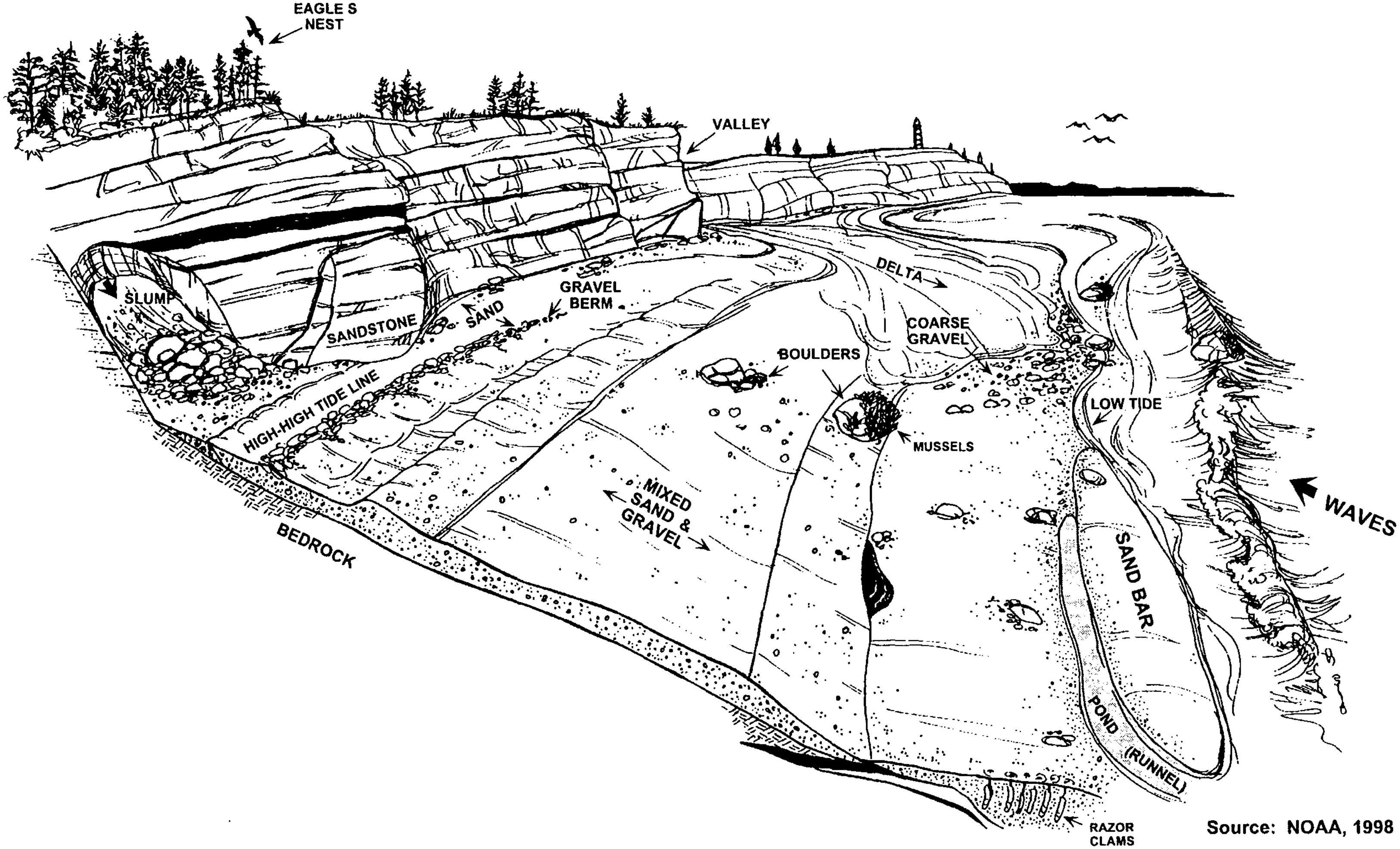
### *Sensitivity*

Mixed sand and gravel beaches have medium sensitivity to oil spills. Biological communities are sparse because of sediment mobility, desiccation, and low organic matter. Most invertebrates living in this habitat are deep burrowers, such as oligochaete worms. The wrack can contain large numbers of amphipods.

Oil penetration into the beach sediments may be up to 20 inches (50 centimeters); however, the sand fraction can be quite mobile, and oil behavior is much like on a sand beach if the sand fraction exceeds about 40 percent. Therefore, deep oil penetration and long-term persistence are lower than on gravel beaches. Oil can occur below the depth at which the sediments are regularly reworked by erosion and deposition cycles, particularly if the oil is deposited high on the beach out of the reach of normal wave activity or deeply buried after a storm. Erosion can be a concern when large quantities of sediment are physically removed. In more sheltered areas, asphalt pavements can form if heavy surface oil deposits are not removed. Once formed, these pavements can persist for years.

Figure 17 illustrates a mixed sand and gravel beach (ESI classification 5). Table 21 shows the relative impacts from various response methods on mixed sand and gravel beaches.

# MIXED SAND AND GRAVEL BEACHES




Source: NOAA, 1998

Figure 17

**Table 21.** Relative environmental impact from response methods for MIXED SAND AND GRAVEL BEACHES. This table should not be used without the accompanying text in the document.

| | Category | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | B | B | C | C |
| Barriers/Berms | C | C | C | B | B |
| **Manual Oil Removal/Cleaning** | D | C | B | A | A |
| Mechanical Oil Removal | D | C | B | B | B |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | D | B | B | B | B |
| **Vegetation Cutting/Removal** | – | C | C | C | C |
| Flooding (deluge) | A | A | B | C | C |
| **Low-pressure, Ambient Water Flushing** | B | A | A | B | C |
| High-pressure, Ambient Water Flushing | – | – | C | D | D |
| **Low-pressure, Hot Water Flushing** | – | – | C | C | C |
| High-pressure, Hot Water Flushing | – | – | D | D | D |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | – | B | – | – |
| Surface Washing Agents | – | – | C | C | C |
| **Nutrient Enrichment** | – | A | A | B | C |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | C | C | C |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Mixed Sand And Gravel Beaches*

### Natural Recovery

- Lower impact for small spills, lighter oil types, and remote areas.

### Barriers/Berms

- Only considered to build up low spots to protect back shore areas.

### Manual Oil Removal/Cleaning

- Gasoline evaporates quickly; therefore, manual cleanup causes habitat disruption, worker safety concerns, and generates waste with no benefits due to removing oil; similar, but lesser, concerns for diesel-like oils.
- Minimizes sediment removal, problem erosions, and waste disposal.
- Preferable when oil is mostly on the surface, not subsurface.

### Mechanical Oil Removal

- Tends to remove large amounts of clean sediment with the oil.
- Applicable for high concentrations of deeply penetrated oil, which is difficult to remove otherwise.
- Gasoline evaporates quickly; therefore, mechanical cleanup causes habitat disruption, worker safety concerns, and generates waste with no benefits from removing oil; similar but lesser concerns for diesel-like oils.
- Vehicle use may mix oil in deeper because of soft substrate and patchy distribution of very loose gravel.

### Sorbents

- Overuse generates excess waste.
- Useful for recovering oil released during natural recovery or when other response methods are no longer effective.
- Heavy oils are released from the shoreline at a slow rate, so less oil will be mobilized for recovery by sorbents.
- Specialized sorbents can be used effectively for lighter oils.

### Vacuum

- Early use of vacuum on pooled, liquid oil can prevent deeper penetration.
- Not applicable to gasoline and diesel-like spills because the oil quickly soaks in rather than remaining on the sediment surface.
- Early use of vacuum on pooled oil can prevent deeper penetration.

- Will minimize amount of sorbent waste when used with flushing efforts.
- Trenches can be used to collect oil in sand portion of the beach in order to increase the effectiveness of vacuum recovery. Trenching should be used with restraint as it often increases sediment contamination without increasing the effectiveness of vacuum recovery.

<u>Debris Removal</u>

- Degree of oiling that warrants debris removal and disposal depends on amount of use by humans and sensitive animals.

<u>Sediment Reworking/Tilling</u>

- Use to break up heavy surface oil or expose persistent subsurface oil, particularly where sediment removal will cause erosion.
- Use only where there is sufficient exposure to waves to rework the sediments into their original profile and distribution.
- Gasoline evaporates quickly; sediment reworking causes habitat disruption and worker safety concerns with no benefits due to removing oil.

<u>Vegetation Cutting/Removal</u>

- Removal of dune vegetation could cause destabilization and erosion.

<u>Flooding</u>

- For gasoline and diesel-like spills, may speed flushing of subsurface oil.
- Only effective when the oil is fluid or loosely adhered to the sediment surface, rather than penetrated or buried.
- Use on heavy oils is likely to leave large amounts of residual oil.

<u>Low-pressure, Ambient Water Flushing</u>

- For gasoline and diesel-like spills, may speed flushing of subsurface oil.
- Most effective when the oil is fluid and adhered loosely to the sediments.
- Care should be taken to avoid erosion of the sand fraction.
- Use on heavy oils is likely to leave large amounts of residual oil.

<u>High-pressure, Ambient Water Flushing</u>

- High-pressure water jets will flush oiled sediments into subtidal habitats.
- Use on heavy oils is likely to leave large amounts of residual oil.

<u>Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing</u>

- Can be necessary to mobilize viscous, sticky oils.

- Care should be taken to avoid erosion of the sand fraction.
- Any organisms present will be affected by hot water.
- Care must be taken to prevent warmed oil from moving deeper into the sediments.

**Steam Cleaning**

- Highly intrusive technique; will kill any organisms present.
- Potential for released oil to penetrate deeper into the sediments.

**Sand Blasting**

- Highly intrusive technique; will kill any organisms present.
- Excessive pressures can cause erosion of the sand fraction.

**Solidifiers**

- Early use may prevent pooled oil from penetrating deeper.
- Not generally applicable for Category I light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.
- Can be useful in recovering sheens being released from the beach when deployed as booms and pillows.

**Surface Washing Agents**

- Can be used to reduce the need for high temperature or high pressure to remove persistent oils.
- Individual products vary in their toxicity and ability to recover the treated oil.

**Nutrient Enrichment**

- Potentially effective for light to medium oils that leave thin residues; less effective for thick, weathered oil residues.
- Most applicable as a secondary technique after gross oil removal.
- For Category III, IV, and V oils, may require sediment reworking and tilling for nutrient enrichment to be effective.

Natural Microbe Seeding

- There is insufficient information on impact and effectiveness in intertidal habitats.

*In-situ* Burning

- Can result in physical residues and long-term impacts to biota.
- Most oils when ignited will penetrate the substrate, leaving insufficient surface thickness to burn.
- Category I and II oils are not expected to accumulate sufficiently to burn.

## Gravel Beaches

### *Habitat Description*

Gravel beaches are characterized by a substrate composed predominantly of gravel-sized sediments. By definition, gravel includes sediments ranging in size from granules greater than 0.08 inches (greater than 2 mm) to boulders greater than 10 inches (greater than 256 mm). Shell fragments can form gravel-sized sediments in some areas. The sand fraction on the surface is usually less than 10%, although the sand content can increase to 20% with depth. These beaches are highly permeable because there are few sand-sized sediments to fill the pore spaces between the individual gravel particles. Gravel beaches tend to be steeper than those composed of sand, with a slope between 10° and 20°. Gravel substrates may have low bearing capacity and, consequently, may not support vehicular traffic. Typically, well-sorted beaches are exposed to some wave or current action that reworks the sediments and removes the finer-grained sediments. However, the sediment distribution does not necessarily indicate the energy setting at a particular shoreline; sheltered beaches can still have a large gravel source, particularly in glaciated areas where the gravel can include large boulders. There can be high annual variability in the degree of exposure and, thus, in the frequency and depth of annual sediment reworking. An armor of larger gravel can effectively seal the subsurface sediments from physical reworking by normal wave action. Natural replenishment rates are slow for gravel.

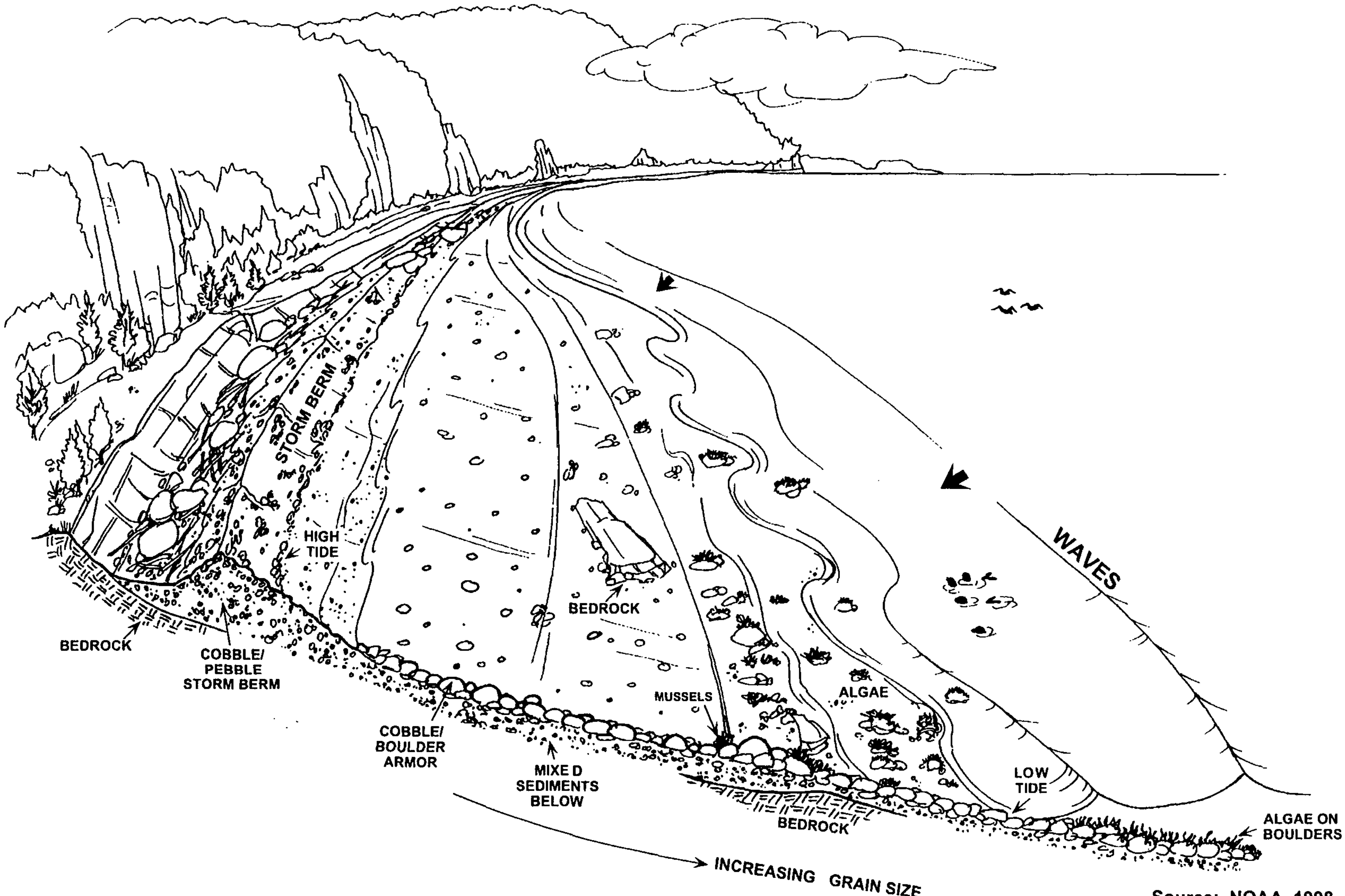
### *Sensitivity*

Gravel beaches are ranked the highest of all beaches in their sensitivity to oil spills primarily because of the potential for deep oil penetration and slow natural removal rates of subsurface oil. Biological communities in the beach sediments are sparse because of sediment mobility, desiccation, and low organic matter. The larger and more stable gravel at the lower intertidal zone can support relatively rich assemblages of attached algae, mussels, barnacles, snails, and polychaetes.

Oil can penetrate to depths below those of annual reworking, resulting in long-term persistence of the oil, particularly when armored. The slow replenishment rate makes removing oiled gravel highly undesirable, and cleanup of heavily oiled gravel beaches is particularly difficult. Formation of persistent asphalt pavements is likely where there are heavy surface oil deposits.

Figure 18 illustrates a gravel beach (ESI classification 6A). Table 22 shows the relative impacts from various response methods on gravel beaches.

## GRAVEL BEACHES




Source: NOAA, 1998

Figure 18

**Table 22.** Relative environmental impact from response methods for GRAVEL BEACHES. This table should not be used without the accompanying text in the document.

| | Category | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | – | B | B | B | B |
| **Manual Oil Removal/Cleaning** | D | C | B | B | A |
| Mechanical Oil Removal | D | D | C | C | C |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | – | B | B | B |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | D | B | B | B | B |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | A | A | B | C | C |
| **Low-pressure, Ambient Water Flushing** | A | A | A | B | C |
| High-pressure, Ambient Water Flushing | – | – | B | B | B |
| **Low-pressure, Hot Water Flushing** | – | – | C | B | B |
| High-pressure, Hot Water Flushing | – | – | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | – | B | – | – |
| Surface Washing Agents | – | – | B | B | B |
| **Nutrient Enrichment** | – | A | A | B | B |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | C | C | C |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Gravel Beaches*

<u>Natural Recovery</u>

- Least impact for small oil spills, lighter oil types, and remote areas.

<u>Barriers/Berms</u>

- Only considered to build up low spots to protect back shore areas.

<u>Manual Oil Removal/Cleaning</u>

- Minimizes sediment removal and problems of erosion and waste disposal.
- Gasoline evaporates quickly; therefore, manual cleanup causes habitat disruption, worker safety concerns, and generates waste with no benefits from removing oil; similar but lesser concerns for diesel-like oils.
- Deep penetration of liquid oil in porous gravel reduces effectiveness.

<u>Mechanical Oil Removal</u>

- Deep penetration of oil in porous gravel is likely to require the removal of large amounts of clean gravel with the oil.
- Slow replenishment rate of gravel increases the risk of erosion after removal.
- Equipment operations on gravel could mix oil deeper into the sediments because of low trafficability.

<u>Sorbents</u>

- Overuse generates excess waste.
- Useful for recovering oil released during natural recovery or when other response methods are no longer effective.
- Heavy oils are released from the shoreline at a slow rate, so less oil will be mobilized for recovery by sorbents.
- Specialized sorbents can be used effectively for lighter oils.

<u>Vacuum</u>

- Early use of vacuum on pooled, liquid oil can prevent deeper penetration.
- Not applicable to gasoline and diesel-like spills because the oil quickly soaks in rather than remaining on the sediment surface.
- Will minimize amount of sorbent waste when used with flushing efforts.

**Debris Removal**

- Degree of oiling that warrants debris removal and disposal depends on use by humans and sensitive resources.

**Sediment Reworking/Tilling**

- Used where gravel removal is not feasible because of erosion concerns.
- Often conducted in conjunction with removal or flushing of heavily oiled areas.
- Sufficient exposure to waves is required to rework the sediments into their original profile and distribution, especially if sediments are moved lower on the beach face, such as during berm relocation.
- Gasoline evaporates quickly; therefore, sediment reworking causes habitat disruption and worker safety concerns, with no benefits from removing oil.

**Vegetation Cutting/Removal**

- Little vegetation is usually present in this habitat.

**Flooding**

- For gasoline and diesel-like spills, may speed flushing of subsurface oil.
- Usually used with flushing techniques to prevent the oil from re-adhering.
- Use on heavy oils is likely to leave large amounts of residual oil.

**Low-pressure, Ambient Water Flushing**

- Use for large boulders which cannot be readily flooded.
- Only effective when the oil is fluid or loosely adhered to the surface sediments.
- Use on heavy oils is likely to leave large amounts of residual oil.

**High-pressure, Ambient Water Flushing**

- Not applicable to lighter oils which have penetrated the gravel since the spray only hits the surface sediments.
- Very viscous oils will require extremely high pressure to mobilize them.

**Low-pressure, Hot Water Flushing**

- Not applicable to lighter oils which have penetrated the gravel since the spray only hits the surface sediments.
- May be needed to mobilize viscous oils.
- Any organisms present will be adversely affected by hot water.

- Care must be taken to prevent warmed oil from moving deeper into the sediments.

**High-pressure, Hot Water Flushing**

- Not applicable to lighter oils which have penetrated the gravel since the spray only hits the surface sediments.
- Very viscous oils will require extremely high pressure and heat to mobilize them.
- High-pressure water jets are likely to flush oiled sediments into subtidal habitats.
- Any organisms present will be adversely affected by hot water and high pressure.
- Care must be taken to prevent warmed oil from moving deeper into the sediments.

**Steam Cleaning**

- Highly intrusive technique; will kill any organisms present.

**Sand Blasting**

- Highly intrusive technique; will kill any organisms present.

**Solidifiers**

- Early use may prevent pooled oil from penetrating deeper.
- Not generally applicable for light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.
- Can be useful in recovering sheens being released from the beach when deployed as booms and pillows.

**Surface Washing Agents**

- Can be used to reduce the need for high temperatures or high pressure to remove persistent oils.
- Can be only tool which will remove viscous oils without removing sediment or using high pressure/hot water.
- Individual products vary in their toxicity and ability to recover the treated oil.

**Nutrient Enrichment**

- Potentially effective for light to medium oils that leave thin residues; less effective for thick, weathered oil residues.
- Most applicable as a secondary technique after gross oil removal.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness in intertidal habitats.

***In-situ* Burning**

- Category I and II oils are not expected to accumulate sufficiently to burn.
- Can result in physical residues and long-term impacts to biota.
- Heated oil could deeply penetrate porous gravel during the burn.

## Riprap

### *Habitat Description*

Riprap structures include revetments, groins, breakwaters, and jetties, which are constructed of boulder-sized pieces of rock, rubble, or formed concrete pieces (e.g., tetrapods). Revetments are placed parallel to the shoreline for shore protection. Groins are oriented perpendicular to shore to trap sediment. Jetties are designed to protect and maintain channels, and breakwaters are offshore structures constructed to protect an area from wave attack. Riprap structures have large void spaces and are highly permeable. These structures are common along developed shores, particularly in harbors, marinas, and residential areas. The range in degree of exposure to waves and currents varies widely, from low in dead-end canals, to high on offshore breakwaters. Boat wakes can generate wave energy in otherwise sheltered areas.

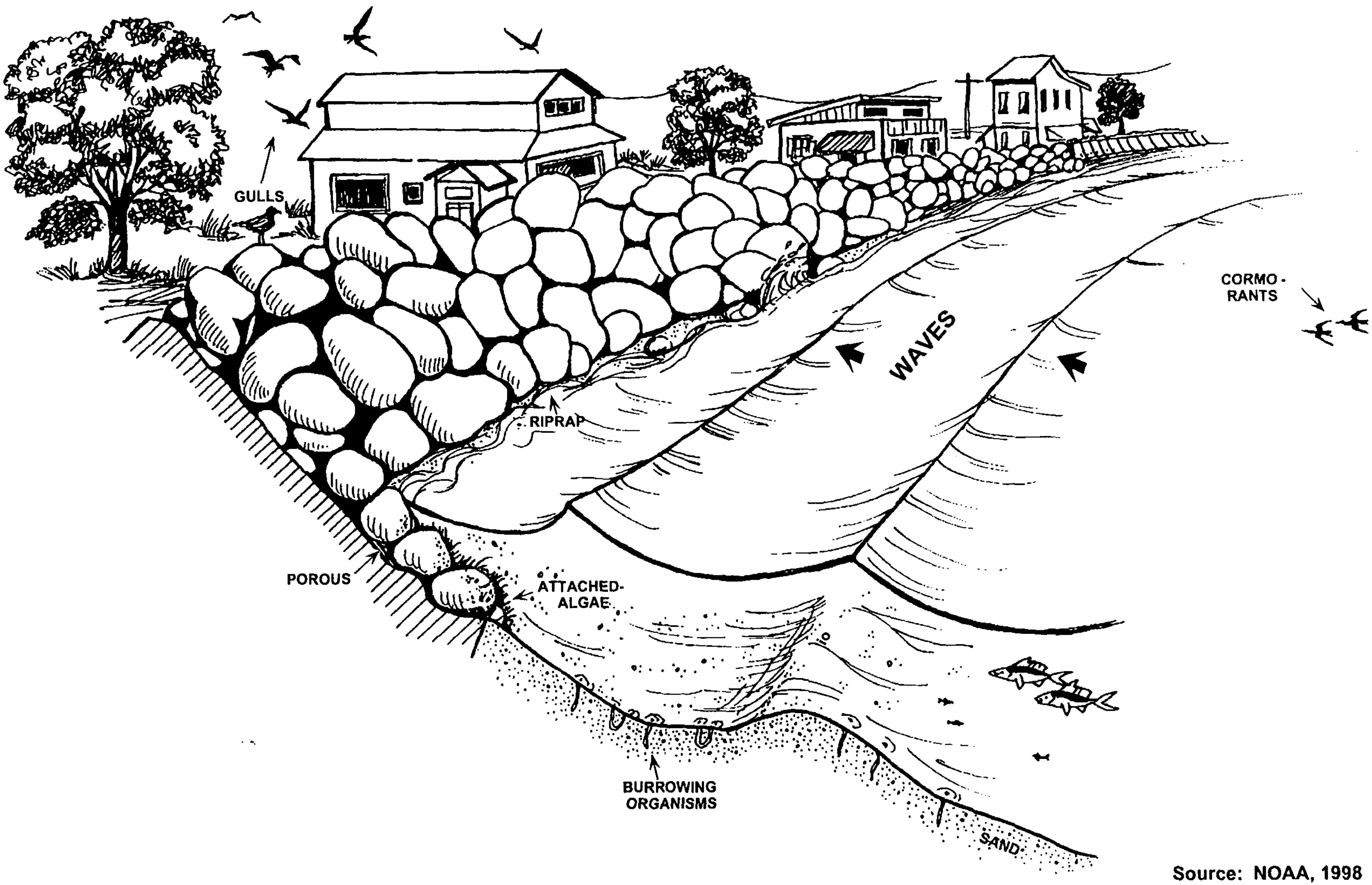
### *Sensitivity*

Riprap structures are ranked as intermediate in sensitivity to oil spills. The attached biological communities can be highly variable, from rich to sparse. Detached structures are commonly used as resting sites for birds, such as pelicans and cormorants. More intrusive cleanup techniques are often conducted due to their overall lower biological value, higher public demand for oil removal for aesthetic reasons, and need to minimize human exposure to oil in populated areas.

Riprap poses significant cleanup problems because of the large, irregular surface area, inaccessible void spaces, and heavy accumulations of debris. Oil trapped in the riprap is difficult to remove and could become a source of chronic sheening, oiling, and remobilization.

Figure 19 illustrates riprap (ESI classification 6B). Table 23 shows the relative impacts from various response methods on riprap.

# RIPRAP




Source: NOAA, 1998

Figure 19

**Table 23.** Relative environmental impact from response methods for RIPRAP.
This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | A | A | A | A |
| Mechanical Oil Removal | – | – | B | C | C |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | – | A | A | A |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | A | A | B | C | C |
| **Low-pressure, Ambient Water Flushing** | A | A | B | C | C |
| High-pressure, Ambient Water Flushing | A | A | B | B | C |
| **Low-pressure, Hot Water Flushing** | – | C | C | C | C |
| High-pressure, Hot Water Flushing | – | C | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | B | B | – | – |
| Surface Washing Agents | – | – | B | B | B |
| **Nutrient Enrichment** | – | A | A | B | B |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | D | D | – |

Category Descriptions

I – Gal – Gasoline products
II – DiII – Diesel-like products and light crude oils
III – MIII – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Riprap*

Natural Recovery

- Most effective for lighter oils and more exposed settings.
- Heavier oils may necessitate removing persistent residues.

Barriers/Berms

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Manual Oil Removal/Cleaning

- Effective for removing debris and small, persistent pockets of oil.

Mechanical Oil Removal

- Only considered where large amounts of viscous oil have penetrated and persisted in the structure, creating a chronic sheening problem in a high-use area.
- Could require some removal and replacement of oiled riprap.

Sorbents

- Use along riprap structures to recover residual sheening oil after other cleanup methods have been conducted.
- Oil snares are more effective on heavy oil than other sorbent types.
- Overuse generates excess waste.
- Specialized sorbents can be used effectively for lighter oils.

Vacuum

- Early use of vacuum on pooled oil in crevices can increase the oil recovery rate and minimize oil losses during flushing.
- Can only remove thick oil from accessible areas, so high residues likely.
- Not applicable to gasoline and diesel-like spills because the oil quickly soaks in rather than remaining on the sediment surface.
- Will minimize amount of sorbent waste when used with flushing efforts.

Debris Removal

- Degree of oiling that warrants debris removal and disposal depends on human and sensitive resource use of the site.

**Sediment Reworking/Tilling**

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

**Vegetation Cutting/Removal**

- Little vegetation is usually present in this habitat.

**Flooding**

- Cannot effectively flood large, irregular riprap shapes, thus surface coatings likely to remain.
- May be used in developed areas where pockets of volatile products pose human health concerns.

**Low-pressure, Ambient Water Flushing**

- Only effective when the oil is fluid.
- Directed water spray can help remove trapped oil, even for gasoline.
- Use on heavy oils is likely to leave large amounts of residual oil in crevices.

**High-pressure, Ambient Water Flushing**

- Directed water spray can help remove oil, even gasoline, from crevices.
- May flush oiled sediments (if present) into adjacent subtidal habitats.

**Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing**

- High water temperatures are often needed to liquefy viscous oils.
- High water pressures are often needed to remove weathered oils.
- Any organism will be adversely affected by hot water and high pressure.

**Steam Cleaning and Sand Blasting**

- Used when removal of persistent oil is required for aesthetic reasons.

**Solidifiers**

- May be useful in recovering sheens, when deployed as booms and pillows.
- Not generally applicable for Category I light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.

**Surface Washing Agents**

- May be an effective for removing viscous oil from riprap structures.
- May reduce the need for high temperatures or high pressure to remove persistent oils.
- Individual products vary in their toxicity and ability to recover the treated oil.

**Nutrient Enrichment**

- Potentially effective for lighter oils that leave thin residues; less effective for thick, weathered oil residues.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness, particularly for applications on man-made structures.

***In-situ* Burning**

- Category I and II oils are not expected to accumulate sufficiently to burn.
- Thick oil likely to occur as isolated pockets that are difficult to access and burn.
- Can result in physical residues and long-term impacts to biota.
- Public and property safety issues in developed areas will be of special concern.

## Exposed Tidal Flats

### *Habitat Description*

Exposed tidal flats are characterized by a substrate composed predominantly of sand, although they may be mixed with varying amounts of silt, clay, or gravel (see Appendix C for grain-size chart). They are more common in areas with medium to large tidal ranges, and their width can vary from 3 to 6 feet (1 to 2 meters) to over 1,000 yards (one kilometer). They most commonly occur in estuaries and at the mouths of tidal inlets. The presence of sand on the tidal flat indicates that tidal or wind-driven currents and waves are strong enough to remove the muddy fraction. The sediments are mostly water saturated, with only the topographically higher ridges drying out at low tide. The flats vary widely in their bearing strength, though most are soft with low trafficability. They often are associated with wetlands on the landward side of the tidal flat.

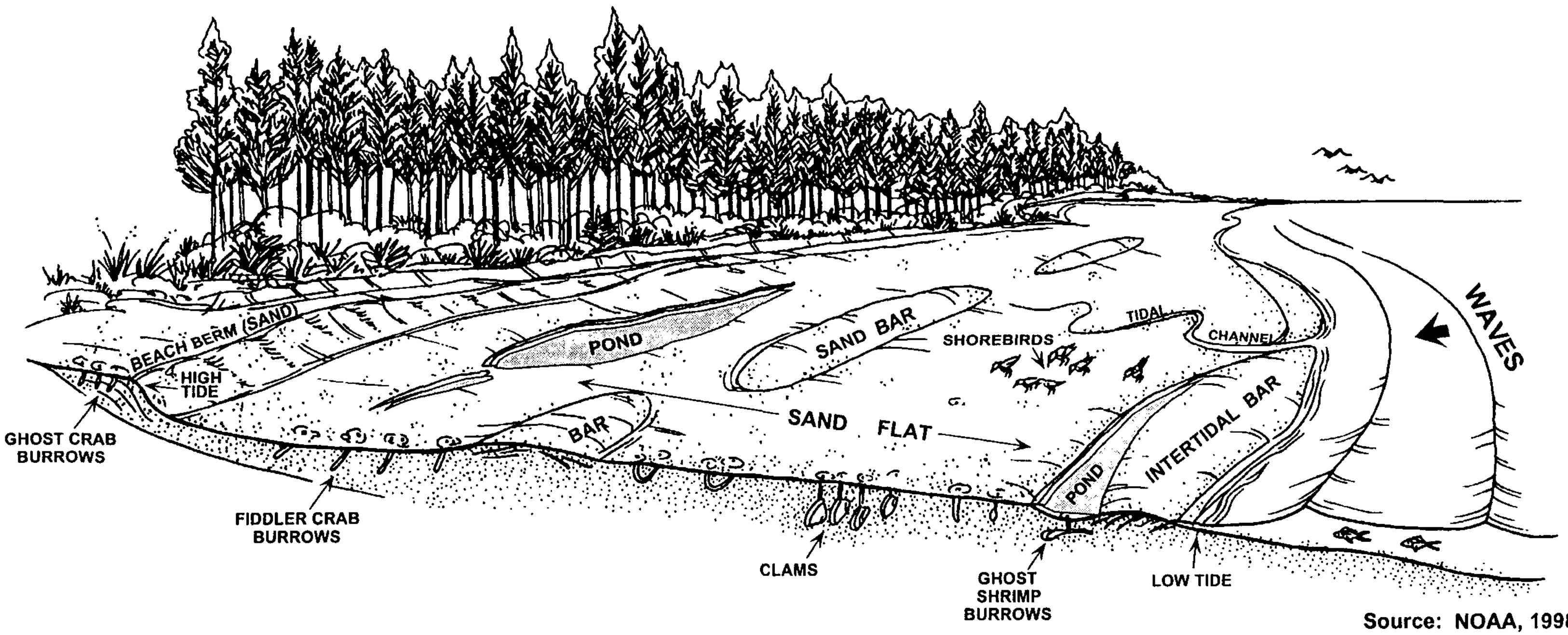
### *Sensitivity*

Exposed tidal flats are highly sensitive to oil spills and subsequent response activities. The sediments can be rich in organic matter and support an abundance of infauna. There can be extensive seagrass beds on the lower edges of the flat. They usually are important foraging and resting grounds for birds and rearing areas for fish and shellfish. Biological impacts may be severe and can extend to predators who rely on this habitat for food.

Oil will not usually adhere to wet tidal flat sediments, but will move across the flats and accumulate at the high-tide line. Even when large slicks spread over the tidal flats at low tide, the rising water lifts the oil, and tidal currents move it along shore. Oil will not penetrate water-saturated sediments, but it will penetrate the drained tops of sand bars and holes formed by decaying roots or animal burrows. The low bearing capacity of these habitats means that response actions can easily leave long-lasting imprints, cause significant habitat disruption, and mix the oil deeper into the sediments. When subsurface sediments are contaminated, oil will weather slowly and may persist for years. Response activities may be hampered by limited access, wide areas of shallow water, fringing vegetation, and soft substrate.

Figure 20 illustrates an exposed tidal flat (ESI classification 7). Table 24 shows the relative impacts from various response methods on exposed tidal flats.

## EXPOSED TIDAL FLATS




Source: NOAA, 1998

Figure 20

**Table 24.** Relative environmental impact from response methods for EXPOSED TIDAL FLATS. This table should not be used without the accompanying text in the document.

| | Category | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | – | C | B | B | B |
| Mechanical Oil Removal | – | D | D | D | D |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | C | B | B | B |
| **Debris Removal** | – | B | B | B | B |
| Sediment Reworking/Tilling | – | – | C | C | C |
| **Vegetation Cutting/Removal** | – | D | D | D | D |
| Flooding (deluge) | – | A | A | A | B |
| **Low-pressure, Ambient Water Flushing** | – | B | B | C | C |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | – | – | – |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Exposed Tidal Flats*

**Natural Recovery**

- Least impact for small spills and lighter oils, to prevent physical disturbances associated with cleanup efforts.
- For large spills or heavy oils, expect some persistence in burrows, where the sediments dry out at low tide, and at the high-tide line.

**Barrier/Berms**

- On tidal flats, this technique would involve constructing sediment dikes, dams, or filter fences across tidal channels to protect wetlands.
- Specialized booms can be deployed above the low tide line to protect sheltered tidal flats and marshes.

**Manual Oil Removal/Cleaning**

- Use where persistent oil occurs in moderate to heavy amounts, or where sensitive resources must be protected.
- Response crews may trample the substrate and intertidal seagrasses, mix oil deeper into the sediments, and contaminate clean areas.

**Mechanical Oil Removal**

- Soft substrates will not support vehicular traffic.
- Will likely cause extensive physical habitat disruption.

**Sorbents**

- Useful as long as the oil is mobilized and recovered by the sorbent, which is less effective for heavier oils.
- Overuse generates excess waste.
- Careful placement and recovery is necessary to minimize substrate disruption.
- Specialized sorbents can be used effectively for lighter oils.

**Vacuum**

- Use to remove oil pooled on the surface.
- Digging trenches to collect oil should be used sparingly because oil can be mixed deeper into the sediment.
- Disruption of soft substrates can be limited by placing boards on the surface and controlling access routes.

- Early use of vacuum on pooled oil can prevent deeper penetration.
- Not applicable to gasoline spills because the oil quickly evaporates.

**Debris Removal**

- Degree of oiling that warrants debris removal and disposal depends on use by sensitive resources.
- Extensive disruption of soft substrate likely by foot traffic.

**Sediment Reworking/Tilling**

- Most effective when conducted underwater, so that the released oil floats to the surface for recovery.
- Causes extensive sediment disruption, but may be better than leaving heavy oil residues on the flat.

**Vegetation Cutting/Removal**

- Cleanup operations in seagrass beds are likely to disturb the rhizomes, greatly increasing the effects of the oil.
- Oiled seagrass blades quickly slough off, particularly in exposed areas, minimizing the need for cutting to protect other users of the habitat.

**Flooding**

- May be effective in keeping for fresh, fluid oils from penetrating the sediments.
- Local topography may limit the ability to control where the water and released oil flow and, thus, the effectiveness of recovery, particularly on wide flats.
- There will be some sediment disruption from equipment deployment and maintenance.

**Low-pressure, Ambient Water Flushing**

- Only effective when the oil is fluid and adhered loosely to the sediments.
- Requires pressure adjustments to minimize the amount of sand mobilized.
- Local topography may limit the ability to control where the water and released oil flow and effectiveness of recovery.
- May need to operate from boats or plank walkways to minimize trampling by crews.

High-pressure, Ambient Water Flushing

- High pressure is not appropriate for these substrates because of excessive sediment flushing.

Low-pressure, Hot Water Flushing

- Highly intrusive technique; will kill any organisms present.

High-pressure, Hot Water Flushing

- High pressure is not appropriate for these substrates because of excessive sediment flushing.

Steam Cleaning

- High pressure is not appropriate for these substrates because of excessive sediment flushing.

Sand Blasting

- Not appropriate for soft substrate because of excessive sediment flushing.

Solidifiers

- High likelihood of disruption and mixing of oil deeper into the substrate during application and retrieval.
- Not generally applicable for Category I light oils which usually rapidly evaporate, or for heavy oils which are too viscous.

Surface Washing Agents

- Not appropriate for this habitat because it is not effective on exposed tidal flats.

Nutrient Enrichment and Natural Microbe Seeding

- There is insufficient information on impact and effectiveness in tidal flat habitats.

*In-situ* Burning

- Ranking is for tidal flats that are not covered with water. When tidal flats are covered with water, refer to soft bottom subtidal habitat for ISB ranking.
- Heat may impact biological productivity of habitat, especially where there is no standing water to act as a heat sink on top of the mud.
- Heat can impact biological productivity.

## SHELTERED, ROCKY SHORES AND CLAY SCARPS

### *Habitat Description*

Sheltered, rocky shores are characterized by a rocky substrate that can vary widely in its permeability, from smooth vertical bedrock, to porous rubble slopes. They are sheltered from exposure to most wave and tidal energy, thus there is little sorting of sediments accumulating on the bedrock surface. The slope of the shoreline varies from vertical rocky cliffs formed by glacial ice to gently dipping rock shelves on which rocky debris accumulates. The rock surface can be highly irregular, with numerous cracks and crevices. Of particular concern are rocky shores which have a semi-permeable veneer of angular rubble overlying the bedrock.

Sheltered, clay scarps are characterized by a steep, usually vertical scarp in hard-packed and shelf clay. They occur most frequently along man-made canals and waterways, and along bays. They are exposed to only intermittent wave energy or boat wakes. The clay substrate can have many holes from animal burrows and root cavities. Vegetation usually occurs landward of the scarp.

### *Sensitivity*

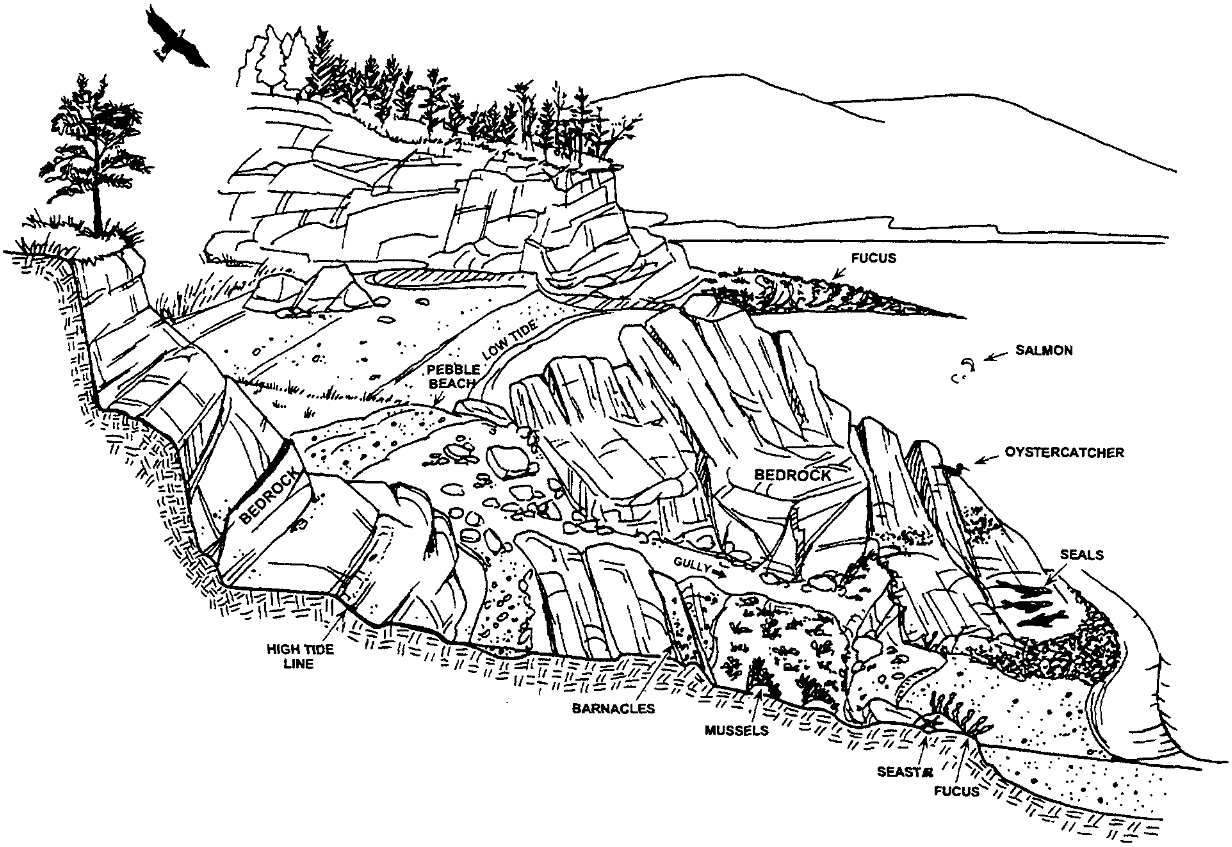
Sheltered, rocky shorelines are considered to be highly sensitive to oil spills. The productivity of the intertidal community can be very high, with abundant attached animals and plants. Clay scarps provide important nursery habitat for fish and forage areas for birds.

In sheltered, rocky settings, oil will readily adhere to the rough rocky surface, forming a distinct band along the upper intertidal zone. Crevices will be sites of oil pooling and persistence. Oil will penetrate and persist in any surface accumulation of sediments or rubble. Medium to heavy oils can weather to be very sticky and form thick black bands, while lighter oils are more readily removed by wave action, evaporation, and response efforts.

Oil is not likely to adhere to the wet clay surface in clay scarps, but penetration into burrows and root cavities is of concern. Oil will adhere to any vegetation on the top of the scarp. Access to this shoreline type is very difficult.

Figure 21 is an illustration of a sheltered, rocky shore (ESI classification 8A). Table 25 shows the relative impact from various response methods on sheltered, rocky shores and clay scarps.

## SHELTERED, ROCKY SHORES




Source: NOAA, 1998

## CLAY SCARPS

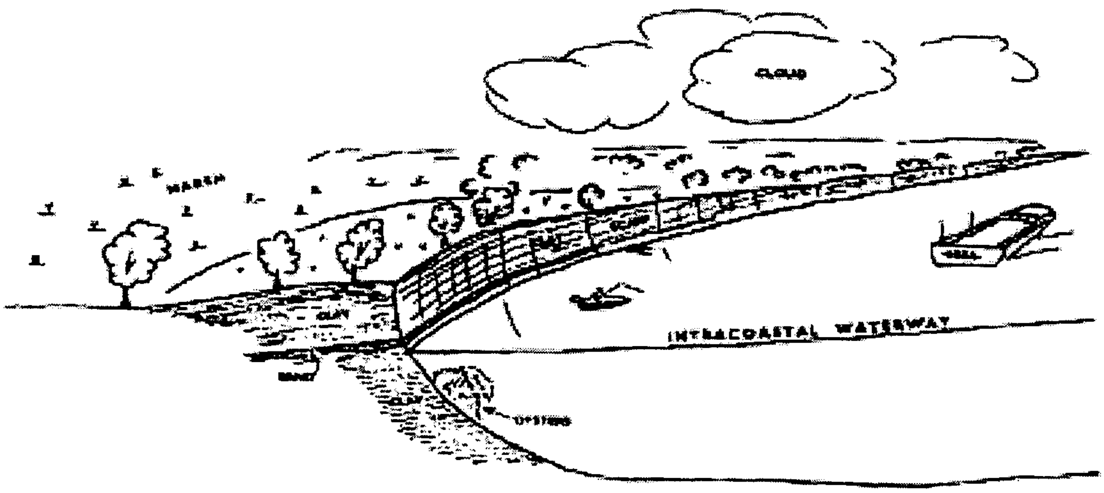



Figure 21

**Table 25.** Relative environmental impact from response methods for SHELTERED, ROCKY SHORES AND CLAY SCARPS. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | C | B | C | C |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | A | A | B | C | C |
| Vacuum | – | B | B | B | C |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | D | D | D |
| Flooding (deluge) | – | A | A | B | C |
| **Low-pressure, Ambient Water Flushing** | – | A | A | B | C |
| High-pressure, Ambient Water Flushing | – | C | B | B | C |
| **Low-pressure, Hot Water Flushing** | – | – | D | D | D |
| High-pressure, Hot Water Flushing | – | – | D | D | D |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | B | B | B |
| **Nutrient Enrichment** | – | A | B | C | C |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | D | C | C | C |

Category Descriptions

I – Gasoline products

II – Diesel-like products and light crude oils

III – Medium grade crude oils and intermediate products

IV – Heavy crude oils and residual products

V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Sheltered, Rocky Shores and Clay Scarps*

Natural Recovery

- Sheltered bedrock may need cleanup because of slow natural removal rates.
- Cleanup of larger spills may be needed because of the amount of oil present.

Barriers/Berms

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Manual Oil Removal/Cleaning

- Expect significant residues with only manual removal of lighter oil because of its fluidity and difficulty of manual pickup, and of heavier oil because of its adhesion.
- Useful for thick oil accumulations in bedrock crevices, sediment pockets, or root cavities.
- On clay scarps, foot traffic should be restricted so as not to disturb the muddy, though cohesive, substrate.

Mechanical Oil Removal

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Sorbents

- Overuse generates excess waste.
- Physical removal rates of medium to heavy oils will be slow, so less oil will be mobilized for recovery by sorbents, particularly for sheltered areas.
- Specialized sorbents can be effectively used for lighter oils.
- On clay scarps, foot traffic should be restricted so as not to disturb the muddy, though cohesive, substrate.

Vacuum

- Variable effectiveness for heavy oils adhered to rough, rocky surfaces, or steep clay scarps.

Debris Removal

- Degree of oiling that warrants debris removal and disposal depends on human and sensitive resource use of the site.

Sediment Reworking/Tilling

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Vegetation Cutting/Removal

- Vegetation present might not recover.

Flooding and Low-pressure, Ambient Water Flushing

- Most effective on fresh, fluid oils.
- Use on heavy oils is likely to leave large amounts of residual oil in the environment.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

High-pressure, Ambient Water Flushing

- Primarily applicable to medium oils while still fresh and liquid.
- Can be effective in removing oil from crevices and pockets of sediment on bedrock.
- There can be dislocation and physical impacts to biota because they are not acclimated to high pressures.
- To reduce risk of transporting oil to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.
- On clay scarps, high pressure wash may erode the substrate.

Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing

- Any organisms in the application area would be adversely affected by hot water.
- Most effective on heavy crudes where heat would make oil more fluid.
- Use is appropriate in limited areas only when oil removal is needed for aesthetic reasons or to protect special species of concern.
- To reduce risk of transporting oil and hot water to unoiled or lesser oiled areas in the lower intertidal zone, conduct flushing only during the upper half of the tidal cycle.

Steam Cleaning and Sand Blasting

- Highly intrusive techniques; will kill any organisms present.
- Use only for aesthetic reasons in very limited rocky areas.

**Solidifiers**

- Use to prevent concentrations of stranded oil from being refloated and transported to more sensitive habitats.
- Not generally applicable for Category I light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.

**Surface Washing Agents**

- Can be an effective tool that will remove sticky oils without hot water, high-pressure washing. Can be used to reduce the need for high temperatures or high pressure to remove persistent oils.
- There will be concerns about toxic effects of the released oil/product when the lower intertidal or nearshore subtidal habitats are biologically rich.
- Individual products vary in their toxicity and recoverability of the treated oil.

**Nutrient Enrichment**

- Potentially effective for lighter oils that leave thin residues; less effective for thick, weathered oil residues.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness.

***In-situ* Burning**

- Can effectively remove heavy oil accumulations on impermeable bedrock surfaces.
- Can result in physical residues and long-term impacts to biota.
- Category I oils are not expected to accumulate sufficiently to burn.

## Sheltered, Solid, Man-made Structures

### *Habitat Description*

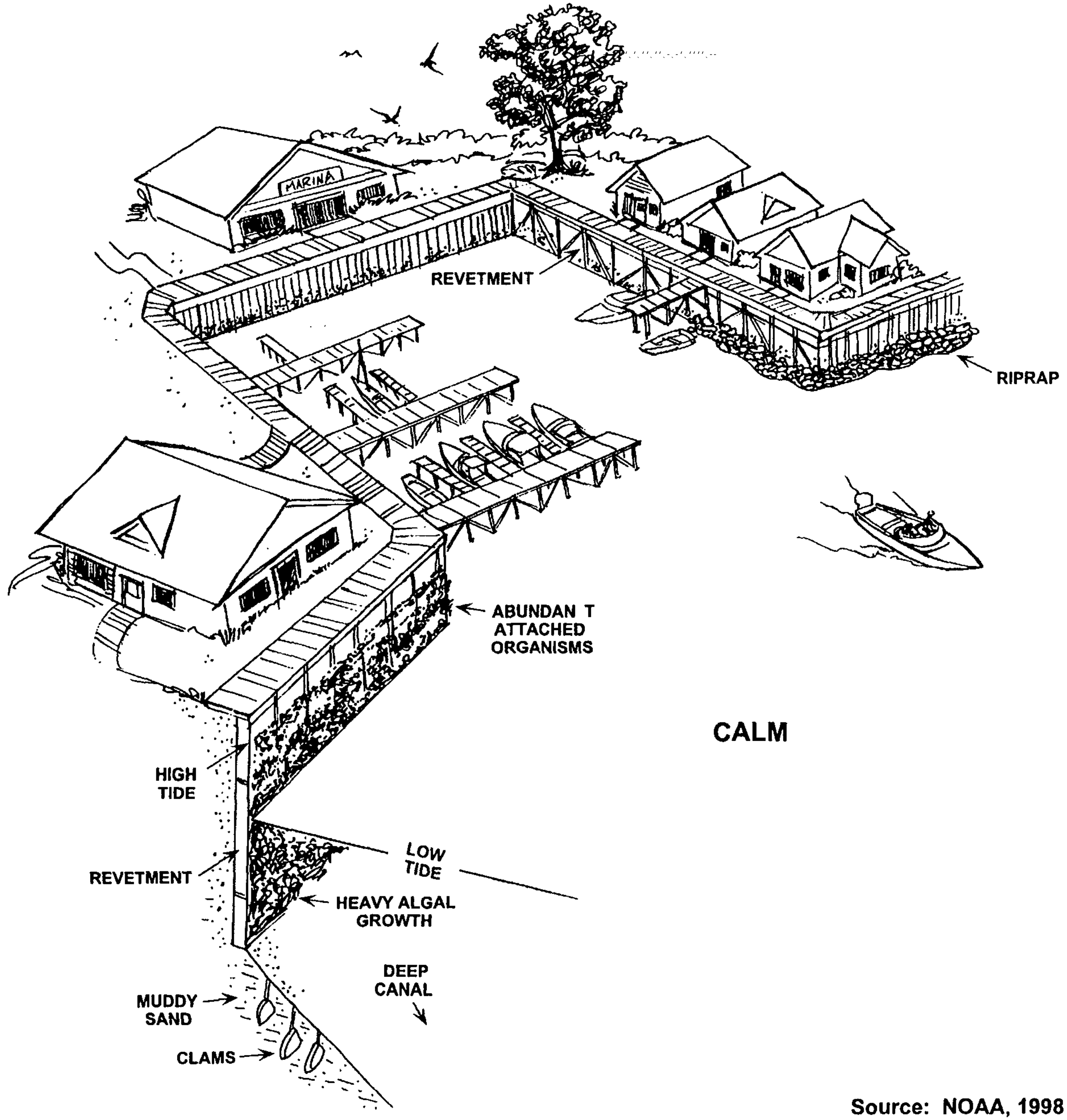
Sheltered, solid, man-made structures, such as seawalls, piers, and bulkheads, are built for shore protection. These vertical structures can be constructed of concrete, wood, stone, or corrugated metal. They usually extend below the water surface, although seawalls can have beaches or riprap in front of them. These structures are common along developed shores, particularly in harbors, marinas, and residential areas. They are sheltered from direct exposure to waves and currents, though boat wakes can generate intermittent wave action.

### *Sensitivity*

Sheltered seawalls are ranked as moderately sensitive to oil spills, primarily because of the low natural removal rates. The intertidal portion can be covered with attached algae and animals, particularly the middle and lower portions. In some areas, such as the southeastern United States, seawalls provide the only hard intertidal substrate and can be heavily colonized. Solid seawalls are generally impermeable to oil penetration, but oil can heavily coat rough surfaces, forming a band at the water line. During high water, oil could flood the structure and contaminate terrestrial habitats. Although the structures can have dense attached organisms on the middle to lower portions, oil usually does not adhere to these areas. Instead, stranded oil often forms a band at the high-tide line, above the zone of attached algae and animals. Often, there are sources of pollutants or habitat degradation nearby. More intrusive cleanup techniques are often used due to the seawall's lower biological importance, higher public demand for oil removal for aesthetic reasons, and need to minimize human exposure to oil in populated areas. Furthermore, it is expected that the artificial substrates will be rapidly recolonized.

Figure 22 illustrates a sheltered, solid, man-made structure (ESI classification 8B). Table 26 shows the relative impacts from various response methods on sheltered, solid, man-made structures.

# SHELTERED, SOLID, MAN-MADE STRUCTURES




Source: NOAA, 1998

Figure 22

**Table 26.** Relative environmental impact from response methods for SHELTERED, SOLID, MAN-MADE STRUCTURES. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | B | B | B | B |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | – | – | – | – |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | – | – | – | – | – |
| **Low-pressure, Ambient Water Fl** | – | A | B | C | C |
| High-pressure, Ambient Water Flus | – | B | B | C | C |
| **Low-pressure, Hot Water Flushin** | – | – | C | C | C |
| High-pressure, Hot Water Flushing | – | – | C | C | C |
| **Steam Cleaning** | – | – | D | D | D |
| Sand Blasting | – | – | D | D | D |
| **Solidifiers** | – | – | – | – | – |
| Surface Washing Agents | – | – | B | B | B |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products IV – Heavy crude oils and residual products

II – Diesel-like products and light crude oV – Non-floating oil products

III – Medium grade crude oils and intermediate products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.

B = May cause some adverse habitat impact.

C = May cause significant adverse habitat impact.

D = May cause the most adverse habitat impact.

I = Insufficient Information - impact or effectiveness of the method could not be evaluated.

— = Not applicable.

## *Response Methods: Sheltered, Solid, Man-made Structures*

Natural Recovery

- Medium to heavier oils may necessitate removing persistent residues.

Barriers/Berms

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Manual Oil Removal/Cleaning

- Significant oily residues will likely remain on rough surfaces.

Mechanical Oil Removal

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Sorbents

- Heavy oils are released from the shoreline at a slow rate, so less oil will be mobilized for recovery by sorbents.
- Overuse results in excess waste generation.
- Specialized sorbents can be used effectively for lighter oils.

Vacuum

- Oil is not likely to pool in sufficient quantities to use this technique.

Debris Removal

- Floating debris often accumulates (along with oil) in dead-end canals.

Sediment Reworking/Tilling

- Substrate is not amenable to reworking and would require excessive physical disruption that might permanently alter the substrate.

Vegetation Cutting/Removal

- Little vegetation is usually present in this habitat.

Flooding

- Cannot be used effectively on steep habitats.

Low-pressure, Ambient Water Flushing

- Only effective when the oil is fluid.
- Use on heavy oils is likely to leave large amounts of residual oil.

**High-pressure, Ambient Water Flushing**

- Effective for removing sticky oils from solid surfaces.
- Use on heavy oils is likely to leave large amounts of residual oil.

**Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing**

- High water temperatures are often needed to liquefy heavy oils.
- High water pressures are often needed to remove weathered oils from solid substrates. However, use is appropriate in limited areas only when oil removal is needed for aesthetic reasons or to protect special species of concern.

**Steam Cleaning and Sand Blasting**

- Used when removing persistent oil is required for aesthetic reasons.

**Solidifiers**

- Not appropriate due to the vertical characteristics of this habitat.

**Surface Washing Agents**

- Can be used to reduce the need for high temperatures or high pressure to remove persistent oils.
- Individual products vary in their toxicity and ability to recover the treated oil.

**Nutrient Enrichment**

- There is insufficient information on impact and effectiveness, particularly for applications on man-made structures.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness, particularly for applications on man-made structures.

***In-situ* Burning**

- Oil is not expected to accumulate sufficiently to burn.
- Possibility of secondary fires may preclude use.

## PEAT SHORES

### *Habitat Description*

Peat shorelines comprise about 70 percent of the Beaufort Sea coast of Alaska. They are formed as a result of eroding tundra cliffs adjacent to the intertidal zone.

In the Arctic, eroding peat tundra shores generate large amounts of eroded peat that accumulate as thick mats in depositional areas in the intertidal zone. Where peat forms a cliff, the exposed shore face is frozen. The shores are highly erosional [shoreline retreat rates of 3 feet (1 meter) per year are common], and erosion occurs from wave action, ice scour, and melting of the frozen peat.

Peat shores are most often found as a mat or veneer in a dewatered state which is deposited on a sand or gravel beach, and there may be another thin and temporary layer of sand overlying the peat. It usually forms as deposits fewer than 8 inches (20 centimeters) thick, which are considered to be relatively transient. Peat shores have slurry-type materials (which have the appearance of coffee grounds) which can be found at the foot of eroding peat scarps and in depositional areas. The slurry is considered to be a relatively permanent, if mobile, feature moving along shore with the currents. Slurry mats can be up to 20 inches (50 centimeters) thick and 33 feet (10 meters) wide.

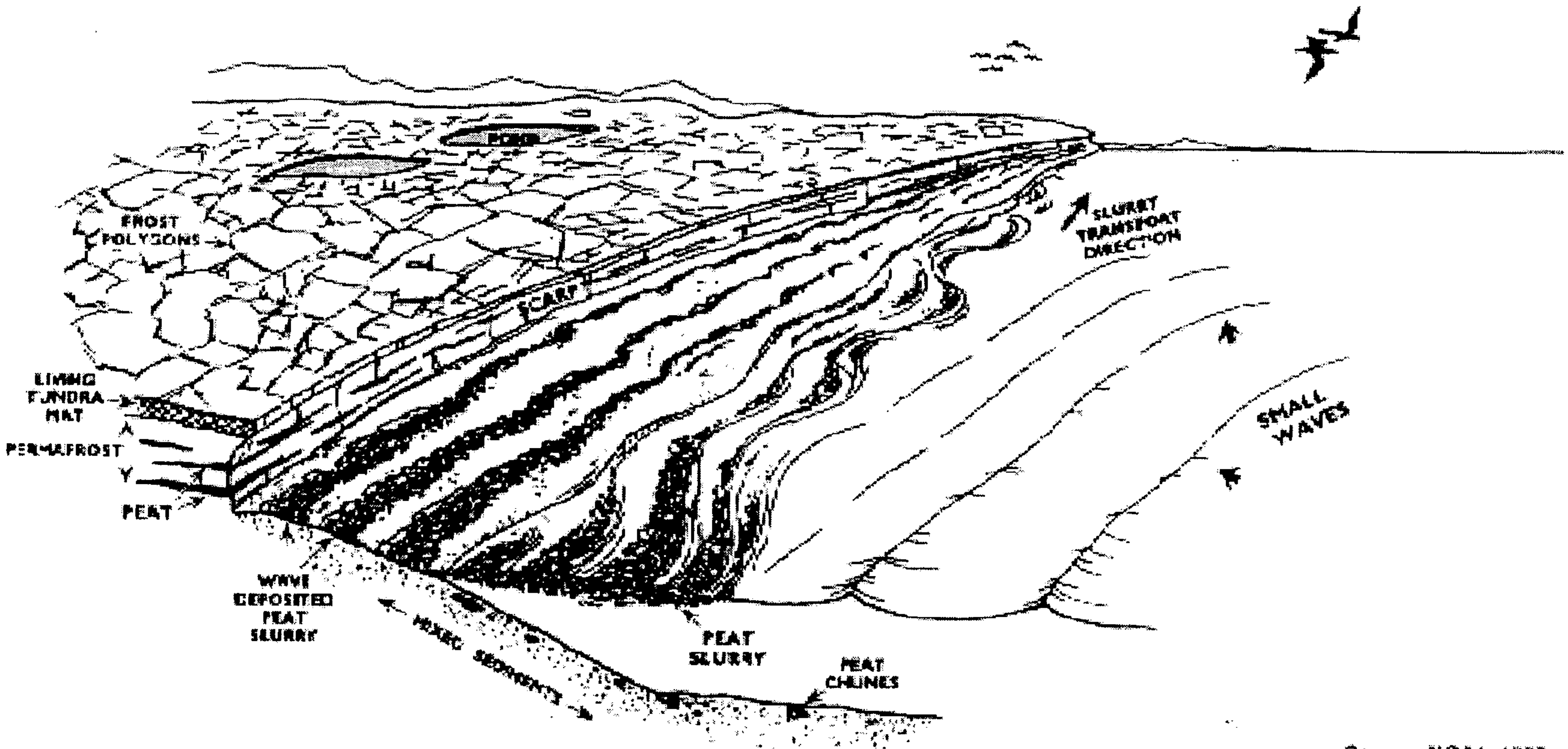
### *Sensitivity*

Peat shores are considered to be moderately sensitive to oil spills. The intertidal zone is not particularly important as biological habitat, but peat shores are often found in association with tundra that is highly susceptible to physical damage from foot and vehicular traffic.

Oil penetration and persistence are expected to be very low in frozen peat shores. However, light oils can penetrate peat slurries, especially when the peat is dry. Peat resists penetration by heavy oil, even when dry. Oiled peat can act as a reservoir from which oil can leach over time. The slurry will react to oil similarly to loose granular sorbent and will partially contain and prevent the oil from spreading. Response and cleanup activities on peat shorelines will be difficult and disruptive. Peat shores can be highly erosional, and natural cleaning may be the only viable option in many instances.

Figure 23 illustrates a peat shore (ESI classification 8C). Table 27 shows the relative impacts from various response methods on peat shores.

# PEAT SHORES




Source: NOAA, 1993

Figure 23

**Table 27.** Relative environmental impact from response methods for PEAT SHORES. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | C | B | B | B | B |
| Mechanical Oil Removal | D | D | D | D | D |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | B | B | B | B |
| **Debris Removal** | C | B | B | B | B |
| Sediment Reworking/Tilling | C | C | B | B | B |
| **Vegetation Cutting/Removal** | D | D | C | C | C |
| Flooding (deluge) | C | B | B | C | D |
| **Low-pressure, Ambient Water Flushing** | C | B | B | C | D |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | – | – | – | – |
| Surface Washing Agents | – | – | – | – | – |
| **Nutrient Enrichment** | – | B | B | C | C |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products

II – Diesel-like products and light crude oils

III – Medium grade crude oils and intermediate products

IV – Heavy crude oils and residual products

V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Peat Shores*

### Natural Recovery

- Least damaging for light to moderate amounts of oil in inaccessible areas.
- With high erosion rates, oil is likely to have a short residence time.

### Barriers/Berms

- Excessive physical disruption can completely alter the substrate, hydrology, and vegetation patterns for many years.

### Manual Oil Removal/Cleaning

- Trampling of peat and tundra is unavoidable in oiled and access areas.
- Trampling is of less concern where peat is frozen or work is conducted from boats.
- Even partial removal of heavily oiled peat/slurry would be beneficial.

### Mechanical Oil Removal

- Excessive physical disruption and mixing of oil into the peat likely from equipment.

### Sorbents

- Sorbents are more effective when the oil is liquid and fresh.
- Overuse generates excessive waste, which is a particular problem in this habitat.

### Vacuum

- Most effective where water access is good or when substrate is frozen and can support vehicles.
- Only useful when oil is pooled, not too full of debris, and not too viscous.

### Debris Removal

- Degree of oiling that warrants debris removal and disposal depends on use by humans and sensitive resources.
- Lesser concerns where peat is frozen solid or work is conducted from boats.

### Sediment Reworking/Tilling

- Substrate disruption is of limited concern because of high erosion rates so long as adjacent tundra is not disturbed.

Vegetation Cutting/Removal

- Removal of living tundra only appropriate where heavily oiled.

Flooding and Low-pressure, Ambient Water Flushing

- Oil must be liquid, thus not effective on viscous oils.
- Large quantities of peat could be eroded from the treatment area during this process.

High-pressure, Ambient Water Flushing

- High-pressure water spray will erode unnecessarily large amounts of peat.

Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing

- Hot water is too intrusive for Arctic habitats.

Steam Cleaning

- Not appropriate for soft substrates.

Sand Blasting

- Not appropriate for soft substrates.

Solidifiers

- Use likely to increase oil adherence to peat and slow removal rates of residual oil.

Surface Washing Agents

- Not appropriate because not effective. Cleaner will absorb into peat.

Nutrient Enrichment

- Applicable where nutrient concentrations are low enough to be a limiting factor for oil degradation.
- Effective after gross oil removal is completed.
- There is limited information on impact and effectiveness on peat-rich shorelines.

Natural Microbe Seeding

- There is insufficient information on impact and effectiveness on peat-rich shorelines.

## *In-situ* Burning

- Burning of organic substrates is not appropriate because of risk of an uncontrolled fire.

## SHELTERED TIDAL FLATS

### *Habitat Description*

Sheltered tidal flats are characterized by a flat gradient and a substrate composed predominantly of silt and clay sediments, although they may be mixed with varying amounts of sand or gravel (see Appendix C for grain-size chart). The sediments are mostly water-saturated and have low bearing strength and trafficability. They are sheltered from wave action and strong tidal currents, although there can be strong currents in channels draining across the flats. There can be seagrass beds associated with these flats. Sheltered tidal flats are commonly associated with wetlands on the landward side.

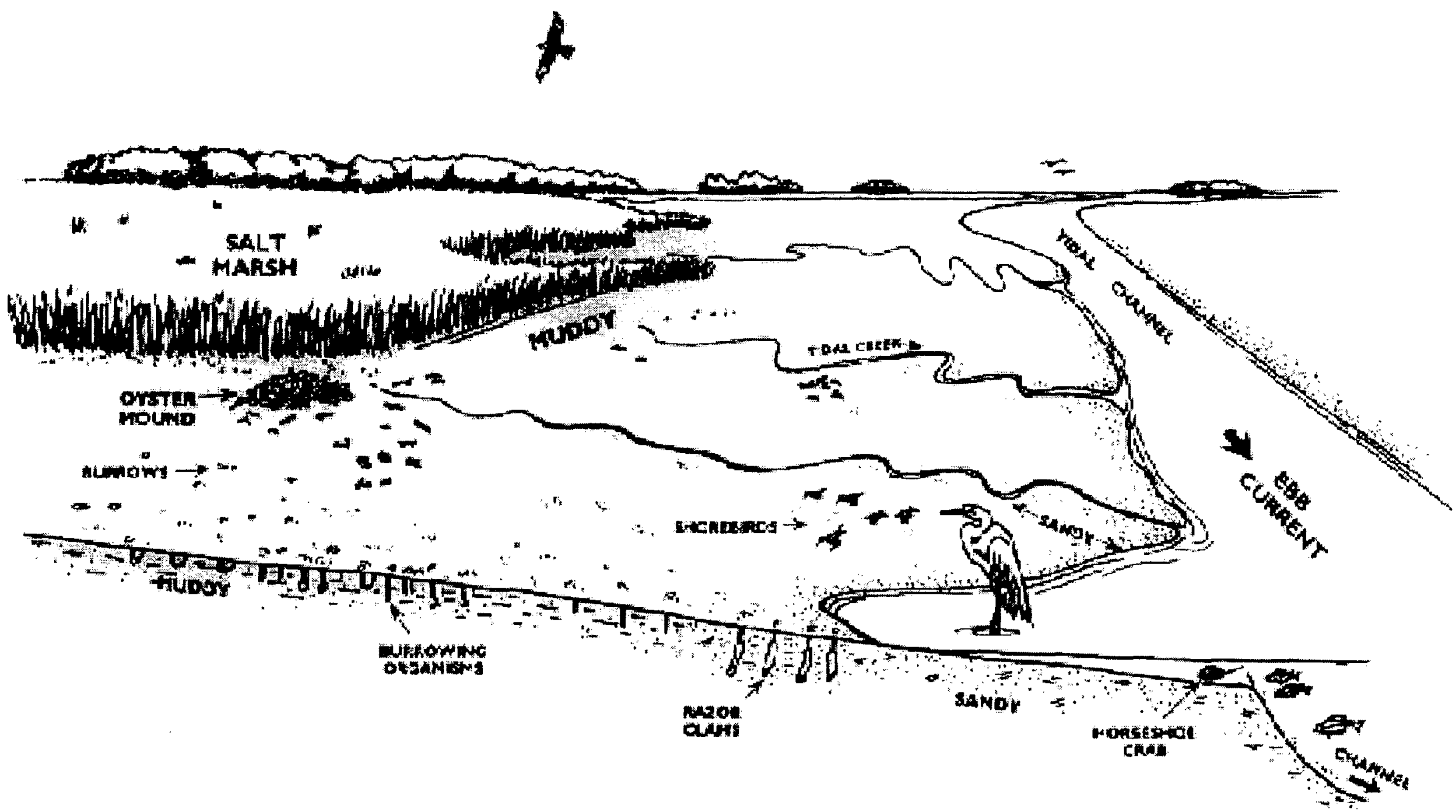
### *Sensitivity*

Sheltered tidal flats are highly sensitive to oil spills and subsequent response activities. Shoreline sediments are likely to be rich in organic matter and support an abundance of infauna. They usually are important feeding grounds for birds, rearing areas for fish, and habitats for shellfish beds.

Oil will not penetrate muddy sediments because of their low permeability and high water content, except through decaying root and stem holes or animal burrows. Under heavy oiling conditions, the oil can spread over the flats at low tide; however, the rising tide tends to lift the oil from the wet sediment surface and concentrate it at the high-tide line. Light oils can adhere to, and contaminate, intertidal mud. Natural removal rates can be very slow, chronically exposing sensitive resources to the oil. The low bearing capacity of these shorelines means that response actions can easily leave long-lasting imprints, cause significant erosion, and mix the oil deeper into the sediments. When subsurface muddy sediments are contaminated, oil will weather slowly and may persist for years. Response activities may be hampered by limited access, wide areas of shallow water, fringing vegetation, and soft substrate, making it almost impossible to clean these habitats without extensive disruption to the substrate.

Figure 24 illustrates a sheltered tidal flat (ESI classification 9). Table 28 shows the relative impacts from various response methods on sheltered tidal flats.

## SHELTERED TIDAL FLATS




Source: NOAA, 1998

Figure 24

**Table 28.** Relative environmental impact from response methods for SHELTERED TIDAL FLATS. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* *I* | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | – | D | C | C | C |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | A | A | B | B |
| Vacuum | – | C | B | B | B |
| **Debris Removal** | – | B | B | B | B |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | D | D | D |
| Flooding (deluge) | – | B | B | B | C |
| **Low-pressure, Ambient Water Flushing** | – | C | C | D | D |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | – | – | – |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Sheltered Tidal Flats*

**Natural Recovery**

- Least impact for small spills and lighter oils, to prevent disruptions associated with cleanup efforts.
- For large spills or heavy oils, expect long-term persistence in low-energy settings.

**Barrier/Berms**

- This technique consists of sediment dikes, dams, or filter fences placed across tidal channels to protect wetlands.
- Because of the soft substrate, extreme care is needed to minimize physical disruption during installation and removal.
- Specialized booms can be deployed above the low tide line to protect sheltered tidal flats and marshes.

**Manual Oil Removal/Cleaning**

- Use where persistent oil occurs in moderate to heavy amounts, or where sensitive resources must be protected.
- Response crews will likely trample soft substrates, mix oil deeper into the sediments, and contaminate clean areas.

**Mechanical Oil Removal**

- Soft substrates will not support vehicular traffic.
- Will likely cause extensive physical habitat disruption.

**Sorbents**

- Useful as long as the oil is mobilized and recovered by the sorbent.
- Overuse generates excess waste.
- Careful placement and recovery is necessary to minimize substrate disruption.
- Specialized sorbents can be used effectively for lighter oils.

**Vacuum**

- Use to remove oil pooled on the surface.
- Avoid digging trenches to collect oil which can mix oil deeper into the sediment.
- Disruption of soft substrates can be limited by placing planks on the surface, working from small boats, and controlling access routes.

**Debris Removal**

- Degree of oiling that warrants debris removal and disposal depends on use by sensitive resources.
- Assumes that heaviest amounts of debris usually accumulate on the landward side of the flat, which would be accessible from land or by small boat.

**Sediment Reworking/Tilling**

- Will cause extensive physical habitat and sediment disruption.

**Vegetation Cutting/Removal**

- Cleanup operations in seagrass beds are likely to disturb the rhizomes, greatly increasing the effects of the oil. Recovery will vary depending on the affected species.
- Oiled seagrass blades quickly slough off, particularly in exposed areas, minimizing the need for cutting to protect other users of the habitat.

**Flooding**

- Effective only for fresh, fluid oils, so less effective on heavier oils.
- Local topography may limit the ability to control where the water and released oil flow and effectiveness of recovery.

**Low-pressure, Ambient Water Flushing**

- Mud is readily suspended if substrate is not firm.
- Not effective for higher-viscosity oils that will not move with low pressure.
- Local topography may limit the ability to control where the water and released oil flow and effectiveness of recovery.

**High-pressure, Ambient Water Flushing**

- High pressure is not appropriate because of excessive sediment flushing.

**Low-pressure, Hot Water Flushing**

- Highly intrusive technique; will kill any organisms present.

**High-pressure, Hot Water Flushing**

- High pressure is not appropriate because of excessive sediment flushing.

Steam Cleaning

- High pressure is not appropriate because of excessive sediment flushing.

Sand Blasting

- Not appropriate for soft substrate because of excessive sediment flushing.

Solidifiers

- High likelihood of disruption and mixing of oil deeper into the substrate during application and retrieval. Might be justified to immobilize large amounts of oil temporarily stranded on the flat.
- Not generally applicable for Category I lights oils which usually rapidly evaporate, nor for heavy oils which are too viscous.

Surface Washing Agents

- Not appropriate on sheltered tidal flats because products are not effective in this habitat.

Nutrient Enrichment and Natural Microbe Seeding

- There is insufficient information on impact and effectiveness in mud habitats.

*In-situ* Burning

- Ranking is for tidal flats that are not covered with water. When tidal flats are covered with water, refer to soft bottom subtidal habitat for ISB ranking.
- Heat may impact biological productivity of habitat, especially where there is no standing water to act as a heat sink on top of the mud.
- Heat can impact biological productivity.

## SALT TO BRACKISH MARSHES

### *Habitat Description*

Salt to brackish marshes occur along tidally influenced waterbodies where the water salinity averages at least five parts per thousand. Marshes are mostly herbaceous, and the few woody species occur mostly at higher elevations. Surfaces of wetlands usually have a low gradient. The substrate can vary from sand to mud, though organic, muddy soils are most common. The substrate can be riddled with burrows and holes from decaying plant stems. Because marshes grow in the mid- to upper-intertidal zone, they are often fronted by other shoreline types.

### *Sensitivity*

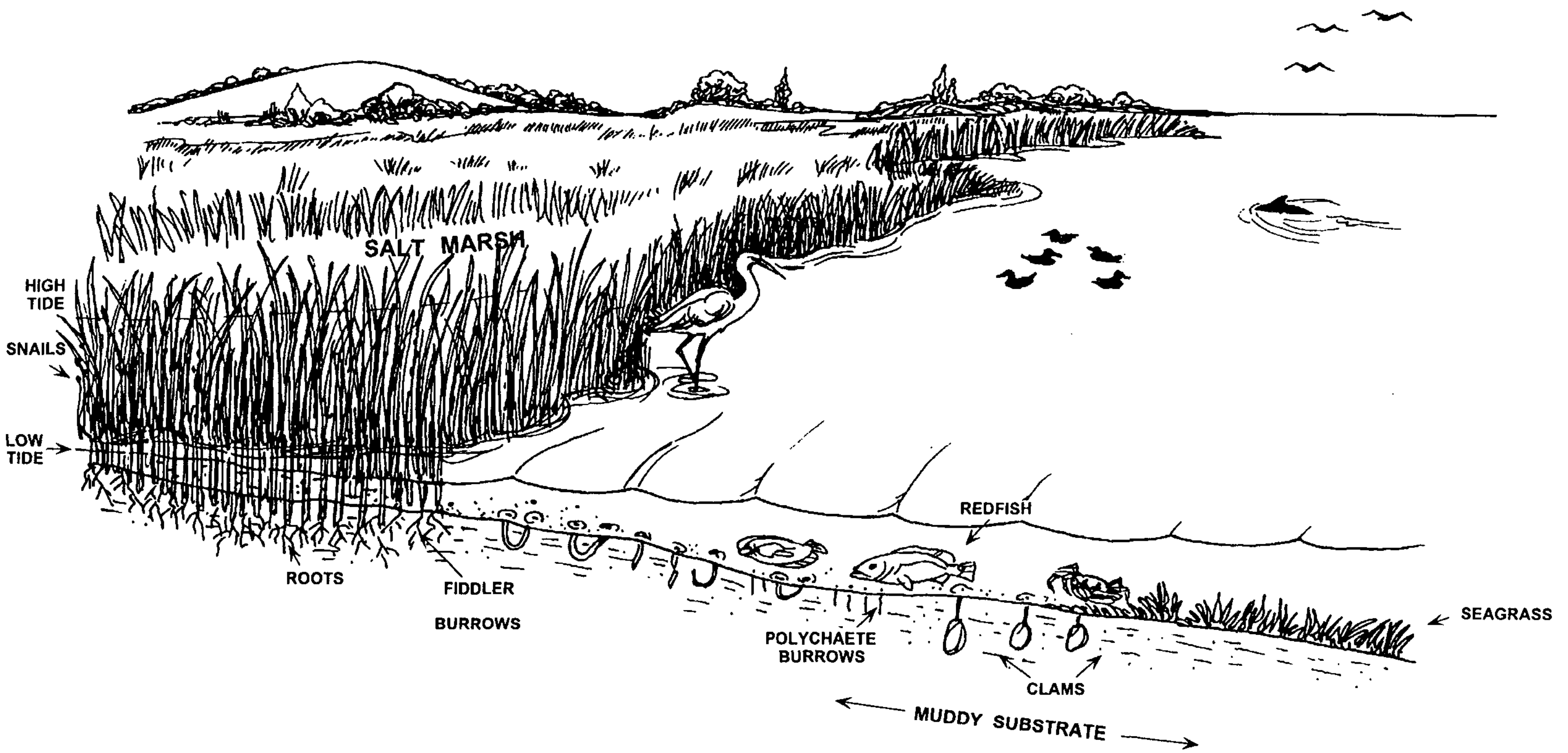
Marshes are highly sensitive to oil spills. They are among the most productive ecosystems in the world. They are highly valuable and supply many ecological functions such as providing nursery habitat for many types of animals, enhancing water quality through nutrient loading, and protecting the shoreline against erosion. Humans rely on marshes for food, recreation, and water treatment.

Oil spills affect both the habitat (vegetation and sediments) and the organisms that directly and indirectly rely on the habitat. There are many factors that affect the behavior and impact of spilled oil on marshes, including: oil type, extent of vegetation contamination, degree of sediment contamination, exposure to natural removal processes, time of year, and differences among species. In addition to direct impacts to vegetation, oil can affect detritus-based food webs, which are fundamentally important in wetlands, by slowing decomposition rates of plant material.

Many species are reliant upon wetlands for their reproductive and early life stages when they are most sensitive to oil. Some endangered animals and plants occur only in wetlands, and spills in such areas would be of particular conservation concern. The threat of direct oiling of animals using the wetland often drives efforts to remove oiled vegetation. Cleanup activities can cause more harm than leaving the oil in place; therefore, careful analysis of benefits versus impacts is required.

Figure 25 illustrates a salt to brackish marsh (ESI classification 10A). Table 29 shows the relative impacts from various response methods on salt to brackish marshes.

## MARSHES (SALT TO BRACKISH)




Source: NOAA, 1998

Figure 25

**Table 29.** Relative environmental impact from response methods for SALT TO BRACKISH MARSHES. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | B | B | B |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | D | D | C | C | C |
| Mechanical Oil Removal | D | D | D | D | D |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | B | B | B | B |
| **Debris Removal** | – | B | B | B | B |
| Sediment Reworking/Tilling | D | D | D | D | D |
| **Vegetation Cutting/Removal** | D | D | C | C | C |
| Flooding (deluge) | B | B | B | B | B |
| **Low-pressure, Ambient Water Flushing** | B | B | B | B | B |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | B | B | I |
| **Nutrient Enrichment** | – | A | B | B | B |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | B | B | B | C |

Category Descriptions

I – Gasoline products

II – Diesel-like products and light crude oils

III – Medium grade crude oils and intermediate products

IV – Heavy crude oils and residual products

V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Salt To Brackish Marshes*

Natural Recovery

- Least impact for small to moderate spills and lighter oils; avoids damage often associated with cleanup activities.
- Some cleanup may be warranted where large numbers of animals are likely to become oiled during wetland use.

Barrier/Berms

- This technique consists of sediment dikes, dams, or filter fences placed in tidal channels in the marsh.
- Because of the soft substrate, extreme care is needed to minimize physical disruption during installation and removal.

Manual Oil Removal/Cleaning

- Used where persistent oil occurs in heavy amounts and where sensitive resources using the marshes are likely to be oiled.
- Response crews may trample roots and mix oil deeper into the sediments.

Mechanical Oil Removal

- Using vehicles in soft substrate will probably cause extensive physical disruption.
- Can completely alter the marsh substrate, hydrology, and vegetation patterns for many years.

Sorbents

- Useful as long as the oil is mobilized and recovered by the sorbent.
- Care is necessary during placement and recovery to minimize disturbance of substrate and vegetation.
- Overuse generates excess waste.
- Specialized sorbents can be used effectively for lighter oils.

Vacuum

- Can be effective in removal of pooled oil from the marsh surface.
- Trampling of vegetation and substrate can be limited by operating from small boats or placing planks on the surface and limiting traffic.

## Debris Removal

- The removal of heavily oiled and mobile debris, such as oiled wrack, may reduce contamination of wildlife using the marsh and transport of oil off-site.

## Sediment Reworking/Tilling

- No benefit from mixing oil deeper into fine-grained and organic soils.

## Vegetation Cutting/Removal

- Used to prevent oiling of sensitive animals using the marsh.
- Most appropriate for oils that form a thick, sticky coating on the vegetation, such as medium and heavy oils.
- Could delay recovery of the vegetation due to both oil impact and physical destruction by cleanup crews.
- Trampling of vegetation could be reduced by controlling access routes, using planks placed on surface, or conducting operations from boats.

## Flooding and Low-pressure, Ambient Water Flushing

- If water pressures are too high, the substrate and vegetation may be disturbed.
- Can be used selectively to remove localized heavy oiling.
- Can be difficult to direct water and oil flow towards recovery devices.
- Use on heavy oils is likely to leave large amounts of residual oil.
- Care must be taken to avoid disturbing the substrate and vegetation.

## High-pressure, Ambient Water Flushing

- Not appropriate for vegetative habitats because of sediment flushing.

## Low-pressure, Hot Water Flushing

- Highly intrusive technique; will kill any organisms present.

## High-pressure, Hot Water Flushing

- Not appropriate for vegetative habitats because of sediment flushing.

## Steam Cleaning

- Not appropriate for vegetative habitats because of sediment flushing.

## Sand Blasting

- Not appropriate for vegetative habitats because of sediment flushing.

Solidifiers

- Use likely to increase oil adherence to vegetation, and slow removal rates of residual oil, but may be only technique to immobilize oil in a marsh.
- Not generally applicable for Category I light oils which usually rapidly evaporate, nor for heavy oils which are too viscous.

Surface Washing Agents

- Field application is often difficult and ineffective. Care must be taken to limit sediment disturbance.
- Individual products vary in their toxicity and recoverability of the treated oil.
- Can be used to reduce the need for high temperatures or high pressure to remove persistent oils.

Nutrient Enrichment

- Could result in eutrophication and acute toxicity, particularly from ammonia, because of shallow waters and low mixing rates.

Natural Microbe Seeding

- There is insufficient information on impact and effectiveness in wetlands.

*In-situ* Burning

- May be one of the least physically damaging means of heavy oil removal.
- Presence of a water layer on marsh surface during the burn can protect roots.
- Heavy, viscous oils will leave higher amounts of residue which will require removal.
- Amount of damage resulting from burning can be seasonally dependent.
- Category I oils are not expected to accumulate sufficiently to burn.

## MANGROVES

### *Habitat Description*

Mangrove forests are the dominant estuarine and nearshore coastal community in tropical and subtropical regions. They are closely linked to other nearshore communities, such as seagrass beds, reef flats, and subtidal coral reefs. Mangroves grow in the intertidal zone, and the high-tide line can be located deep inside the forest. Mangroves root in soft sediment; their trunks and prop roots serve as hard substrate for the attachment and growth of sessile animals and plants. They characteristically occur in muddy, anaerobic soils; thus, oxygen is obtained from the atmosphere via specialized pores (lenticels) primarily located on the intertidal surfaces of trees. Lenticels occur on prop roots and lower trunks of red mangroves, on the lower trunks of white mangroves, and on the finger-like pneumatophores of black mangroves. Mangroves reproduce through seed dispersal.

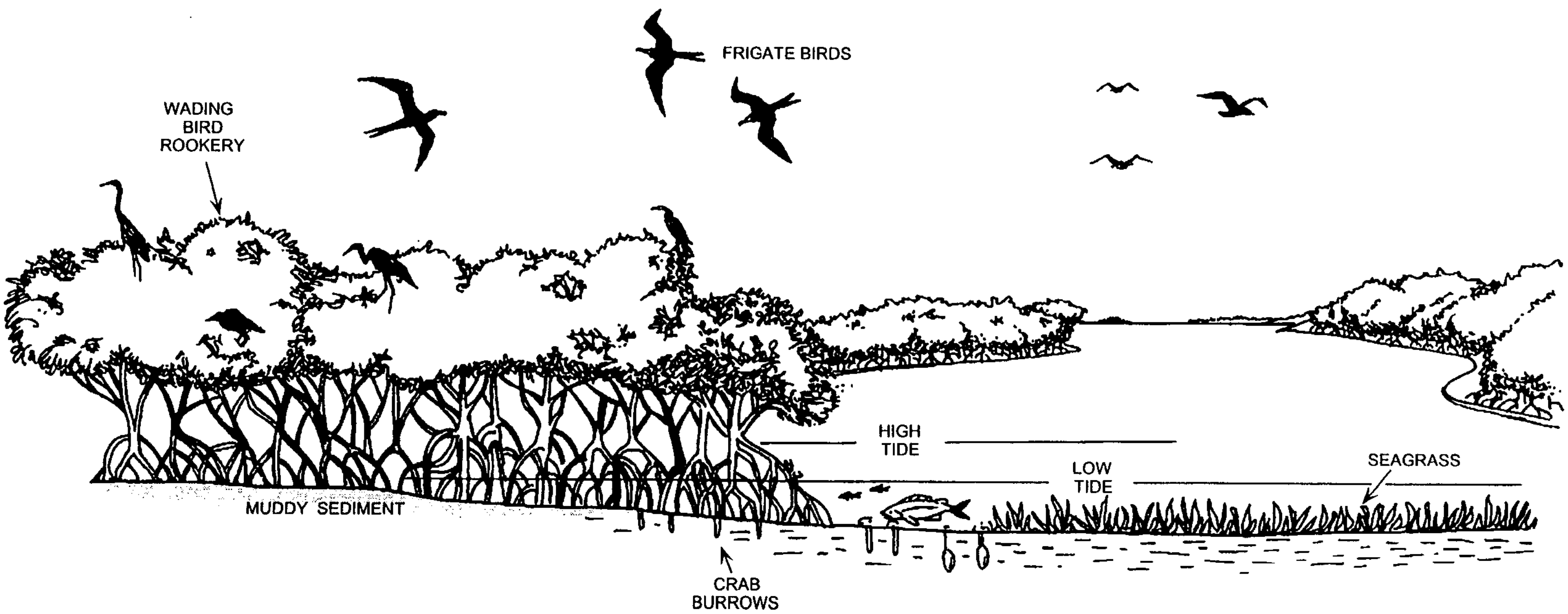
### *Sensitivity*

Mangroves are highly sensitive to oil spills. They are highly productive, serve as nursery habitat for many commercially and recreationally important species, and may support a great diversity and abundance of animal and plant species. They serve as buffers for storm waves, limiting erosion, and protecting upland communities.

The nature and degree of oil spill impacts are related to many variables, including: the type and amount of oil, the mangrove life stage, topographic elevation, degree of sediment contamination, and exposure to natural removal processes. Impacts to mangroves can result from direct toxicity through absorption of the oil, disruption of water intake through the roots, and physical blockage of gas-exchange lenticels by oil coating. In addition, oil can affect detritus-based food webs, which are fundamentally important in wetlands, by slowing decomposition rates of plant material. Greatest impacts occur where oil concentrates against the high-tide shoreline or interior berm. Effects on all growth stages can become chronic if oil permeates soft, anaerobic sediments and is chronically released. Access to mangrove forests is very difficult; the tangle of prop roots and pneumatophores can limit even foot traffic. Often the only practical response option is removal of oiled wrack from the outer fringe and passive collection of oil as it is naturally released.

Figure 26 illustrates a mangrove (ESI classification 10D). Table 30 shows the relative impacts from various response methods on mangroves.

# MANGROVES




Source: NOAA, 1998

Figure 26

**Table 30.** Relative environmental impact from response methods for MANGROVES.
This table should not be used without the accompanying text in the document.

| | Category | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | A | A |
| Barriers/Berms | B | B | B | B | B |
| **Manual Oil Removal/Cleaning** | – | D | C | C | C |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | A | A | A | B |
| Vacuum | – | B | B | B | B |
| **Debris Removal** | – | A | A | A | A |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | – |
| Flooding (deluge) | – | B | B | B | B |
| **Low-pressure, Ambient Water Flushing** | – | B | C | C | C |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | I | I | I |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | – | – | – | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Mangroves*

**Natural Recovery**

- Least impact for small spills and lighter oils; avoids damage often associated with cleanup activities.
- Some cleanup can be warranted where large amounts of oil persist and act as a source of chronic re-oiling of adjacent sensitive habitats or prevent recovery.

**Barriers/Berms**

- This technique consists of sediment dikes, dams, or filter fences placed in tidal channels in the marsh.
- Because of the soft substrate, extreme care is needed to minimize physical disruption during installation and removal.

**Manual Oil Removal/Cleaning**

- Access is so difficult that cleanup crews will damage roots and mix oil deeper into the sediments.

**Mechanical Oil Removal**

- Soft substrates will not support vehicular traffic.
- Access is so difficult that equipment will damage roots and mix oil deeper into the sediments.

**Sorbents**

- Useful as long as the oil is mobilized and recovered by the sorbent.
- Care is necessary during placement and recovery to minimize disturbance of substrate and mangrove roots.
- Overuse generates excess waste.
- Specialized sorbents can be effectively used for lighter oils.

**Vacuum**

- Difficulty of access limits effectiveness to only liquid oils that can be concentrated by tidal currents in recovery areas.

**Debris Removal**

- Oil often accumulates in the wrack, thus its removal can decrease oil persistence and potential for contamination of adjacent areas.

Sediment Reworking/Tilling

- Not appropriate because it causes extensive physical habitat and sediment disruption.

Vegetation Cutting/Removal

- Not appropriate because of long-term recovery of the forest (5-25 years); this technique will cause excessive habitat destruction.

Flooding and Low-pressure, Ambient Water Flushing

- Can be most effective method for removing oil trapped in the forest.
- Can be difficult to direct water and oil flow towards recovery devices.
- Use on heavy oils is likely to leave residual oil in the environment.

High-pressure, Ambient Water Flushing

- Not appropriate for vegetative habitats because of sediment flushing.

Low-pressure, Hot Water Flushing

- Highly intrusive technique; will kill any organisms present.

High-pressure, Hot Water Flushing

- Not appropriate for vegetative habitats because of sediment flushing.

Steam Cleaning

- Not appropriate for vegetative habitats because of sediment flushing.

Sand Blasting

- Not appropriate for vegetative habitats because of sediment flushing.

Solidifiers

- Use is likely to trap detritus in oil and slow removal rates of residual oil, but might be only technique to immobilize pooled oil in the mangrove forest.
- Not generally applicable for Category I light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.

Surface Washing Agents

- More information and experience needed on available products, their effectiveness, and impact of use on mangroves and receiving waters; laboratory test results on one product are promising.
- Individual products vary in their toxicity and recoverability of the treated oil.

**Nutrient Enrichment and Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness in mangroves.

***In-situ* Burning**

- Not appropriate because of long-term recovery of the forest (5-25 years); this technique will cause excessive habitat destruction.

## INUNDATED, LOWLAND TUNDRA

### *Habitat Description*

Inundated, lowland tundra occurs in areas where very low-lying sections of the Arctic shoreline have recently been "drowned" or flooded by the sea, due to subsidence. This class also includes low-lying areas not normally in the intertidal zone but which can be frequently inundated by salt water during spring tide or wind-induced surges. Strong onshore winds can raise normal water levels by up to 3 feet (one meter), and the floodwaters can travel up to hundreds of meters inland. These low-lying areas often have a complex and convoluted shoreline comprised of a combination of tundra, vegetated flats and river banks, peat mats, brackish lagoons, and small streams. Where present, the vegetation is salt-tolerant and may be more adapted to drier conditions than the salt marshes. These shorelines have high ice content. The surface material is mostly peat, with little mineral sediments.

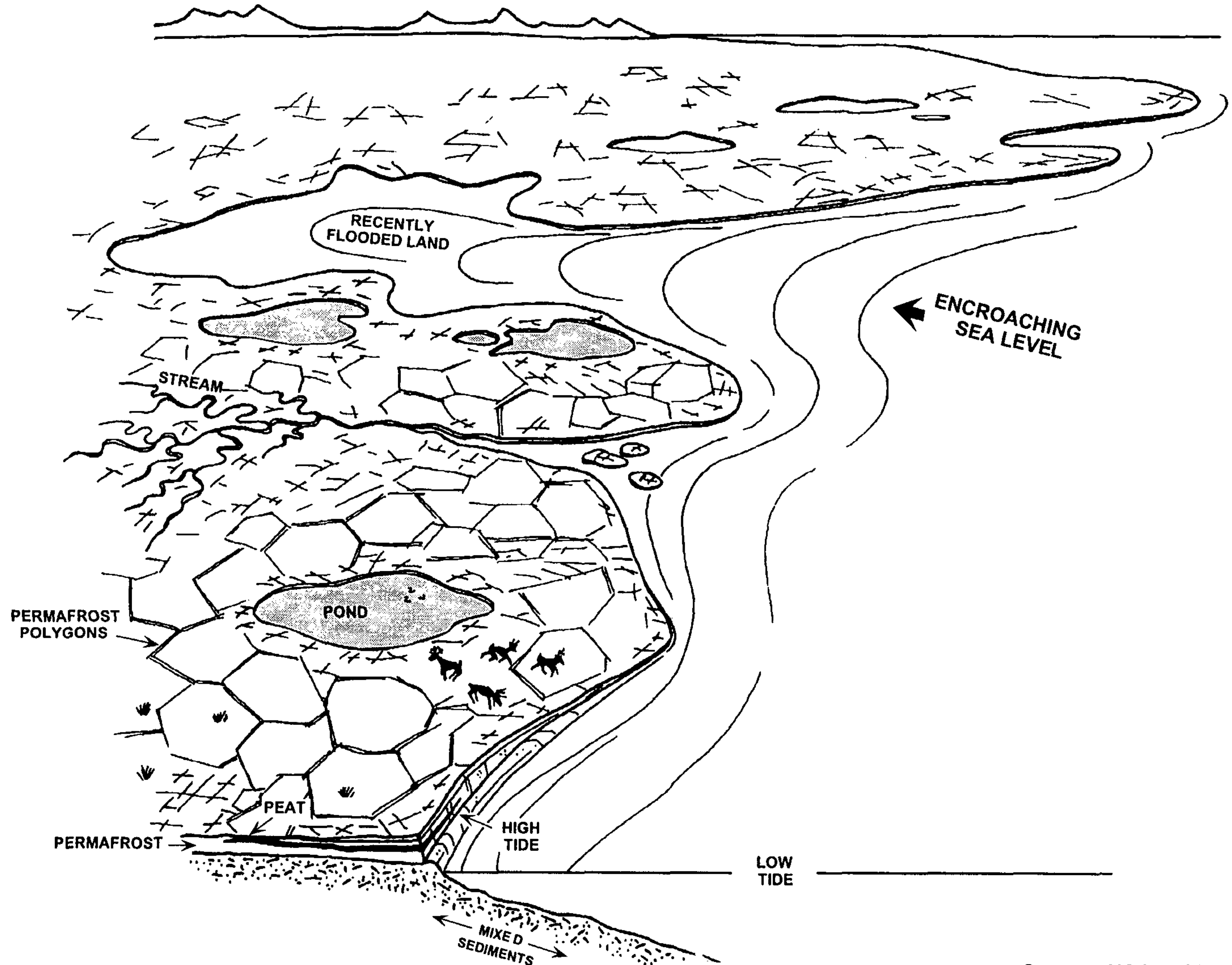
### *Sensitivity*

Inundated, lowland tundra is highly sensitive to oil spills; it is a living plant community which is highly susceptible to long-term damage from physical disruption. These areas are important to migrating birds from June through September, as they feed on insects, insect larvae, and worms.

This shoreline type is ranked as highly sensitive because of the extensive physical damage to the tundra likely during any cleanup attempts and the persistence of spilled oil in Arctic environments where open, ice-free water occurs for only a short period. During storm surges, spilled oil could become stranded hundreds of meters inland, making cleanup even more difficult. During the summer months, the surface sediments and/or peat deposits are often water-saturated, so stranded oil is likely to remain on the surface. Shallow nearshore water may limit water access and make land access, and possible temporary roadways, necessary. However, access and movement on the land may be difficult due to the complicated character of the shoreline and many water-saturated areas. Response operations could be less damaging when the substrate is frozen.

Figure 27 illustrates an inundated, lowland tundra (ESI classification 10E). Table 31 shows the relative impacts from various response methods on inundated, lowland tundras.

# INUNDATED, LOWLAND TUNDRA




Source: NOAA,1998

Figure 27

**Table 31.** Relative environmental impact from response methods for INUNDATED, LOWLAND TUNDRA. This table should not be used without the accompanying text in the document.

| | *Category* | | | | |
|---|---|---|---|---|---|
| *Response Method* | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | A | A | B | B |
| Barriers/Berms | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | D | C | C | C | C |
| Mechanical Oil Removal | D | D | C | C | C |
| **Sorbents** | – | C | C | C | – |
| Vacuum | – | B | B | B | C |
| **Debris Removal** | – | C | C | C | C |
| Sediment Reworking/Tilling | – | – | – | – | – |
| **Vegetation Cutting/Removal** | D | D | D | D | D |
| Flooding (deluge) | C | C | C | D | – |
| **Low-pressure, Ambient Water Flushing** | – | D | D | – | – |
| High-pressure, Ambient Water Flushing | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – |
| **Solidifiers** | – | C | C | – | – |
| Surface Washing Agents | – | – | – | – | – |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ* Burning** | – | C | C | C | – |

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Response Methods: Inundated, Lowland Tundra*

Natural Recovery

- Least impact for small to moderate spills, particularly where access is limited or difficult, as is the usual case for this shoreline type.
- Some cleanup can be warranted where large amounts of oil persist and act as a source of chronic re-oiling of adjacent sensitive habitats.

Barriers/Berms

- Excessive physical disruption can completely alter the substrate, hydrology, and vegetation patterns for many years.

Manual Oil Removal/Cleaning

- Applicable for small areas with large amounts of a persistent oil.

Mechanical Oil Removal

- Would require roadway construction for access.
- Soils too soft in summer to support equipment; consider only after freeze-up.
- Can completely alter the substrate, hydrology, and vegetation patterns for many years.

Sorbents

- Overuse generates excessive waste, which is a particular problem in this habitat.
- Physical removal rates of heavy oils will be slow, so less oil will be mobilized for recovery by sorbents.
- Care is necessary during placement and recovery to minimize disturbance from foot traffic; use of minimum disturbance access is essential.
- Specialized sorbents can be used effectively for lighter oils.

Vacuum

- Use to recover pools of mobile oil, if the oil is not too debris-laden nor viscous.

Debris Removal

- Applicable for small areas with large amounts of heavily-oiled debris.
- In summer, crews should use plank walkways or snow shoes to minimize damage.

**Sediment Reworking/Tilling**

- Should not be considered because the damage to the permafrost is too great.

**Vegetation Cutting/Removal**

- Consider only where the vegetation is heavily oiled; remove only the top 2 inches (5 centimeters) or so, to avoid damage to the roots.
- Avoid trampling and raking oil into living plants.

**Flooding and Low-pressure, Ambient Water Flushing**

- Oil must be liquid, thus less effective on viscous oils.
- If water pressures are too high, large quantities of peat could be eroded from the treatment area during this process.
- Will require extensive on-ground operations, with disturbances from foot traffic and access ways likely.
- If salt-tolerant species are present, seawater could be applicable. If only freshwater species are present, use only freshwater.

**High-pressure, Ambient Water Flushing**

- High-pressure spray will disrupt vegetation, substrate, and root systems.

**Low-pressure, Hot Water Flushing and High-pressure, Hot Water Flushing**

- Hot water is too intrusive for biota.

**Steam Cleaning**

- Not applicable for vegetative substrates.

**Sand Blasting**

- Not applicable for vegetative substrates.

**Solidifiers**

- Use likely to increase adherence to vegetation and slow weathering/removal rates of residual oil.
- Not generally applicable for Category I light oils which usually quickly penetrate the sediments, nor for heavy oils which are too viscous.

**Surface Washing Agents**

- More information needed on available products, their effectiveness, and impact of use on tundra vegetation.

**Nutrient Enrichment**

- There is limited information on impact and effectiveness.

**Natural Microbe Seeding**

- There is insufficient information on impact and effectiveness on substrates.

***In-situ* Burning**

- For heavier oils, burning on tundra could cause oil on the surface to penetrate more deeply into the peaty substrate, increasing the persistence and effects of the oil.
- High water content of peat could make burning ineffective, leaving a persistent, sticky surface residue that is even more difficult to remove than the original oil.
- Could be less physically damaging if there is an insulating water layer to protect the plant roots and prevent penetration of oil into the substrate.

# 5.5 ICE

## HABITAT DESCRIPTION

Ice forms on the sea surface during winter in cold climates and can persist for several months. Most of this ice is floating but, occasionally, the ice is frozen to the bottom. For this manual, ice habitats have been divided into two categories:

- **Accessible Ice** which can safely support the personnel and equipment suitable for response to a particular oil spill on, in, under, or adjacent to solid ice, and
- **Inaccessible Ice** which cannot safely support response personnel and response equipment. Oil spills on, in, under, or adjacent to brash ice, small or fast moving floes, or other ice types which are "inaccessible" must be treated from the air or from vessels working in, or alongside, the ice.

The ice environment, in general, has a low sensitivity to oil spills. In most instances, ice along the shoreline or in the adjacent nearshore water acts as a natural barrier, reducing the amount of oil that might otherwise make contact with the shoreline.

During the ice growth phase, oil in or under the ice can become encapsulated within the ice. During a thaw, or if the surface of the ice is melting and wet, oil is unlikely to adhere to the ice surface and will tend to remain on the water surface or in leads. In the spring, before the ice becomes inaccessible, oil in or below sea ice will often migrate through brine channels to the surface.

The ice habitat presents unique safety issues in terms of cold, ice stability, and wildlife interactions. Due to safety issues associated with work near a gasoline spill, most techniques, except low-pressure cold-water flushing, *in-situ* burning, berms/barriers, and physical herding, have been classified as non-applicable (–) for this oil type.

Some methods, including flooding, debris removal, sediment reworking, vegetation cutting and removal, high-pressure flushing, sand blasting, solidifiers and surface washing agents, are not considered suitable for use in these environments.

Table 32 shows the relative impact from various response methods on accessible ice. Table 33 (page 5-153) shows the relative impact from various response methods on inaccessible ice.

**Table 32.** Relative environmental impact from response methods for ACCESSIBLE ICE environments. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* | | | | |
|---|---|---|---|---|---|
| | *I* | *II* | *III* | *IV* | *V* |
| **Natural Recovery** | A | B | B | C | C |
| Booming | – | B | B | B | – |
| **Skimming** | – | A | A | A | – |
| Barriers/Berms | B | B | B | – | – |
| **Physical Herding** | B | B | B | B | – |
| Manual Oil Removal/Cleaning | – | A | A | A | A |
| **Mechanical Oil Removal** | – | B | B | B | B |
| Sorbents | – | B | B | B | – |
| **Vacuum** | – | A | A | A | A |
| Low-pressure, Ambient Water Flushing | B | B | B | B | C |
| **Low-pressure, Hot Water Flushing** | – | B | B | B | C |
| Steam Cleaning | – | B | B | B | C |
| **Dispersants** | – | B | B | – | – |
| Emulsion-treating Agents | – | I | I | I | I |
| **Elasticity Modifiers** | – | A | – | – | – |
| Herding Agents | I | I | I | – | – |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ Burning*** | B | B | B | B | – |

Category Descriptions

I – Gasoline products

II – Diesel-like products and light crude oils

III – Medium grade crude oils and intermediate products

IV – Heavy crude oils and residual products

V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Accessible Ice*

**Natural Recovery**

- In certain ice situations, natural recovery may be the only response option, and is the preferred option for spills of light oils, such as gasoline, since they evaporate quickly.
- The natural recovery option becomes less favored as the spill size increases.

**Booming**

- Under partial ice cover conditions, booms can be used in a manner similar to open water situations.
- Moving ice in a lead can damage a boom, or it may become trapped in the ice.
- Booms can be used to enhance oil containment in ice slots.

**Skimming**

- The type of skimmer used will depend on the characteristics and accessibility of the oil being recovered.
- Rope mop skimmers have been useful for recovering oil in leads.
- Ice can damage skimmers or reduce their effectiveness.

**Barriers/Berms**

- May not be as necessary for heavy oils since they do not flow readily in ice. Oil-contaminated barriers and berms may present a disposal problem.

**Physical Herding**

- Can be used to enhance other response methods.
- Can accelerate oil emulsification or entrainment into the water column.

**Manual Oil Recovery/Cleaning**

- This is the preferred removal method.
- Minimal environmental impact and produces only small amounts of waste for disposal, but it is personnel-intensive.
- Safety considerations constrain use for gasoline spills.

**Mechanical Oil Removal**

- Can be used for larger spills, but has a higher environmental impact than manual cleaning, since more waste is generated.
- Due to the larger amount of material that can be handled, smaller spills can be treated more quickly.

**Sorbents**

- Personnel-intensive and produces large amounts of oily waste material.

**Vacuum**

- One of the preferred response methods.
- For Category V oils, it can be used only for pooled oil on the ice surface, or on the ocean floor in localized, shallow water situations.

**Low-pressure, Ambient Water and Hot Water Flushing**

- Both are viable options to move the oil around the water or ice to facilitate other response options.
- Less desirable for Category V oils, since the oil can sink if flushed into the water.
- One variation of flushing involves using a flame thrower to melt the ice surface and mobilize the oil.

**Steam Cleaning**

- Can be used in certain situations, since there is a reduced threat to biota in the ice environment. Less desirable for Category V oils, since the oil will sink if flushed into the water.

**Dispersants**

- Can be used on floating, diesel-like and medium oils in open water situations.

**Emulsion-treating Agents**

- Insufficient information on emulsion-treating agents in ice conditions. Effectiveness is strongly oil-type specific.
- Require mixing energy to promote breaking of the treated emulsion.

**Elasticity Modifiers**

- Suitable for enhancing skimmer performance with diesel-like oils.
- Effectiveness does not appear to be significantly affected by ambient temperature.
- Viscous residue that forms when elasticity modifiers are used with medium and heavy oils is difficult to remove from pumps and tanks.

**Herding Agents**

- Insufficient information on herding agents in an ice environment.
- Ineffective for heavy and Category V oils.

**Nutrient Enrichment and Natural Microbe Seeding**

- Not useful on spilled Category I oils.
- For the other oil types, there is insufficient information regarding use in ice.

***In-situ* Burning**

- Widely accepted especially for spills where manual and mechanical methods are less effective.
- Difficult to ignite heavy oils unless special methods are used [thick slicks >4 inches (10 centimeters), special igniters, and burning promoters].
- Heavier oils tend to produce more residue.

**Table 33.** Relative environmental impact from response methods for INACCESSIBLE ICE environments. This table should not be used without the accompanying text in the document.

| *Response Method* | *Category* *I* | *II* | *III* | *IV* | *V* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | B | B | B |
| Booming * | – | B | B | B | – |
| **Skimming** | – | A | A | A | – |
| Barriers/Berms | – | – | – | – | – |
| **Physical Herding** | B | B | B | B | – |
| Manual Oil Removal/Cleaning | – | – | – | – | – |
| **Mechanical Oil Removal** | – | B | B | B | B |
| Sorbents | – | B | B | B | – |
| **Vacuum** | – | A | A | A | – |
| Low-pressure, Ambient Water Flushing | – | B | B | B | – |
| **Low-pressure, Hot Water Flushing** | – | B | B | B | – |
| Steam Cleaning | – | – | – | – | – |
| **Dispersants** | – | B | B | – | – |
| Emulsion-treating Agents | – | I | I | I | I |
| **Elasticity Modifiers** | – | B | – | – | – |
| Herding Agents | I | I | I | – | – |
| **Nutrient Enrichment** | – | I | I | I | I |
| Natural Microbe Seeding | – | I | I | I | I |
| ***In-situ Burning*** | B | B | B | – | – |

* For light ice conditions only.

Category Descriptions

I – Gasoline products
II – Diesel-like products and light crude oils
III – Medium grade crude oils and intermediate products
IV – Heavy crude oils and residual products
V – Non-floating oil products

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

## *Inaccessible Ice*

Natural Recovery

- Favored for light oil spills in inaccessible ice, since there are few alternatives.
- Becomes less favored as the spill size increases.

Booming

- Generally, cannot be used except in certain light ice conditions.

Skimming

- Ice can damage skimmers or reduce their effectiveness. Type of skimmer used will depend on the characteristics and accessibility of the oil.

Barriers/Berms

- Not feasible in this environment.

Physical Herding

- Requires vessel access.
- Can be used to enhance other response methods.
- Can accelerate oil emulsification or entrainment into the water column.

Manual Oil Recovery/Cleaning

- Not a feasible option.

Mechanical Oil Removal

- Requires vessel access.
- Volume of recovered material is high and generally contains a low percentage of oil.
- Waste disposal is a problem.

Sorbents

- Low encounter rate.
- Produces large amounts of oily waste.
- Special disposal considerations.

Vacuum

- Requires vessel access.
- Generally used for pooled oil on small ice floes.

- Relatively small amount of material for disposal.

Low-pressure, Ambient Water and Hot Water Flushing

- Both are viable options to move oil around the water or ice surface to facilitate other response options.
- May sink Category V oils.

Dispersants

- Can be used on floating, diesel-like and medium oils in leads and open water.

Emulsion-Treating Agents

- Insufficient information on emulsion-treating agents in ice conditions.
- Effectiveness is strongly oil-type specific.
- Require mixing energy to break the treated emulsion.

Elasticity Modifiers

- Only suitable for enhancing skimmer performance with diesel-like oils.
- Effectiveness not significantly affected by ambient temperature.
- Highly viscous residue (forms when elasticity modifiers are used with medium and heavy oils) is difficult to remove from pumps and tanks.

Herding Agents

- Insufficient information on herding agents in ice.
- Ineffective for heavy and Category V oils.

Nutrient Enrichment and Natural Microbe Seeding

- Not useful for gasoline.
- Insufficient information regarding these techniques in ice.

*In-situ* Burning

- Widely accepted for medium to large spills.
- Cannot be used with heavy oils because of ignition problems.

# CHAPTER 6.0
# EVALUATION OF RESPONSE OPTIONS BY OIL TYPE

In Chapter 5, habitat matrices display the predicted relative environmental impact for each response method with each oil group. This chapter presents the same information in a slightly different format – by oil type instead of by habitat. Each habitat category, on-water (Tables 34 - 38), shallow subtidal (Tables 39 - 43), shoreline intertidal (Tables 44 - 48), and ice (Tables 49 - 53), has five matrices, one for each of the five oil groups. Each matrix includes the predicted relative environmental impact for each response method with each habitat for that oil type.

Readers are cautioned to read the appropriate text in Chapter 5 before using these matrices. Taking any of this information out of context is not recommended.

**Table 34.** GASOLINE PRODUCTS (Category I): Relative environmental impact from response methods for ON-WATER habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Offshore* | *Bays and Estuaries* |
|---|---|---|
| **Natural Recovery** | A | A |
| Booming-Containment | – | – |
| **Booming-Deflection/Exclusion** | A | A |
| Skimming | – | – |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | – | – |
| **Sorbents** | – | – |
| Debris Removal | – | – |
| **Dispersants** | B | B |
| Emulsion-treating Agents | – | – |
| **Elasticity Modifiers** | – | – |
| Herding Agents | – | – |
| **Solidifiers** | – | – |
| *In-situ* Burning | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 35.** DIESEL-LIKE PRODUCTS AND LIGHT CRUDE OILS (Category II): Relative environmental impact from response methods for ON-WATER habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Offshore* | *Bays and Estuaries* |
|---|---|---|
| **Natural Recovery** | A | B |
| Booming-Containment | A | A |
| **Booming-Deflection/Exclusion** | A | A |
| Skimming | A | A |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | – | – |
| **Sorbents** | B | B |
| Debris Removal | A | A |
| **Dispersants** | A | B |
| Emulsion-treating Agents | B | B |
| **Elasticity Modifiers** | B | B |
| Herding Agents | B | B |
| **Solidifiers** | B | B |
| *In-situ* Burning | A | A |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 36.** MEDIUM GRADE CRUDE OILS AND INTERMEDIATE PRODUCTS (Category III): Relative environmental impact from response methods for ON-WATER habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Offshore* | *Bays and Estuaries* |
|---|---|---|
| **Natural Recovery** | B | B |
| Booming-Containment | A | A |
| **Booming-Deflection/Exclusion** | A | A |
| Skimming | A | A |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | – | C |
| **Sorbents** | B | B |
| Debris Removal | A | A |
| **Dispersants** | A | B |
| Emulsion-treating Agents | B | B |
| **Elasticity Modifiers** | B | B |
| Herding Agents | B | B |
| **Solidifiers** | B | B |
| *In-situ* Burning | A | A |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 37.** HEAVY CRUDE OILS AND RESIDUAL PRODUCTS (Category IV): Relative environmental impact from response methods for ON-WATER habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Offshore* | *Bays and Estuaries* |
|---|---|---|
| **Natural Recovery** | B | C |
| Booming-Containment | A | B |
| **Booming-Deflection/Exclusion** | A | B |
| Skimming | A | A |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | – | B |
| **Sorbents** | B | B |
| Debris Removal | A | A |
| **Dispersants** | A | B |
| Emulsion-treating Agents | B | B |
| **Elasticity Modifiers** | – | – |
| Herding Agents | – | – |
| **Solidifiers** | – | – |
| *In-situ* Burning | A | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 38.** NON-FLOATING OIL PRODUCTS (Category V): Relative environmental impact from response methods for ON-WATER habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Offshore* | *Bays and Estuaries* |
|---|---|---|
| **Natural Recovery** | B | C |
| Booming-Containment | – | – |
| **Booming-Deflection/Exclusion** | – | – |
| Skimming | – | – |
| **Physical Herding** | – | – |
| Manual Oil Removal/Cleaning | – | B |
| **Sorbents** | – | – |
| Debris Removal | – | B |
| **Dispersants** | – | – |
| Emulsion-treating Agents | – | – |
| **Elasticity Modifiers** | – | – |
| Herding Agents | – | – |
| **Solidifiers** | – | – |
| *In-situ* Burning | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 39.** GASOLINE PRODUCTS (Category I): Relative environmental impact from response methods for SHALLOW SUBTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Coral* | *Seagrass* | *Kelp* | *Soft Bottom* | *Mixed and Hard Bottom* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | A | A |
| Booming | – | B | – | A | – |
| **Skimming** | – | – | – | – | – |
| Physical Herding | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | – | – | – | – | – |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | – | – | – | – | – |
| Vacuum | – | – | – | – | – |
| **Debris Removal** | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | B | – | – | – | – |
| Dispersants | – | – | – | – | – |
| ***In-situ* Burning** | – | – | – | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 40.** DIESEL-LIKE PRODUCTS AND LIGHT CRUDE OILS (Category II): Relative environmental impact from response methods for SHALLOW SUBTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Coral* | *Seagrass* | *Kelp* | *Soft Bottom* | *Mixed and Hard Bottom* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | A | A |
| Booming | B | B | B | A | B |
| **Skimming** | B | B | B | A | A |
| Physical Herding | – | B | B | B | A |
| **Manual Oil Removal/Cleaning** | – | – | – | – | – |
| Mechanical Oil Removal | – | – | – | – | – |
| **Sorbents** | A | A | A | A | A |
| Vacuum | – | – | – | – | – |
| **Debris Removal** | – | – | – | – | – |
| Vegetation Cutting/Removal | – | – | – | – | – |
| **Low-pressure, Ambient Water Flushing** | B | – | – | – | – |
| Dispersants | C | C | C | C | B |
| ***In-situ* Burning** | B | B | B | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 41.** MEDIUM GRADE CRUDE OILS AND INTERMEDIATE PRODUCTS (Category III): Relative environmental impact from response methods for SHALLOW SUBTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Coral* | *Seagrass* | *Kelp* | *Soft Bottom* | *Mixed and Hard Bottom* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | A | A |
| Booming | B | B | B | A | B |
| **Skimming** | B | B | B | A | A |
| Physical Herding | – | B | B | B | A |
| **Manual Oil Removal/Cleaning** | B | B | – | B | B |
| Mechanical Oil Removal | – | D | – | – | – |
| **Sorbents** | A | A | A | A | A |
| Vacuum | B | B | – | B | B |
| **Debris Removal** | – | B | – | – | – |
| Vegetation Cutting/Removal | – | C | B | – | – |
| **Low-pressure, Ambient Water Flushing** | B | – | – | – | – |
| Dispersants | C | C | C | C | B |
| ***In-situ* Burning** | B | B | B | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 42.** HEAVY CRUDE OILS AND RESIDUAL PRODUCTS (Category IV): Relative environmental method for the impact from response methods for SHALLOW SUBTIDAL habitats. This table *should not be used without the accompanying text in the document.*

| *Response Method* | *Coral* | *Seagrass* | *Kelp* | *Soft Bottom* | *Mixed and Hard Bottom* |
|---|---|---|---|---|---|
| **Natural Recovery** | A | B | B | B | B |
| Booming | B | B | B | A | B |
| **Skimming** | B | B | B | A | A |
| Physical Herding | – | B | B | B | A |
| **Manual Oil Removal/Cleaning** | B | B | – | B | B |
| Mechanical Oil Removal | D | D | – | C | – |
| **Sorbents** | A | A | A | A | A |
| Vacuum | B | B | – | B | B |
| **Debris Removal** | – | B | – | – | B |
| Vegetation Cutting/Removal | – | C | B | – | – |
| **Low-pressure, Ambient Water Flushing** | C | – | – | – | – |
| Dispersants | C | C | C | C | B |
| ***In-situ* Burning** | B | B | B | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 43.** NON-FLOATING OIL PRODUCTS (Category V): Relative environmental impact from response methods for SHALLOW SUBTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Coral* | *Seagrass* | *Kelp* | *Soft Bottom* | *Mixed and Hard Bottom* |
|---|---|---|---|---|---|
| **Natural Recovery** | B | B | B | B | B |
| Booming | – | – | – | – | – |
| **Skimming** | – | – | – | – | – |
| Physical Herding | – | – | – | – | – |
| **Manual Oil Removal/Cleaning** | B | B | – | B | B |
| Mechanical Oil Removal | D | D | – | C | – |
| **Sorbents** | B | B | – | B | B |
| Vacuum | B | B | – | B | B |
| **Debris Removal** | – | B | – | – | B |
| Vegetation Cutting/Removal | – | C | – | – | – |
| **Low-pressure, Ambient Water Flushing** | C | – | – | – | – |
| Dispersants | – | – | – | – | – |
| ***In-situ* Burning** | – | – | – | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 44.** GASOLINE PRODUCTS (Category I): Relative environmental impact from response methods for SHORELINE INTERTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Exposed, Rocky Shores* | *Exposed, Solid, Man-made Structures* | *Exposed, Wave-cut Platforms* | *Sand Beaches* | *Tundra Cliffs* | *Mixed Sand and Gravel Beaches* | *Gravel Beaches* | *Riprap* | *Exposed Tidal Flats* | *Sheltered, Rocky Shores* | *Sheltered, Solid, Man-made Structures* | *Peat Shores* | *Sheltered Tidal Flats* | *Salt to Brackish Marshes* | *Mangroves* | *Inundated, Lowland Tundra* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Barriers/Berms | – | – | – | B | B | C | – | – | B | – | – | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | – | – | – | D | D | D | D | – | – | – | – | C | – | D | – | D |
| Mechanical Oil Removal | – | – | – | D | C | D | D | – | – | – | – | D | – | D | – | D |
| **Sorbents** | – | – | – | – | – | – | – | – | – | A | – | – | – | – | – | – |
| Vacuum | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Debris Removal** | – | – | – | – | – | – | – | – | – | – | – | C | – | – | – | – |
| Sediment Reworking/Tilling | – | – | – | D | D | D | D | – | – | – | – | C | – | D | – | – |
| **Vegetation Cutting/Removal** | – | – | – | – | D | – | – | – | – | – | – | D | – | D | – | D |
| Flooding (deluge) | – | – | – | A | A | A | A | A | – | – | – | C | – | B | – | C |
| **Low-pressure, Ambient Water Flushin** | – | – | – | B | C | B | A | A | – | – | – | C | – | B | – | – |
| High-pressure, Ambient Water Flushing | – | – | – | – | – | – | – | A | – | – | – | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Solidifiers** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Surface Washing Agents | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Nutrient Enrichment** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Natural Microbe Seeding | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| ***In-situ* Burning** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 45.** DIESEL-LIKE PRODUCTS AND LIGHT CRUDE OILS (Category II): Relative environmental impact from response methods for SHORELINE INTERTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Exposed, Rocky Shores* | *Exposed, Solid, Man-made Structures* | *Exposed, Wave-cut Platforms* | *Sand Beaches* | *Tundra Cliffs* | *Mixed Sand and Gravel Beaches* | *Gravel Beaches* | *Riprap* | *Exposed Tidal Flats* | *Sheltered, Rocky Shores* | *Sheltered, Solid, Man-made Structures* | *Peat Shores* | *Sheltered Tidal Flats* | *Salt to Brackish Marshes* | *Mangroves* | *Inundated, Lowland Tundra* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | B | B | B | A | A | A | A | A | A | A | A | A | A |
| Barriers/Berms | – | – | – | B | B | C | B | – | B | – | – | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | – | – | B | B | B | C | C | A | C | C | B | B | D | D | D | C |
| Mechanical Oil Removal | – | – | – | B | C | C | D | – | D | – | – | D | – | D | – | D |
| **Sorbents** | B | B | B | B | B | A | A | A | A | A | A | A | A | A | A | C |
| Vacuum | A | – | A | – | – | – | – | – | C | B | – | B | C | B | B | B |
| **Debris Removal** | A | – | A | A | B | A | A | A | B | A | A | B | B | B | A | C |
| Sediment Reworking/Tilling | – | – | – | B | B | B | B | – | – | – | – | C | – | D | – | – |
| **Vegetation Cutting/Removal** | – | – | – | C | D | C | – | – | D | – | – | D | – | D | – | D |
| Flooding (deluge) | – | – | A | A | A | A | A | A | A | A | – | B | B | B | B | C |
| **Low-pressure, Ambient Water Flushing** | A | A | A | B | B | A | A | A | B | A | A | B | C | B | B | D |
| High-pressure, Ambient Water Flushing | B | B | B | – | – | – | – | A | – | C | B | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | – | – | D | – | – | – | – | C | – | – | – | – | – | – | – | – |
| High-pressure, Hot Water Flushing | – | – | D | – | – | – | – | C | – | – | – | – | – | – | – | – |
| **Steam Cleaning** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Sand Blasting | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Solidifiers** | – | – | C | – | – | – | – | B | C | C | – | – | C | C | C | C |
| Surface Washing Agents | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| **Nutrient Enrichment** | – | – | – | A | B | A | A | A | I | A | I | B | I | A | I | I |
| Natural Microbe Seeding | – | – | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| ***In-situ* Burning** | – | – | D | – | – | – | – | – | – | D | – | – | – | B | – | C |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 46.** MEDIUM GRADE CRUDE OILS AND INTERMEDIATE PRODUCTS (Category III): Relative environmental impact from response methods for SHORELINE INTERTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Exposed, Rocky Shores* | *Exposed, Solid, Man-made Structures* | *Exposed, Wave-cut Platforms* | *Sand Beaches* | *Tundra Cliffs* | *Mixed Sand and Gravel Beaches* | *Gravel Beaches* | *Riprap* | *Exposed Tidal Flats* | *Sheltered, Rocky Shores* | *Sheltered, Solid, Man-made Structures* | *Peat Shores* | *Sheltered Tidal Flats* | *Salt to Brackish Marshes* | *Mangroves* | *Inundated, Lowland Tundra* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | B | B | B | B | B | A | B | B | A | B | B | A | A |
| Barriers/Berms | – | – | – | B | B | C | B | – | B | – | – | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | B | B | B | A | B | B | B | A | B | B | B | B | C | C | C | C |
| Mechanical Oil Removal | – | – | – | B | C | B | C | B | D | – | – | D | – | D | – | C |
| **Sorbents** | A | A | A | A | A | A | A | A | A | B | A | A | A | A | A | C |
| Vacuum | A | – | A | B | B | B | B | A | B | B | – | B | B | B | B | B |
| **Debris Removal** | A | – | A | A | B | A | A | A | B | A | A | B | B | B | A | C |
| Sediment Reworking/Tilling | – | – | – | B | B | B | B | – | C | – | – | B | – | D | – | – |
| **Vegetation Cutting/Removal** | – | – | – | C | D | C | – | – | D | D | – | C | D | C | – | D |
| Flooding (deluge) | – | – | A | A | A | B | B | B | A | A | – | B | B | B | B | C |
| **Low-pressure, Ambient Water Flushin** | A | A | A | B | B | A | A | B | B | A | B | B | C | B | C | D |
| High-pressure, Ambient Water Flushing | B | B | B | – | – | C | B | B | – | B | B | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | C | C | C | C | – | C | C | C | – | D | C | – | – | – | – | – |
| High-pressure, Hot Water Flushing | C | C | C | – | – | D | C | C | – | D | C | – | – | – | – | – |
| **Steam Cleaning** | D | D | D | – | – | D | D | D | – | D | D | – | – | – | – | – |
| Sand Blasting | D | D | D | – | – | – | – | D | – | D | D | – | – | – | – | – |
| **Solidifiers** | – | – | C | B | B | B | B | B | C | C | – | – | C | C | C | C |
| Surface Washing Agents | C | B | C | C | – | C | B | B | – | B | B | – | – | B | I | – |
| **Nutrient Enrichment** | – | – | – | A | B | A | A | A | I | B | I | B | I | B | I | I |
| Natural Microbe Seeding | – | – | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| ***In-situ* Burning** | – | – | D | C | – | C | C | D | – | C | – | – | – | B | – | C |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 47.** HEAVY CRUDE OILS AND RESIDUAL PRODUCTS (Category IV): Relative environmental impact from response methods for SHORELINE INTERTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Exposed, Rocky Shores* | *Exposed, Solid, Man-made Structures* | *Exposed, Wave-cut Platforms* | *Sand Beaches* | *Tundra Cliffs* | *Mixed Sand and Gravel Beaches* | *Gravel Beaches* | *Riprap* | *Exposed Tidal Flats* | *Sheltered, Rocky Shores* | *Sheltered, Solid, Man-made Structures* | *Peat Shores* | *Sheltered Tidal Flats* | *Salt to Brackish Marshes* | *Mangroves* | *Inundated, Lowland Tundra* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | C | B | C | B | B | A | B | B | A | B | B | A | B |
| Barriers/Berms | – | – | – | B | B | B | B | – | B | – | – | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | B | B | B | A | B | A | B | A | B | C | B | B | C | C | C | C |
| Mechanical Oil Removal | – | – | – | B | C | B | C | C | D | – | – | D | – | D | – | C |
| **Sorbents** | A | A | A | A | A | B | B | B | B | C | B | B | B | A | A | – |
| Vacuum | A | – | A | A | A | B | B | A | B | B | – | B | B | B | B | C |
| **Debris Removal** | A | – | A | A | B | A | A | A | B | A | A | B | B | B | A | C |
| Sediment Reworking/Tilling | – | – | – | B | B | B | B | – | C | – | – | B | – | D | – | – |
| **Vegetation Cutting/Removal** | – | – | – | C | D | C | – | – | D | D | – | C | D | C | – | D |
| Flooding (deluge) | – | – | B | B | B | C | C | C | A | B | – | C | B | B | B | – |
| **Low-pressure, Ambient Water Flushing** | B | B | B | B | B | B | B | C | C | B | C | C | D | B | C | – |
| High-pressure, Ambient Water Flushing | B | B | B | – | – | D | B | B | – | B | C | – | – | – | – | – |
| **Low-pressure, Hot Water Flushing** | C | C | C | C | – | C | B | C | – | D | C | – | – | – | – | – |
| High-pressure, Hot Water Flushing | C | C | C | – | – | D | C | C | – | D | C | – | – | – | – | – |
| **Steam Cleaning** | D | D | D | – | – | D | D | D | – | D | D | – | – | – | – | – |
| Sand Blasting | D | D | D | – | – | – | – | D | – | D | D | – | – | – | – | – |
| **Solidifiers** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Surface Washing Agents | C | B | C | C | – | C | B | B | – | B | B | – | – | B | I | – |
| **Nutrient Enrichment** | – | – | – | B | C | B | B | B | I | C | I | C | I | B | I | I |
| Natural Microbe Seeding | – | – | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| ***In-situ* Burning** | – | – | D | C | – | C | C | D | – | C | – | – | – | B | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 48.** NON-FLOATING OIL PRODUCTS (Category V): Relative environmental impact from response methods for SHORELINE INTERTIDAL habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Exposed, Rocky Shores* | *Exposed, Solid, Man-made Structures* | *Exposed, Wave-cut Platforms* | *Sand Beaches* | *Tundra Cliffs* | *Mixed Sand and Gravel Beaches* | *Gravel Beaches* | *Riprap* | *Exposed Tidal Flats* | *Sheltered, Rocky Shores* | *Sheltered, Solid, Man-made Structures* | *Peat Shores* | *Sheltered Tidal Flats* | *Salt to Brackish Marshes* | *Mangroves* | *Inundated, Lowland Tundra* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Natural Recovery** | A | A | A | D | B | C | B | B | A | B | B | A | B | B | A | B |
| Barriers/Berms | – | – | – | B | B | B | B | – | B | – | – | – | B | B | B | – |
| **Manual Oil Removal/Cleaning** | B | B | B | A | B | A | A | A | B | C | B | B | C | C | C | C |
| Mechanical Oil Removal | – | – | – | B | C | B | C | C | D | – | – | D | – | D | – | C |
| **Sorbents** | A | A | A | B | B | B | B | B | B | C | B | B | B | B | B | – |
| Vacuum | A | – | A | A | A | B | B | A | B | C | – | B | B | B | B | C |
| **Debris Removal** | A | – | A | A | B | A | A | A | B | A | A | B | B | B | A | C |
| Sediment Reworking/Tilling | – | – | – | B | C | B | B | – | C | – | – | B | – | D | – | – |
| **Vegetation Cutting/Removal** | – | – | – | C | D | C | – | – | D | D | – | C | D | C | – | D |
| Flooding (deluge) | – | – | B | C | C | C | C | C | B | C | – | D | C | B | B | – |
| **Low-pressure, Ambient Water Flushin** | B | B | B | C | C | C | C | C | C | C | C | D | D | B | C | – |
| High-pressure, Ambient Water Flushing | B | B | B | – | – | D | B | C | – | C | C | – | – | – | – | – |
| ***Low-pressure, Hot Water Flushing*** | C | C | C | C | – | C | B | C | – | D | C | – | – | – | – | – |
| High-pressure, Hot Water Flushing | C | C | C | – | – | D | C | C | – | D | C | – | – | – | – | – |
| **Steam Cleaning** | D | D | D | – | – | D | D | D | – | D | D | – | – | – | – | – |
| Sand Blasting | D | D | D | – | – | – | – | D | – | D | D | – | – | – | – | – |
| **Solidifiers** | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – | – |
| Surface Washing Agents | C | B | C | C | – | C | B | B | – | B | B | – | – | I | I | – |
| ***Nutrient Enrichment*** | – | – | – | C | C | C | B | B | I | C | I | C | I | B | I | I |
| Natural Microbe Seeding | – | – | I | I | I | I | I | I | I | I | I | I | I | I | I | I |
| ***In-situ* Burning** | – | – | – | C | – | C | C | – | – | C | – | – | – | C | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 49.** GASOLINE PRODUCTS (Category I): Relative environmental impact from response methods for ICE habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Accessible Ice* | *Inaccessible Ice* |
|---|---|---|
| **Natural Recovery** | A | A |
| Booming | – | – |
| **Skimming** | – | – |
| Barriers/Berms | – | – |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | B | – |
| **Mechanical Oil Removal** | – | – |
| Sorbents | – | – |
| **Vacuum** | – | – |
| Low-pressure, Ambient Water Flushing | B | – |
| **Low-pressure, Hot Water Flushing** | – | – |
| Steam Cleaning | – | – |
| **Dispersants** | – | – |
| Emulsion-treating Agents | – | – |
| **Elasticity Modifiers** | – | – |
| Herding Agents | I | I |
| **Nutrient Enrichment** | – | – |
| Natural Microbe Seeding | – | – |
| ***In-situ* Burning** | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 50.** DIESEL-LIKE PRODUCTS AND LIGHT CRUDE OILS (Category II): Relative environmental impact from response methods for ICE habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Accessible Ice* | *Inaccessible Ice* |
|---|---|---|
| **Natural Recovery** | B | A |
| Booming | B | B |
| **Skimming** | A | A |
| Barriers/Berms | B | – |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | A | – |
| **Mechanical Oil Removal** | B | B |
| Sorbents | B | B |
| **Vacuum** | A | A |
| Low-pressure, Ambient Water Flushing | B | B |
| **Low-pressure, Hot Water Flushing** | B | B |
| Steam Cleaning | B | – |
| **Dispersants** | B | B |
| Emulsion-treating Agents | I | I |
| **Elasticity Modifiers** | A | B |
| Herding Agents | I | I |
| **Nutrient Enrichment** | I | I |
| Natural Microbe Seeding | I | I |
| ***In-situ* Burning** | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 51.** MEDIUM GRADE CRUDE OILS AND INTERMEDIATE PRODUCTS (Category III): Relative environmental impact from response methods for ICE habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Accessible Ice* | *Inaccessible Ice* |
|---|---|---|
| **Natural Recovery** | B | B |
| Booming | B | B |
| **Skimming** | A | A |
| Barriers/Berms | B | – |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | A | – |
| **Mechanical Oil Removal** | B | B |
| Sorbents | B | B |
| **Vacuum** | A | A |
| Low-pressure, Ambient Water Flushing | B | B |
| **Low-pressure, Hot Water Flushing** | B | B |
| Steam Cleaning | B | – |
| **Dispersants** | B | B |
| Emulsion-treating Agents | I | I |
| **Elasticity Modifiers** | – | – |
| Herding Agents | I | I |
| **Nutrient Enrichment** | I | I |
| Natural Microbe Seeding | I | I |
| ***In-situ* Burning** | B | B |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 52.** HEAVY CRUDE OILS AND RESIDUAL PRODUCTS (Category IV): Relative impact from response methods for ICE habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Accessible Ice* | *Inaccessible Ice* |
|---|---|---|
| **Natural Recovery** | C | B |
| Booming | B | B |
| **Skimming** | A | A |
| Barriers/Berms | – | – |
| **Physical Herding** | B | B |
| Manual Oil Removal/Cleaning | A | – |
| **Mechanical Oil Removal** | B | B |
| Sorbents | B | B |
| **Vacuum** | A | A |
| Low-pressure, Ambient Water Flushing | B | B |
| **Low-pressure, Hot Water Flushing** | B | B |
| Steam Cleaning | B | – |
| **Dispersants** | – | – |
| Emulsion-treating Agents | I | I |
| **Elasticity Modifiers** | – | – |
| Herding Agents | – | – |
| **Nutrient Enrichment** | I | I |
| Natural Microbe Seeding | I | I |
| ***In-situ* Burning** | B | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

**Table 53.** NON-FLOATING OIL PRODUCTS (Category V): Relative environmental impact from response methods for ICE habitats. This table should not be used without the accompanying text in the document.

| *Response Method* | *Accessible Ice* | *Inaccessible Ice* |
|---|---|---|
| **Natural Recovery** | C | B |
| Booming | – | – |
| **Skimming** | – | – |
| Barriers/Berms | – | – |
| **Physical Herding** | – | – |
| Manual Oil Removal/Cleaning | A | – |
| **Mechanical Oil Removal** | B | B |
| Sorbents | – | – |
| **Vacuum** | A | – |
| Low-pressure, Ambient Water Flushing | C | – |
| **Low-pressure, Hot Water Flushing** | C | – |
| Steam Cleaning | C | – |
| **Dispersants** | – | – |
| Emulsion-treating Agents | I | I |
| **Elasticity Modifiers** | – | – |
| Herding Agents | – | – |
| **Nutrient Enrichment** | I | I |
| Natural Microbe Seeding | I | I |
| ***In-situ* Burning** | – | – |

The following categories are used to compare the relative environmental impact of each response method for the specific environment or habitat for each oil type:

A = May cause the least adverse habitat impact.
B = May cause some adverse habitat impact.
C = May cause significant adverse habitat impact.
D = May cause the most adverse habitat impact.
I = Insufficient Information - impact or effectiveness of the method could not be evaluated.
— = Not applicable.

# APPENDIX A
# REGULATORY CONSIDERATIONS

Planning and response activities in the US are defined by the National Oil and Hazardous Substances Pollution Contingency Plan; but there are other mandates which influence some contingency planning decisions and incident-specific response options and strategies. The laws which govern planning for, and responding to, marine oil spills are:

- The Oil Pollution Act of 1990 (OPA 90);
- The Marine Mammal Protection Act;
- The Endangered Species Act;
- The Resource Conservation and Recovery Act;
- The National Historic Preservation Act; and
- Various state statutes and regulations (which may be more onerous than Federal requirements).

The influence each of the Federal requirements has on oil spill preparedness and response is briefly discussed below.

## OIL POLLUTION ACT

OPA 90 requires, among other provisions, that a system of government and industry response plans be prepared and approved, and that Natural Resource Damage Assessment (NRDA) activities be conducted to restore the environment.

Response plans must be prepared by the industry owners and operators of facilities, vessels, and pipelines that present a substantial threat of an oil discharge to the environment. The government must prepare area contingency plans to assure that sufficient resources exist to respond to worst case discharges in each area.

Although NRDA activities have been required for hazardous substance releases for some time, OPA 90 confirmed that appointed Federal, state, and tribal trustees will seek to recover natural resource damages in the event of discharges of oil into the waters of the United States. OPA 90 specified that NOAA is responsible for NRDA oil discharge regulations. NRDA activities occur separately from response actions, and much information is shared between the two; but actions taken during response can negatively impact both oil spill response and NRDA activities (e.g., impede and delay decision-making). The activities in the statute are separate; but, in practice, they become interrelated.

## MARINE MAMMAL PROTECTION ACT

The Marine Mammal Protection Act of 1972 (reauthorized in 1994) requires that efforts be made to protect rookeries, mating grounds, and areas of similar significance for each species of marine mammal, from the adverse effects of human actions, such as oil spills. Both the Department of Commerce, specifically the National Marine Fisheries Service (NMFS), and the Department of the Interior (DOI) are responsible for the conservation and management of various species. NMFS has responsibility over pinnipeds, other than walruses, and cetaceans; the DOI is responsible for walruses, sea otters, polar bears, manatees, and dugongs. Actions taken during oil spill response must be consistent with this act.

## ENDANGERED SPECIES ACT

The Endangered Species Act of 1973 provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through Federal action and by encouraging the establishment of state programs. Section 7 requires Federal agencies to ensure that any action authorized, funded, or carried out by them, e.g., the use of dispersants and *in-situ* burning, is not likely to jeopardize the continued existence of listed species nor modify their critical habitats.

## RESOURCE CONSERVATION AND RECOVERY ACT

The Resource Conservation and Recovery Act of 1976 (RCRA) contains standards for treating, containing, transporting, and disposing of hazardous wastes. Four characteristics (toxicity, ignitability, reactivity, and corrosivity) determine if a material is a hazardous waste. If an oil tests positive in any characteristic, it is treated as a hazardous waste and RCRA standards apply. If the oil tests negative, the oil is not considered hazardous under RCRA (but it may be treated as such by states, which can be more stringent). Complying with disposal regulations can slow down or halt recovery and cleanup if treating, containing, transporting, and disposing of recovered oil, oily water, and debris isn't planned and handled expeditiously. EPA and state representatives can assist the Responsible Party with RCRA compliance during planning and response.

## NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act/Archeological Resources Protection Act protects fossils, archeological, or historical artifacts. Shoreline cleanup operations may uncover or damage archeological features, artifacts, or cultural resources unless appropriate procedures are implemented during response.

# APPENDIX B
# OIL CHARACTERISTICS

**Table 54.** Visual observations and estimating volume of undispersed oil.

| Oil Color | Code | Thickness Range (mm) | $m^3$ of oil per $km^2$ |
|---|---|---|---|
| Brown or Black | B | 50-5,000 | 50-5,000 |
| Emulsion | E | 200-10,000 | 200-10,000* |
| Rainbow | R | 0.15-2.0 | 0.15-2.0 |
| Gray or Silver Gray | G | 0.04-0.15 | 0.04-0.15 |

* This refers to the volume of the fluid. The water to oil ratio in many emulsions is as high as 4:1.

The thickness in microns (mm) has the same value as the volume in $m^3$ per $km^2$. These values assume continuous coverage of surface and should be adjusted for situations where the oil covers only a fraction of the area.

# APPENDIX C
# GRAIN-SIZE SCALE

**Table 55.** Grain-size scale.

| Wentworth Scale (Size Description) | | Phi Units* Φ | Grain Diameter d (millimeters) |
|---|---|---|---|
| Gravel | Boulder | | |
| | | -8 | 256.0 |
| | Cobble | | |
| | | -6 | |
| | Pebble | | |
| | | -2 | 4.0 |
| | Granule | | |
| | | -1 | 2.0 |
| Sand | Very Coarse | | |
| | | 0 | 1.0 |
| | Coarse | | |
| | | 1 | 0.5 |
| | Medium | | |
| | | 2 | 0.25 |
| | Fine | | |
| | | 3 | 0.125 |
| | Very Fine | | |
| | | 4 | 0.0625 |
| Silt | | | |
| | | 8 | 0.00391 |
| Clay | | | |
| | | 12 | 0.00024 |
| Colloid | | | |

Modified from the US Army Coastal Engineering Center, Shore Protection Manual (1973).

$$^*\phi = -\log_2 d(\text{mm}) = \frac{-\log_{10} d}{\log_{10} 2}$$

# APPENDIX D
# SHORELINE HABITAT SYNONYMS

Several schemes have been developed to categorize marine shorelines or habitats. Although similar in nature, there are differences in terminology and definitions among the schemes. Table 56 provides a cross-link among the schemes used in other marine manuals. The text that follows provides a list of terms and definitions associated with these shoreline or habitat types.

**Table 56.** Habitat schemes used in other manuals.

| API Marine Manual Intertidal Habitats (1985) | NOAA ESI Marine Shoreline Habitats | Environment Canada Marine Shoreline Types (1992/1995) |
|---|---|---|
| Exposed, Rocky Shore | Exposed, Rocky Cliffs | Bedrock |
| Exposed Seawalls | Seawalls and Piers; Exposed, Rocky Shores and Vertical, Hard Man-made Structures* | Man-made Solid and Ice |
| Exposed, Wave-cut Platforms and Reef Flats | Exposed, Wave-cut Platforms | Bedrock |
| Fine- to Medium-grained Sand Beaches/Tundra Cliffs | Fine-grained; Fine- to Medium-grained Sand Beaches** | Sand; Tundra Cliff |
| Coarse-grained Sand Beaches | Coarse-grained Sand Beaches; Medium- to Coarse-grained Sand Beaches* | Sand |
| Mixed Sand and Gravel Beaches | Mixed Sand and Gravel (or Shell) Beaches; Artificial Fill* | Mixed Sand and Gravel |
| Gravel Beaches | Gravel Beaches | Pebble-cobble; Boulder |
| Riprap | Gravel Beaches and Riprap Structures; Exposed Riprap* | Boulder |
| Exposed Tidal Flats | Exposed Tidal Flats | Sand Tidal Flats; Mud Tidal Flats |
| Sheltered, Rocky Shores and Reef Flats | Sheltered, Rocky Shores; Sheltered, Permeable Rocky Shores** | Bedrock |
| Sheltered Seawalls | Seawalls and Piers; Sheltered, Coastal Structures* | Man-made Solid and Ice |
| Eroding Peat Scarps | Eroding Peat Scarps | Peat |
| Sheltered Tidal Flats | Sheltered Tidal Flats | Sand Tidal Flats; Mud Tidal Flats |
| Marshes (salt to brackish) | Fringing and Extensive Marshes | Marsh |
| Inundated, Lowland Tundra | – | Inundated, Lowland Tundra |
| Mangroves | Mangroves | – |

* From Tropical Coastal Environments Template.

** From Alaska Template.

**Artificial Fill**

- Material placed by humans at the shoreline to raise the land surface or extend land into the water (for example, the construction of roads across shallow bays). The material usually contains a range of sediment sizes and would be equivalent to natural mixed sand and gravel, but generally is more hard packed and poorly sorted.

**Bedrock**

- Solid bedrock or rock that occurs at the coast or in the shore zone. Synonymous with rocky shores which are steep (>45°). Includes platforms (bedrock) and shelving bedrock shore types, both of which have low-angle or near-horizontal slopes.

**Boulder**

- A class of sediments with a grain size diameter greater than 10 inches (256 millimeters).

**Clay**

- A class of sediments with a grain size diameter less than 0.0002 inches (0.004 millimeters).

**Coarse Sediment**

- A descriptive term that is synonymous with shingle, is almost synonymous with the term gravel, and includes all sediments larger than sand (i.e., granule, pebble, cobble, and boulder sediments). From an oil spill perspective, there is a distinct difference between fine sediment and coarse sediment in terms of:
  - penetration and retention of oil in a beach, as only light oils (gasoline, diesel-like products, light crudes) can penetrate fine sediment, all except the very viscous oils can penetrate coarser sediments, and
  - operations, as the bearing capacity and traction for vehicles decreases significantly as the sediment size becomes coarser than sand.

**Cobble**

- A class of sediments with a grain size diameter greater than 2.5 inches (64 millimeters) and less than 10 inches (256 millimeters).

**Fine Sediment**

- A descriptive term that includes all sediment smaller than granules (i.e., sand, silt, clay). From an oil spill perspective, there is a distinct difference between fine sediment and coarse sediment in terms of:

- penetration and retention of oil in a beach, as only light oils (gasoline, diesel-like products, light crudes) can penetrate fine sediment, all except the very viscous oils can penetrate coarser sediments, and
- operations, as the bearing capacity and traction for vehicles decreases significantly as the sediment size becomes coarser than sand.

**Granule**

- A class of sediments with a grain size diameter greater than 0.08 inches (2 millimeters) and less than 0.16 inches (4 millimeters). Sometimes also called "gravel".

**Gravel**

- Gravel includes all sediments in the granule, pebble, cobble, and boulder size ranges; i.e., all sediments with a grain size diameter greater than 0.08 inches (2 millimeters). Gravel is almost synonymous with coarse sediment, and confusingly, it is sometimes also used as a synonym for granule.

**Inundated Lowland Tundra**

- Tundra is a common terrestrial feature of high latitude (polar) regions. Where low-lying areas near the coast become flooded during periods of high water levels (surges or storm tides), or where there is local subsidence, the tundra can become part of the shore zone. Characterized by a complex and convoluted shoreline, tundra has a living surface vegetation that is salt-tolerant. In areas of higher coastal relief, this lowland shore-zone type may give way to tundra cliffs.

**Mixed Sand and Gravel**

- Mixed sand and gravel includes all sediments in the sand, granule, pebble, cobble, and boulder size ranges; i.e., with a grain size diameter greater than 0.002 inches (0.0625 millimeters) and less than 10 inches (256 millimeters). This sediment type is distinctly different from both sand or fine sediment types and also gravel or coarse sediment types, as the coarser fractions (pebbles or cobbles) are infilled with sands and granules. From an oil fate and persistence perspective, in terms of oil penetration and retention, this sediment type is similar to a sand beach, whereas, from an operational perspective, in terms of bearing capacity and traction, the sediment is more similar to pebble and cobble sediments.

**Mud**

- A general term for sediments composed of silt and clay.

## Peat

- Peat is an organic material that can accumulate in the shore zone as a result of eroding coastal peat bogs, tundra cliffs, or inundated lowland tundra. The material is composed of plant remains and forms an unconsolidated, fibrous deposit.

## Pebble

- A class of sediments with a grain size diameter greater than 0.16 inches (4 millimeters) and less than 2.5 inches (64 millimeters). Sometimes referred to as pea gravel.

## Riprap

- Material placed as a shoreline control structure to prevent erosion or to provide protection from wave action (for example, as a breakwater). The material may be quarried rock, concrete forms, or construction debris. The material has a grain size diameter greater than 10 inches (256 millimeters) and is therefore analogous to natural boulder sediments. However, the structure is usually built so that the material is immobile.

## Rock

- Solid bedrock or rock that occurs at the coast or in the shore zone. Synonymous with rocky shores which are steep (>45°). Includes platform (bedrock) and shelving bedrock shore types, both of which have low-angle or near-horizontal slopes.

## Rocky Shores

- Solid bedrock or rock that occurs at the coast or in the shore zone. Synonymous with rocky shores which are steep (>45°). Includes platform (bedrock) and shelving bedrock shore types, both of which have low-angle or near-horizontal slopes.

## Sand

- A class of sediments with a grain size diameter greater than 0.002 inches (0.0625 millimeters) and less than 0.08 inches (2 millimeters). For more information on the sand classifications, refer to Table 55.

## Shingle

- A term that is not in common use in North America that is synonymous with coarse sediment and includes pebble and cobble sediments. The term also implies that the sediment particles are well-rounded.

## Shore Zone

- The coastal area that is affected by marine processes. The area usually is subdivided into across-shore zones based on location with respect to the intertidal area. Shore zones and tidal zones are synonymous.

| | | |
|---|---|---|
| - Nearshore | Subtidal | below the mean low tide mark |
| - Foreshore | Intertidal | between the mean low and mean high tide marks |
| - Backshore | Supratidal | above the mean high tide mark |

## Silt

- A class of sediments with a grain size diameter greater than 0.0002 inches (0.00391 millimeters) and less than 0.002 inches (0.0625 millimeters).

## Sorting

- Refers to the degree to which individual sediment classes have been separated or winnowed by natural processes at the shoreline. Identification of an individual sediment class (e.g., fine sand or pebble) usually is indicative of well-sorted sediments and that this one class of material dominates that section of the shore zone. Artificial fill and mixed sand and gravel are, by definition, a mixture of different size sediments. However, mixed sand and gravel may exhibit sorting by layering, with a well-sorted surface coarse sediment layer resting on a subsurface, poorly-sorted, mixed sediment of fine and coarse materials.

## Tundra Cliffs

- This shoreline type is found in high-latitude or polar regions and is an unconsolidated bluff or cliff that contains ice. Erosion of the unconsolidated sediment by shore-zone processes exposes ground ice that has formed in the subsurface of the tundra. In lower-lying regions, this may give way to an inundated lowland tundra shore-zone type.

## Unconsolidated Bluff or Cliff

- A coastal feature that occurs where the backshore is composed of unconsolidated sediment (e.g., sand or gravel material) and is directly eroded by shore-zone processes.

# APPENDIX E
# ADDITIONAL READING LIST

## General Scientific References

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# APPENDIX F
# SYNOPSIS OF DOCUMENT PREPARATION

Three documents were produced in 1983-92:

1. API publication 4435, "Oil Spill Cleanup: Options for Minimizing Ecological Impacts," which provided a technical information summary of marine habitats and ecological processes and spill response options;
2. API publication 4398, "Oil Spill Response: Options for Minimizing Adverse Ecological Impacts," which provided concise field-oriented ratings of response options for marine spills; and
3. NOAA 1992 publication. "Shoreline Countermeasures Manual" which provided a significant portion of the initial effort in the development of response options by shoreline type for this document.

During the intervening years there have been improvements in response equipment, new techniques, understanding of marine habitats, and new regulations. There was great interest in updating these documents. Beginning in 1995, a work group was established at API to facilitate completion of this project for the sponsors (API, NOAA, USCG, and EPA).

Two documents will be produced which have benefited from the assistance of many people and organizations:

- a detailed reference (this volume) primarily intended for planners; and
- a concise version primarily intended for responders.

The first major milestone in preparing these documents was the conduct of a technical workshop held during the summer of 1996 in Salt Lake City. Document assumptions were tested, response methods were evaluated, and special issues were discussed.

Attendees at the Salt Lake City workshop included:

Yvonne Addassi/CA
Bennett Anderson/DE
Ian Buist/SLRoss
James Clow/Texaco
Al Allen/Spiltec
Richard Brocchini/US Navy
Andrie Chen/Exxon
Jack Farlow/EPA
John Ferlund/Clean Casco Bay
David Fritz/Amoco
Ronald Goodman/Imperial Oil
George Henderson/FL

Vickie Huyck/USCG
Robert Fiocco/Exxon
Jerry Galt/NOAA
Christopher Gregory/Clean Coastal Waters
Thom Hooper/WA
Bela James/Shell
Mark Jones/Florida Power & Light
Jan Kucklick/SEA
Doug Lentsch/CISPRI
Anthony Locke/Canadian Wildlife Service
Gary Mauseth/Beak
Wolfgang Konkle/Exxon
Kenneth Lee/Canadian Fisheries and Oceans
June Siva/ENSR
Robert Martin/TGLO
Joseph Mullin/MMS
Jacqueline Michel/RPI
David Pascoe/USCG
Robert Pavia/NOAA
Scott Robertson/ARCO
David Sait/ME
John Naughton/NOAA
James Payne/Ogden Environmental
Gary Petrae/NOAA
Pasquale Roscigno/MMS
Robert Simmons/Exxon
David Skewes/USCG
Alexis Steen/API
William Stubblefield/ENSR
Albert Venosa/EPA
Ann Hayward Walker/SEA
William Walker/SEA
Mark Weller/Texaco
James Watson/USCG
John Westerlind/Consolidated Edison

In addition to the aid of participants at the workshop, a later draft was subjected to independent peer review in 1998. Further, a core group of volunteers from the API Marine Manual Update Work Group has guided this document to completion. These volunteers were:

David Fritz/BP-Amoco
Ronald Goodman/Imperial Oil
Vickie Huyck/USCG
Bela James/Equilon
Royal Nadeau/EPA
Robert Pavia/NOAA
David Stalfort/API-USCG
Alexis Steen/API

Based on the input from workshop participants and peer reviewers, many changes have been made to the original drafts. This document has been organized to be most useful for contingency planners and to function as a technical resource.