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A Field Guide to
Oil Spill Response on Marine Shorelines

Canada

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A Field Guide to Oil Spill Response on Marine Shorelines

Environment and Climate Change Canada

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Preface

This field guide is about the protection and cleanup of oil spills on marine shorelines. It is one of a series produced by Environment and Climate Change Canada to provide the best available knowledge, guidance, and standards for responders and decision-makers dealing with oil spills in marine and freshwater shoreline environments.

These field guides combine existing scientific and technical knowledge with experience from recent responses, experts, and practitioners in order to assist and educate spill responders and enhance the spill response process.

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Shoreline cleanup following the 2006 *M/V Westwood Anette* spill.

Manual wet mixing using rakes agitates sediments and releases oil which is contained by floating boom (seen along the top of the photo). The oil that is released is recovered by passive use of sorbents (snares) anchored to the beach face. See Figure 5.19 for a view at low tide. At right, the oiled snare is being replaced.

QUICKSTART GUIDE

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1. Introduction

1.1 OBJECTIVES AND PURPOSE

This field guide provides advice and guidance on the protection and treatment of marine shorelines threatened or impacted by an oil spill. The information is applicable to planners, decision-makers, and field personnel involved in both preparedness and response phases of oil spill cleanup.

The field guide focuses on conventional tactics normally available to responders and that are applicable and appropriate to the coastal marine environments of Canada. As the same physical types of shoreline are found around the world, the field guide is also relevant to oil spills on marine shorelines in most other countries.

Shoreline oil spill response in freshwater lakes, ponds, rivers and streams will be covered in a separate field guide.

1.2 CONTENTS OF THE FIELD GUIDE

The Introduction outlines the key characteristics of the response environment and the types of shoreline covered by this field guide, including the basic shore zone terminology, oil categories, and the behaviour of oil at sea and on shorelines. Differences between marine, lake/pond, and river/stream environments are identified in the context of biological sensitivity and productivity based on how these affect the response decision-making process.

Section 2 provides a broad overview of the different aspects of oil spill response on shorelines, including response phases, management activities, and the types of decisions that collectively make up the shoreline protection and shoreline treatment components of a spill response operation.

Response strategies and tactics for shoreline protection both at and near the shore zone are described in Section 3. The characteristics and features of estuaries, deltas, and tidal inlets are described and discussed separately as these are common coastal locations in which tidal flow and/or river or tidal channel processes play an important role in developing protection strategies.

Understanding how oil behaves on different types of shorelines and the potential environmental effects of the various treatment options are key elements in selecting appropriate shoreline treatment options. These aspects of the decision-making process are discussed in Section 4 for sixteen different shoreline types and for shorelines covered with snow. This section identifies key aspects of response operations in environments with a high tidal range, in remote locations, and for nearshore submerged and sunken oil.

Shoreline treatment tactics are described in Section 5. Twenty individual tactics are grouped into the following categories:

- natural recovery;
- washing removal methods;
- physical removal methods;
- in-situ treatment; and
- chemical and biological treatment.

Each treatment tactic is described in terms of its objectives and applications and the associated constraints and limitations. Types and volumes of waste generated by the different treatment options are also discussed in this section.

The field guide has been designed so that individual sections can be used as stand-alone documents.

1.3 THE RESPONSE ENVIRONMENT

This field guide pertains to marine coastal environments. The shoreline types follow the current Environment Canada shoreline classification system used in its Shoreline Cleanup Assessment Technique (SCAT) and when conducting environmental emergency mapping in Canada (Sergy, 2008).

The same types of shoreline are found in different geographic and climatic regions around the world. These shorelines are located in marine coastal environments ranging from exposed, high-energy, open-ocean coasts to sheltered coves, tidal lagoons, or estuaries and in areas with markedly different tidal ranges.

The coastal environment is unique in terms of oil behaviour and spill response operations. On open coasts, high wave energy levels can rapidly physically abrade and weather stranded oil or redistribute sediments so that stranded oil is either eroded or buried. Stranded oil can also be buried or exposed by migrating ridge and runnel systems that result from the on- and off-shore movement of sediment due to changes in wave character at the shoreline.

Marine shorelines are divided into the following zones based on their location in terms of tidal zones.

- The **Supratidal Zone** is the area above the mean high tide zone where wave activity occurs occasionally. This area is also known as the splash zone.
- The **Upper Intertidal Zone** is approximately the upper one third of the tidal zone.
- The **Mid-intertidal Zone** is approximately the middle one third of the tidal zone.
- The **Lower Intertidal Zone** is approximately the lower one third of the tidal zone.

Tidal range is an important factor in terms of the distribution of stranded oil and the shoreline processes that act on that oil. If the tidal range is small or micro-tidal (<1 m), oil is concentrated in a relatively narrow band. On shorelines with a high tidal range, however, oil can be distributed over a wider area, although it tends to concentrate in the upper and mid-intertidal zones. Oil stranded at high tide during the twice-monthly spring tides when water levels are typically one-third higher than at other times of the month (neap tides) will remain above the limit of wave action until the next period of similar higher tides or high water levels.

Ice can form on a shoreline when air temperatures are below freezing. Frozen wave splash, spray, swash, or backshore runoff can form a layer of ice on an intertidal or backshore surface that essentially changes the character of the substrate on a sediment shore from permeable to impermeable.

Spills in Different Response Environments

This field guide and its companion guide address shoreline oil spill response separately in (i) marine and (ii) freshwater environments, i.e., lakes, ponds, rivers, and streams. Technical advisors, specialists, and responders, however, may be required to deal with spill events in any of these different environments or even with a single spill event that affects more than one of these environmental settings.

In spill response, there are many similarities among the different environments, particularly in terms of the decision-making process and the tactics and techniques that are available. On the other hand, there are significant differences that require an adjustment when transferring knowledge and experience from one environment to another. Some of the major differences are identified below.

Biological Productivity and Sensitivity

- Similar shorelines types in different environments, e.g., marine, lake, or river, typically have different biological productivity and sensitivity characteristics.
- In general, there is a lower abundance of biota in the actual 'shoreline zone' of sand, granule, pebble, cobble, boulder, and bedrock shorelines of lakes and rivers than in the same type of shoreline in tidal marine shorelines. Freshwater shorelines are often less sensitive to oil and cleanup operations than similar marine shorelines. In some cases, more aggressive techniques can be considered for freshwater environments than for marine shoreline environments.
- In contrast to the above, differences between marine and freshwater environments are less relevant for mud flats and wetlands because both have relatively high biological productivity and sensitivity to cleanup operations.
- When assessing the sensitivity of river and lake shorelines to response operations, the shallow water zone adjacent to the shoreline just at and below the land-water interface must be taken into consideration. Biological productivity increases substantially in this area.

- Due to the narrow width and/or shallow depth of water in small streams, shallow rivers, and ponds, a major portion of the water column or bottom may be directly or indirectly disturbed by cleanup operations.
- Marine marshes typically have a dense root system with better weight-bearing capacity than the more porous root systems of freshwater wetlands and marshes. This can affect tactics, operations, and oil penetration.
- Biological sensitivity is lower in areas (marine, lake, or river) where ice is common during winter months as plants and animals are scoured and scraped. This is also partly due to the length of the cold winter season.

Water Levels

- Oil stranding, behaviour, and natural removal are affected by water-related processes. Tides and waves are the most important processes in tidal marine waters, waves in lakes and ponds, and currents and water flow in streams and rivers.
- The water level at the time oil is stranded affects which across-shore zones of the shoreline may be affected by the oil and the exposure of that oil to subsequent weathering processes, particularly by physical wave action.
- After oil becomes stranded, water levels can change rapidly and dramatically in rivers and streams, less so for ponds, and marginally for large lakes and marine environments.
- Changing water levels affect operational activities, staging, and access, particularly if the shore zone is narrow or there is a steep backshore.
- Astronomic tidal water levels are usually predictable but on low-lying coasts may be overshadowed by meteorological effects that may be difficult to predict.
- Changes in water levels in lakes and rivers are due to seasonal runoff, local precipitation events, or wind events and thus may be difficult to predict.
- Wind setup and setdown can inundate or expose wide areas of marine or freshwater shorelines within hours on low-lying coasts and even relatively small amounts of precipitation can cause flash floods and overbank flooding in small rivers and streams.
- As water levels change less frequently in freshwater marshes than in tidal marine marshes, edge effects are typically greater in freshwater marshes and inundation more likely in tidal marshes.

Character of the Body of Water

The size of a standing body of water and the water flow conditions in running waters control the potential spreading, transport, and dilution of spilled oil and therefore the size of the affected area, the length of oiled shoreline, and the amount of oiling/impact relative to the size of the water body.

The size of any water body affects the potential for wave generation, which is one of the key elements in natural cleaning of oiled shorelines.

- The smaller the water body, the more likely that oil will be concentrated and stranded as thicker deposits, which in turn could: (1) result in a more severe environmental impact but in a relatively small area and (2) facilitate control and recovery by the response team.
- As the size of the water body increases: (1) the ability to control or contain the oil decreases; (2) the affected area increases in size; (3) the ability to protect sensitive resources at risk decreases; and (4) the scale and cost of the response will likely increase. At the same time, (5) the oil is spread over a wider area so that concentrations are lower and (6) the potential for wave generation increases, with the result that (7) the potential for natural weathering and self-cleaning increases.

1.4 BEHAVIOUR OF OIL

Oil at Sea

Oil spilled in marine environments may remain at sea for days, weeks, or months before reaching a shoreline. For example, oil began to wash ashore in Brittany, more than 500 km away and 6 months after the sinking of *T/V Prestige* off northwest Spain in 2002 and continued to wash ashore for another 5 months. Some very large spills in open ocean have not caused any shoreline oiling.

The *T/V Atlantic Empress* lost 287,000 tonnes of oil off the coast of Trinidad in 1979 and the *T/V Odyssey* lost 132,000 tonnes in the North Atlantic off eastern Canada in 1988. In both cases, regional ocean currents carried the oil away from land. In contrast, oil spilled onto coastal waters may be driven shoreward and become stranded within hours or days depending on the location of the spill and local winds and surface water currents. In these cases, there is only a short window of opportunity in which to implement shoreline protection strategies.

The longer the oil remains at sea, the more weathering takes place. A key weathering process is the evaporation of the light fractions, which reduces the volume of the oil and changes its physical and chemical character. Emulsification is another critical process that can occur depending on the character of the spilled oil, physical oceanographic conditions, and the length of time that the oil remains on the water. These conditions typically produce water-in-oil emulsions that can increase the volume of the spilled oil by a factor of 3 or more.

The density of sea water is typically on the order of 1.02 to 1.03 g/cm^3 (1,020 to 1,030 kg/m^3) depending on temperature and salinity. The density of brackish water is between that of sea water and fresh water (~1.0 g/cm^3). Changes in the temperature of surface water, due to diurnal or seasonal heating and cooling or water exchange between fresh, brackish, and sea water, can determine whether an oil slick floats or submerges by altering the density of the water body.

Oil on the Shoreline

Although many factors are involved, the fate and behaviour of oil stranded on a shoreline are related primarily to the character of the oil, the physical character of the shoreline, and the physical processes occurring at the shoreline.

- The composition of each crude oil or product varies in terms of chemical compounds. This affects the physical properties of the oil, e.g., viscosity, density, solubility, interfacial tension, and stickiness. These properties affect oil behaviour and change over time due to natural weathering and transformation processes that occur in the environment, both at sea before the oil reaches land and on the shoreline after it is washed up and becomes stranded.
- The physical character of the shoreline refers to factors such as the nature of the substrate (solid or sediment), the form (cliff or beach), the slope of the intertidal zone, and the depth of the water table.
- Physical processes refer to dynamic coastal processes, such as tide, wind, water flow, and currents.

These factors influence the oil conditions, such as oil penetration, retention, burial, persistence, and natural removal rates, all of which need to be addressed by planners when developing treatment plans. It is important to recognize that in many situations, the environment is variable and dynamic over time. The effect on oil behaviour is always changing and can sometimes be dramatic.

To address differences in oil character, a five-tier oil classification system is used in this field guide to describe the oil. The classifications are:

- volatile oils (gasoline products);
- light oils (diesel and light crudes);
- medium oils (intermediate products and medium crudes);
- heavy oils (residual products, heavy fuel oils such as Bunker C, and heavy crudes); and
- solid oils that do not pour (bitumen, weathered Bunker C, tar, and asphalt).

The materials on marine shorelines and the physical processes that act on those materials are similar on shorelines around the world. The principles that govern oil behaviour, persistence, and weathering therefore have application to different locations and environments globally. Additional information on the behaviour of stranded oil specific to different types of marine shorelines is provided in Section 4 of this field guide.

2. Shoreline Oil Spill Response

This section provides an overview of the different aspects of response phases, management activities, and the types of decisions that collectively make up the shoreline protection and shoreline treatment components of a spill response operation.

2.1 THE RESPONSE FRAMEWORK

The primary objective of an oil spill response operation is to minimize further impact of the oil on the environment and on public health. Although this typically involves a range of decisions and actions, the components of the spill response operation can be broadly organized and addressed in a logical and sequential manner. Understanding the framework of this process, as well as being aware of state-of-the-art knowledge, tools, and best practices contribute to the decision-making process during a spill.

When a coastal or marine oil spill occurs, a number of options are available to minimize its effects. These options are shown in Figure 2.1. If possible, the most immediate actions should focus on controlling the spill at its source. At the same time, strategies for on-water containment and recovery (control on water) should focus on reducing the volume of spilled oil and minimizing the spread of the oil and the size of the affected area.

This field guide describes the protection and treatment or cleanup of shorelines, which is the fallback approach after source control and/or control on water.

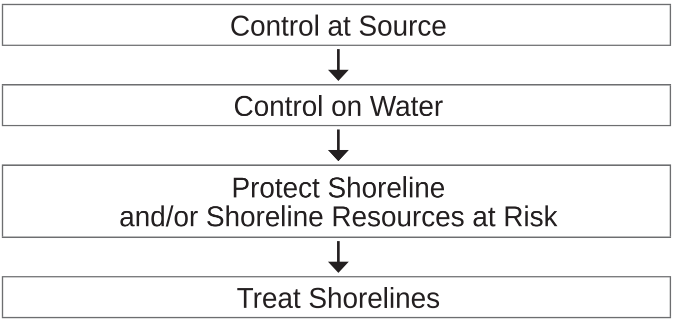

Figure 2.1 Spill Control Options

2.2 SHORELINE RESPONSE PHASES

The framework for shoreline response actions and decisions is shown in Figure 2.2. This step-wise process consists of the following four phases that form a cycle which continually improves knowledge and the effectiveness of the response.

1. In most situations, both government and potential responsible parties contribute to a pre-spill **Preparation Phase** by developing resources (knowledge, tools, and expertise) to be included in contingency or response plans and called upon when a spill occurs. Training, drills, and exercises are crucial elements of response readiness in this phase.

2. The **Reactive Phase** or **Emergency Response Phase** immediately follows a spill incident. At this phase, the primary focus of the response operation is typically source control and/or control on water. Shorelines are addressed in the context of protection priorities for sensitive areas, strategies, and tactics. The initial response actions may take place before a spill management team is organized and typically follow strategies prescribed in oil spill response or oil spill contingency plans.

3. The response operation transitions from the reactive phase to a **Planned Response Phase** under the direction of the spill management team. For shoreline treatment, management by objectives involves a series of planned activities based on an assessment of the situation and decisions about response priorities. Planned shoreline protection and treatment activities include determining the process by which treatment completion can be achieved. Operational endpoints or targets must be established quickly as these targets determine the level of operational effort in the response.

4. The **Completion and Monitoring Phase** consists of an inspection process to ensure that shoreline treatment has been completed according to the plans. This process eventually leads to closure. Ideally, a post-incident assessment takes place, during which lessons learned can be fed back into an improved prevention and preparedness plan.

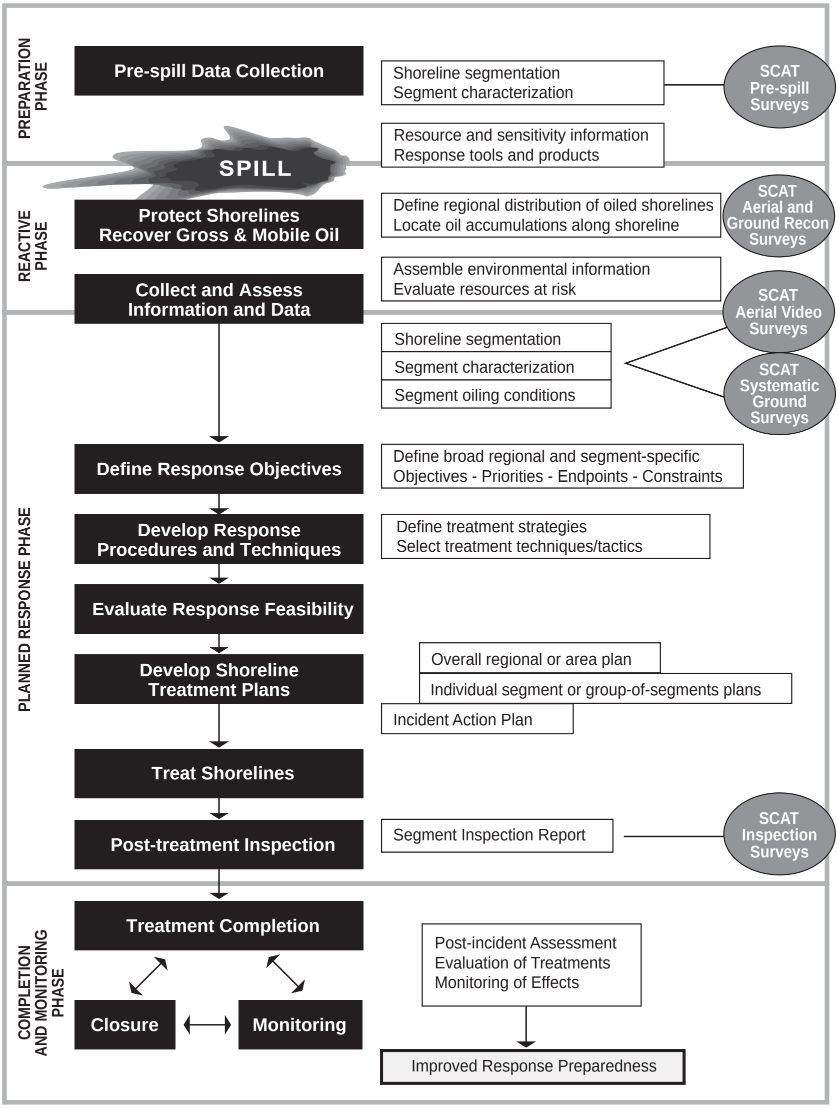

Figure 2.2 **The Shoreline Response and Decision Framework**
(from Sergy and Owens, 2007)

2.3 PREPARATION PHASE

Pre-spill preparation activities greatly improve oil spill response effectiveness. For shoreline response, there are four important elements of planning or preparedness.

Pre-spill SCAT Surveys

Mapping projects can be linked to the SCAT process to create shoreline segments and acquire basic physical shoreline data for each segment in the same way that data would be generated during the response. These data include shoreline type, substrate type, coastal character, and access. These key elements of the SCAT database are then in place before a potential incident. They are particularly appropriate for high-risk locations.

Collection of Environmental Data

Information on ecological, economic, and cultural resources and other baseline data is commonly collected for resource management. The nature and location of this information should be identified to facilitate rapid access during the spill response in order to evaluate the resources at risk, set priorities, and define endpoints.

Preparedness Planning and Products

A wide array of applications, tools, and products can be produced to improve response readiness. Examples include contingency plans, response manuals, sensitivity maps, and recommendations for shoreline protection and treatment strategies, tactics, and priorities.

Training, Drills, and Exercises

Agencies, private companies, and individuals involved as managers, responders, or in an advisory or oversight role during a spill response require training to understand roles and responsibilities. A program of drills or exercises based on likely local, regional, or national spill response scenarios is a crucial component of this training and of spill response readiness.

What is SCAT?

During an oil spill, **Shoreline Cleanup Assessment Technique (SCAT)** teams survey the affected area to provide geo-referenced documentation on oil and shoreline conditions in a rapid, accurate, and systematic process, using standardized methods and terminology. The data and information generated by the SCAT surveys are crucial to the decision-making process and are the basis of spill planning for the operational stages of the shoreline response. A SCAT program can include several types of field surveys, data management procedures, and a number of different types of products that can be used by the planners and decision-makers on the spill management team. Oil spill response plans typically include the SCAT process as part of the Environmental Unit in the spill management organization.

A detailed case study of a SCAT program is described in Owens et al., 2005b and 2008.

2.4 EMERGENCY RESPONSE PHASE

In the initial emergency or reactive response phase, the shoreline response strategy is relatively straightforward. The primary objectives are to:

- assess the magnitude of shoreline oiling (actual and predicted);
- protect valuable resources at risk on vulnerable shorelines; and
- recover or contain mobile oil on the shoreline.

During this emergency phase, the character of the spill and the scale of the affected or potentially affected shoreline area are rapidly assessed. This assessment is supported by (a) estimates of potential coastal land falls (trajectory analysis) and (b) aerial and ground reconnaissance SCAT surveys. This information is then used to establish shoreline protection priorities and strategies and initial shoreline treatment priorities.

Reconnaissance SCAT Survey

The objective of a reconnaissance SCAT survey is to quickly define the overall scale of the problem in order to develop regional objectives and facilitate more detailed planning for the next stage of the response (Owens and Sergy, 2004a). Detailed mapping or documentation are not required from reconnaissance surveys, except to provide information on the general geographic distribution of oil and amounts of oil on the shoreline. When the affected shoreline area is small and can be surveyed in one or two days, a ground or boat survey would probably be sufficient. An aerial reconnaissance is required for longer sections of coast.

During a reconnaissance survey, the remobilization potential of any stranded oil is also evaluated. Once oil reaches a section of coast, it may be possible to remove the mobile oil or to contain that oil against the shore so that it is not re-floated and transported elsewhere. This type of emergency phase strategy can minimize spreading and the extent of the affected area. For example, if stranded oil poses an immediate threat to wildlife or public health, information obtained by the reconnaissance SCAT survey would be applied to identify those locations for priority treatment or cleanup.

Shoreline Protection - Priorities and Strategies

Information from a variety of sources, including overflights, ground- or boat-based observations, and a reconnaissance SCAT survey, is used in the initial decision-making process to identify the direction in which the oil is likely to move or to locate stranded oil. Initial protection priorities are selected based on the transport pathway and combined existing environmental information on resources at risk in the path of the spill.

Environmental Information Inputs

Environmental baseline information should be acquired and evaluated as soon as possible. If pre-spill SCAT survey data are not available, a SCAT aerial video survey may be desirable in the emergency response phase to create shoreline segments.

2.5 PLANNED RESPONSE PHASE

As the response operation transitions from the emergency or reactive response phase to a managed and planned series of activities, site-specific information is required in order to decide on an appropriate shoreline treatment strategy and operational endpoints. This planned phase is managed through a decision-making process that allows operational activities to be developed within a set of specified goals.

Management by objectives for shoreline treatment is achieved by following a sequence of steps.

1. Collect and organize detailed information on the shoreline character, oiling conditions, and local environment using systematic SCAT surveys and existing information about resources.
2. Define broad regional and site-specific (segment) response objectives, such as treatment endpoints, priorities, and constraints.
3. Develop strategies to meet the objectives.
4. Select appropriate tactics or techniques to implement the strategies.

5. Evaluate the feasibility of the strategies and tactics in light of the environmental conditions, the character of the spill, and operational factors such as available resources; accessibility; sea state, currents, and wind; and safety.
6. Prepare an overall programmatic Shoreline Treatment Plan and individual segment plans.
7. Obtain appropriate approvals, permission, or permits.
8. Implement the field response operations plan, i.e., treat the shorelines.
9. Inspect and determine when treatment has achieved the planned objectives.

Shoreline Character and Oiling Conditions

SCAT teams systematically survey the affected area to provide accurate geo-referenced documentation on the physical character of the shoreline and on surface and subsurface oiling conditions using standardized methods and terminology (Owens and Sergy, 2000, 2004a). These data are critical as they provide the basis for the entire sequence of shoreline treatment or cleanup planning and field operations through to completion.

In addition, the SCAT field teams document operational features, backshore staging conditions, access, and operational or safety constraints. The teams can identify or verify environmental, cultural, recreational, and economic features and constraints. Frequently, SCAT teams are asked to provide recommendations for appropriate treatment techniques and to define constraints or limitations on the application of cleanup techniques, so that the treatment operations do not result in additional damage to the shore zone.

Shoreline Segments

The essential first step of a SCAT survey is to divide the coastline into planning and operational work units called **segments**, within which the shoreline character is relatively homogeneous in terms of physical features and sediment type. These segments are the basis for the development of treatment plans. Each segment is assigned a unique location identifier. Segment boundaries are established on the basis of prominent geological features, such as a headland, changes in shoreline or substrate type, a change in oiling conditions, or to delineate the boundary of an operations area. Segment lengths are small enough to obtain adequate resolution and detail on the distribution of oil, but also of a size that is operationally practical. Creating too many small segments can generate too much data and/or is not operationally effective. Most segments in oiled areas would range from 0.2 to 2.0 km in length.

A SCAT Systematic Ground Survey is the basis for detailed data collection. For larger spills and/or if pre-spill SCAT data are not available, it may be appropriate to conduct a SCAT Aerial Video Survey before ground surveys to rapidly generate information for identifying segments and to map locations and lengths of oiled shorelines at the level of detail required to initiate planning.

SCAT teams should focus on the tasks described above and should not be asked to sample, collect oiled wildlife, or perform environmental assessment or other unrelated tasks. Such tasks could easily complicate data management, compromise the objectivity of the team, and invariably slow the rate of progress and therefore delay transfer of information to the Operations team.

Treatment Objectives

An important element of the planned response phase involves making final decisions about treatment objectives, priorities, cleanup endpoints, and constraints. These criteria lay the groundwork for and determine the nature of subsequent planning and treatment. This is usually the first opportunity for organized cooperation and input from various stakeholders and to address and manage the expectations of these stakeholders.

Although general and specific treatment objectives, priorities, and endpoints can be established at a broad regional level, a set of criteria must be developed for each segment in order to implement a treatment operation. The criteria may be unique to a segment, common to segment groups, or apply to an entire region.

Treatment Priorities - One of the objectives of a SCAT survey is to identify the character and amount of oil that has stranded so that the Environmental Unit of the Planning Section can assess the risk(s) associated with the presence of that oil. The timing and sequence of shoreline treatment activities are based on this risk assessment. Those segments where mobile or pooled oil could remobilize or where the oil poses an immediate and real threat to ecological resources or public health are often given a higher priority.

Treatment Endpoints - Shoreline treatment or shoreline cleanup endpoints are specific criteria assigned to a segment that define when sufficient treatment effort has been completed for that segment. In effect, the endpoints are the practical definition of 'clean'[1] for that particular segment of shoreline in that particular spill. The endpoints are a standard against which the treatment activities can be evaluated. When the pre-defined endpoints have been achieved, the specified treatment of that segment of oiled shoreline has reached the agreed objective or goal and the operations team has completed the assignment in that segment.

1 There is no consensus in defining the term 'clean' or the concept of 'how clean is clean' (Baker, 1997). In effect, 'clean' is defined by the treatment endpoints, which in turn are set by the treatment objectives (Sergy and Owens, 2007).

The Shoreline Segment as a Work Unit

Ultimately, each segment of shoreline is considered individually at both planning and operational stages. Each segment has a set of criteria and conditions, i.e., objectives, endpoints, constraints, priorities, and tactics, that are reflected in a treatment plan.

Treatment Strategies and Tactics

Regional and segment-specific treatment strategies are developed in the context of treatment objectives, priorities, endpoints, and constraints. These strategies are based on information about oiling conditions, shoreline character, and environmental resources at risk. Specific tactics, techniques, and procedures are defined to meet the treatment objectives and strategies.

Shoreline treatment or cleanup tactics should be compatible with the character of the shore zone and with the oiling conditions (type and volume of oil) as documented by the SCAT process. The character of the different types of shorelines and preferred treatment options are summarized in Section 4. As all options except natural recovery intrude to some extent on the ecological character of the shoreline, the appropriateness and the anticipated effects of the selected tactic(s) must be assessed as part of the decision-making process.

Twenty categories of shoreline treatment tactics and their applicability to the various shoreline types are described in Section 5. These are grouped on the basis of three primary treatment strategies: natural recovery, physical removal, and chemical or biological treatment.

Feasibility and Safety

The ability of the response team(s) to achieve the desired cleanup goals and endpoints and the safety aspects of the field operations are two important considerations in the decision-making process for shoreline treatment.

After the Planning Section has established the endpoints for a segment or section of coast, the Operations Section prepares a plan designed to achieve that goal. If Operations questions the feasibility or practicality of achieving the endpoints or is concerned about safety issues, Planning may have to reconsider and work with Operations to identify target endpoints that are practical, effective, safe, and achievable. There is little value in attempting to clean or treat a shoreline if it is expected that the endpoints cannot be met.

Safety is the primary objective of all spill response operations, for both responders and the public. The primary safety issues are:

- the character of the spilled oil (in particular the volatility of light oils or products);
- the operating environment (temperature, winds, waves, currents, tides);
- site conditions (boulders, wide tidal flats, bedrock cliffs); and
- wildlife or plants (bears, poison oak).

Sometimes, cleanup or treatment recommendations may be altered or not carried out due to one or more safety concerns.

Shoreline Treatment Plans

Shoreline Treatment Plans are the culmination of the sequence of planning activities that provide a 'what-where-when-how' methodology for Operations to treat the shorelines (see details on page 22). Ideally, these plans reflect the deliberate assessment and decisions of stakeholders and are in essence an agreement on the best course of action.

A broad regional programmatic treatment plan is used to set the framework, whereas individual segment treatment plans and recommendations provide the necessary segment-specific detail. The treatment plans contain appropriate permits and approvals and are, in effect, the work order and instructions for Operations to proceed (also referred to as the Incident Action Plan).

2.6 COMPLETION AND MONITORING PHASE

As a result of treatment activities or natural removal processes, at some point the conditions within each shoreline segment approach or achieve the specific endpoints pre-established for that segment. A process is therefore required to assess and verify that the endpoint condition(s) are achieved and to permit treatment operations either to demobilize for that location, move elsewhere, or proceed to the next stage of treatment.

The primary elements of this phase include:

- a treatment inspection by the SCAT team and/or an inspection team that represents the interests of both the responsible parties and stakeholders;
- a decision on the treatment completion; and
- a decision on closure and/or the need for subsequent monitoring.

The inspection process and the criteria used to determine whether the treatment objectives have been met should be established as part of the planning process before treatment begins. Further details on inspection procedures are described on page 24.

2.7 RESPONSE DECISION-MAKING

The framework and elements of the shoreline treatment decision-making process are outlined in Sections 2.1 to 2.5 which present the logical and systematic step-wise progression of tasks. Although straightforward in concept, applying the decision-making process may be more complicated.

Spill Management

Managing a spill response operation is a cooperative effort that may involve national, regional, and local government agencies, local communities, the organization responsible for the spill when the source of the spill is known, and response contractors acting on behalf of that organization. The leadership of the response operation is assigned to the party responsible for the spill. In the case of an unknown party for marine spills in Canada, that role is assumed by the Canadian Coast Guard.

The structure of a spill management team varies depending on the size of the spill, the agencies involved, and the geographic location. For small spills that involve a few responders for a short period of time, the operation may involve only a supervisor and a cleanup crew.

A formal spill management team would normally be assembled for an operation that covers more then a few hundred metres of coast or is likely to continue for several weeks or longer. Historically, the command structure and management organization have varied. In recent years, however, a variation of the Incident Command System (ICS) has been widely adopted.

The most common format for such a team involves an **On-Scene Commander or Coordinator (OSC)** who is supported by four sectional individuals or teams (Planning, Logistics, Operations, and Finance). The Safety Officer reports directly to the OSC.

The Planning Section is responsible for decisions about shoreline treatment. Within the Planning Section, the Environmental Unit typically includes the SCAT team and representatives from government agencies and other stakeholder groups. The recommendations from the Environmental Unit become the core of the Shoreline Treatment Plans.

Developing and implementing treatment decisions involve both Logistics to provide the personnel and materials required to carry out the field activities and Operations for advice on feasibility, safety, and practicality.

The decisions made by the spill management team are based on available information in the following areas.

- Oil transport: Where will the oil go?
- Weathering: What is the oil like and how will it change?
- Resources at risk: What is in the spill path?
- Response options: What is feasible with available resources?
- Response priorities: What risks have a time element?

This information is then used to decide the following.

- Operational priorities: What actions take place first?
- Treatment guidelines: What can and cannot be done?
- Endpoint criteria: When can Operations stop?
- Sign-off procedures: How do monitoring and inspection activities determine when treatment has been completed?

The SCAT Team and SCAT Data Collection

SCAT data collection surveys, at different levels of detail, are used to provide real-time information on various aspects of shoreline conditions. The information is used:

- in the emergency or reactive response phase, to help define the regional scale and scope of the problem;
- in the initial stage of the planning phase, to provide details required to define treatment objectives, priorities, endpoints, and constraints;
- in the operational phase, to provide overviews of the spill response status and specific instructions to cleanup crews on each segment of shoreline; and
- in the completion phase, to provide a basis for post-treatment inspection and evaluation.

The collection and analysis of SCAT field data must be completed in a timely manner. Field activities are of diminished value if the results are not available quickly, usually within a day, and in the form required by planners. The need for appropriate levels of data analysis and data management procedures must be recognized early as data backlogs can occur rapidly during the initial response phase. Details on SCAT data management can be found in Lamarche et al., 2005.

Depending on the size of a spill, the different SCAT functions can be carried out by one or several trained individuals including a SCAT coordinator/manager, a data manager, and a field survey team leader.

From a technical perspective, the SCAT field team must include a person with oil spill experience and SCAT training who can identify and document oil on the shore, from the air or on the ground.

Depending on the spill circumstances, the team may also benefit from:

(i) an individual familiar with the ecology and biological sensitivities of the affected area;

(ii) an individual familiar with operational issues and shoreline treatment techniques; and in some cases,

(iii) a specialist who can advise on archaeological or cultural resources.

Not everyone can be on the SCAT team

The SCAT survey team must be trained, experienced, and objective in its task. The information collected by the team must be factual, scientific, and free of bias. This ensures that the team serves the needs of the collective stakeholders. Individuals participate on the basis of their expertise, which is required to complete the survey and collect the necessary data.

Oiling Conditions and Environmental Strategies

The presence of oil on a shoreline does not necessarily result in shoreline cleanup or treatment. Non-persistent oils, such as gasoline or diesel, can pose safety issues for responders. If stranded on open coasts, such oils typically weather rapidly, over a period of hours to days, so that natural recovery may be the most appropriate course of action. Making decisions involves evaluating:

- the type and amount of oil on a segment of coast;
- whether the oil is on the surface or has penetrated sediments;
- the likely residence time or persistence of the oil;
- the resources at risk during that residence time period;
- the sensitivity and vulnerability of those resources;
- logistics and access to the affected area or sites;
- the likely effectiveness of cleanup or treatment to reduce environmental impacts or risks; and
- safety.

Most oils stranded on an open coast and exposed to high-energy conditions will probably break down and be removed naturally within days or weeks. This would also be the case on most ice-free open coasts during winter months.

Resources at Risk, Sensitivity, and Vulnerability

The goal of a spill response operation is to minimize additional effects of the spilled oil on the environment or human resources that may be at risk. Environmental atlases or databases have been compiled for most of the coasts of Canada that are at risk for a marine spill. These atlases and databases have been developed to identify the potential risks as part of pre-spill planning and are typically an integral component of oil spill contingency or response plans.

The decision-making process for determining shoreline protection priorities is based on estimates of where the oil is likely to go and the resources at risk in the projected spill pathway. There is a distinction between "sensitivity", which is the response or reaction of a resource to the presence of oil and "vulnerability", which is the probability that a resource would be exposed to or affected by the oil. For example, some bird species, such as surface sea birds and waterfowl, are very vulnerable to an oil spill, whereas aerial sea birds, such as gulls and gannets, are less vulnerable as they spend comparatively little time on the water surface.

Response Priorities

The immediate removal and/or containment of mobile or pooled oil on the shoreline can reduce the on-water effort if that oil is refloated. Mobile oil may also threaten adjacent or nearby resources, unoiled segments of the shoreline, or segments that have already been cleaned.

The presence of oil in a segment may pose an immediate threat to wildlife that use the site or to public health or commercial interests, such as water intakes or recreational beaches.

The SCAT data and information on ecological, cultural, or human use resources are evaluated in the decision-making process to identify priority segments and the sequence of treatment as a whole. From a logistics standpoint, it is often easier and more efficient if the operational team moves progressively along the coast rather than jumping from one segment to another.

Treatment Endpoints

Treatment endpoints are an important and integral part of the decision-making and planning process, the operational response, and the completion phase. Clearly defined endpoints:

- assist the spill management team in selecting treatment objectives and tactics for a specified area or segment before the treatment begins;
- provide shoreline Operation supervisors with a clear goal so that they can tailor their activities towards a known point of completion; and
- provide criteria and standards to allow the inspection team to evaluate the condition of the shoreline and the results of the treatment activities and to determine when the treatment is completed.

Other important benefits of clearly defined endpoints are to:

- make it easier to recognize and assess the various environmental, social, and economic factors that should be considered in the shoreline treatment decision-making process; and
- make it easier to recognize and resolve concerns between the responsible party and stakeholders.

Treatment endpoints are usually established jointly by the spill management team and the responsible government agencies, with input from the responsible party when the source of the spill is known. It is important that all parties understand endpoints and agree on the appearance of the final treated shoreline. A successful and effective response is far more likely when all parties agree about what has to be accomplished. It is also important that those who are measuring endpoints have the necessary experience and ability.

Endpoints based on visual field measurements and observations are suitable for most spills and are recommended as a first option. The visual measurement approach is a rapid and straightforward procedure with simple descriptive and numerical outputs that provide clear guidelines and targets for Operations supervisors. The measurement technique and terminology are typically the same as those used in the SCAT process to describe oil conditions, i.e., using standard descriptors for oil distribution, area, thickness, and character. Guidance and further information about determining and measuring endpoints is available in Sergy and Owens (2007).

The Shoreline Treatment Plan

The end product of the planned response phase is a Shoreline Treatment Plan. The spill management team and representatives of appropriate federal, provincial, and other government or non-government agencies or stakeholders are involved in developing such a plan.

For all but small spills, treatment plans vary in application and scale. The Regional or Area Plan addresses common issues, conditions, and criteria that apply to the entire affected spill area, i.e., to all segments. Segment Plans contain specific modifications to the above as well as detailed site-specific supplemental information for Operations.

Regional or Area Plans

In managing a spill, an overall programmatic plan is usually developed to serve as a framework for the various activities that make up a response operation. Some activities, such as waste management, safety, or logistics, are an integral part of shoreline treatment. Others, such as documentation and finance, deal with non-operational components of spill management. A number of separate plans are typically developed to focus on specific issues, for example, the Wildlife Plan, Waste Management Plan, and Safety Plan.

The Regional Shoreline Treatment Plan typically includes the following topics:

- the SCAT program (teams, schedule, priorities, forms, and data management);
- shoreline segments (geographic area of the SCAT survey and segment maps);
- shoreline treatment endpoints and inspection procedures;
- shoreline operations (management, schedule, and priorities);
- shoreline treatment tactics (approved techniques);
- cultural resources and ecological constraints; and
- safety issues.

Segment Treatment Plans

A treatment plan is prepared for each individual segment. This plan includes the universal conditions of the area plan, plus any changes or supplementary conditions specific to that segment. Sometimes these changes or specific conditions are significant and unique to the segment, for example, if there is a feature of ecological or cultural significance. Whether there is a segment-specific plan or not, approved segment-specific information and instructions must be provided to the Operations team(s).

One approach is to use a short template information transmittal form that summarizes the relevant technical information on each segment needed by Operations. This includes:

- a summary of the oiling conditions (location, amount, character);
- treatment recommendations (tactics, endpoints);
- staging and logistics conditions and constraints:
- waste issues;
- ecological and cultural resource comments and constraints;
- site-specific safety issues; and
- sketch maps and other data that might be useful.

An example of a **Segment Treatment Recommendation Transmittal** (STRT) form is provided in Appendix 1.

Approval and Transmittal of Plans to Operations

Approvals are required for each segment so that Operations can proceed with treatment. The segment treatment plan, which includes the universal conditions of the regional plan plus the segment treatment recommendation summary, is typically combined with a cover document containing signature blocks for approval by responsible agencies as necessary or appropriate.

This package is typically a part of the **Incident Action Plan** (IAP). Both the Canadian and U.S. Coast Guard have IAP forms to summarize the relevant material. Detailed technical information, SCAT data, and specific plans for each segment are bundled under the IAP.

In essence, the Incident Action Plan (with necessary approval and permits) constitutes a work order for that section or segment of shoreline. This ensures that the expectations and instructions of the planners, decision-makers, and safety officers are clearly communicated to the field team supervisors. This plan provides the basis for post-treatment inspection and assessment later in the operation.

Inspection and Completion of Treatment

At some stage in the treatment of a segment, the shoreline operations supervisor or an environmental monitor decides that the pre-established endpoint has been achieved. At that point, the SCAT team and/or a team that represents the interests of both the responsible party and the stakeholders conduct an inspection survey to determine one of the following.

(1) The endpoint criteria/treatment objectives have been met. On some spill responses, this has been referred to as the point when "No Further Treatment" (NFT) is required.

(2) The endpoint criteria have not been achieved and recommendations are made as to where work is required and what should be done to complete the planned endpoint.

(3) One treatment stage has been completed and the next stage can now start.

The survey team's observations and recommendations are recorded on a **Segment Inspection Report (SIR)** or equivalent (see example in Appendix 2). This form records that an inspection has been completed and that either 'no further treatment' is required or specifies the location and extent of further treatment required in order to reach the endpoint(s). In some cases, the inspection team may have the authority to make the NFT decision in the field or they may provide a recommendation to the On-Scene Commander (OSC) who would then approve the recommendation or conduct the final inspection. Once the decision is made and confirmed, the operations can be demobilized from the segment or can progress to the next stage of treatment in that segment.

The path from 'no further treatment' to final closure may be direct or staged. The latter case usually involves monitoring to detect and alert the spill management team if there is a change of conditions that would trigger re-assessment of treatment.

Monitoring

As part of the SCAT and/or spill response program, repeated shoreline monitoring surveys can provide information on changes in oiling conditions.

It may be necessary to assess changes in oiling conditions that result from treatment and cleanup activities and/or natural self-cleaning processes over a period of time (days to months), e.g., is self-cleaning meeting expectations on a particular segment? Likewise it may be necessary to ensure that shoreline conditions in the segment remain acceptable and/or that the endpoints continue to be maintained.

Oil that has remained at sea for extended periods (days to weeks or longer) may cause re-oiling or new oil from a separate source may be stranded, as is often the case where oceanic tar balls are common. Buried subsurface oil that was not previously observed may be exposed by seasonal processes associated with exposed, high wave-energy coasts, especially during the storm season.

Monitoring may also be used to evaluate the effectiveness and effects of treatment decisions and tactics so that response to future oil spills can benefit from the knowledge of previous actions.

3. Shoreline Protection

3.1 INTRODUCTION

This section of the field guide addresses the physical or mechanical tactics and techniques that can be used in the nearshore and at the shoreline to implement a shoreline protection strategy in open-water conditions.

Shoreline protection refers to any defensive response activities that take place at or near the shoreline to prevent oil from making contact with specific vulnerable shore-zone resources in the path of the spill or threatened by the oil. Protection activities differ from other on-water containment and recovery operations that are used to reduce the volume of spilled oil and to minimize the spread of oil on water in a general non-targeted approach.

Objectives

The objectives of shoreline protection are to:

- prevent the oil from contacting a specific section or sections(s) of the shore zone or a specific resource(s) at risk in the shore zone;
- minimize the degree of contact between oil and a specific section(s) of the shore zone or a specific resource(s) at risk in the shore zone;
- prevent the oil from moving alongshore into adjacent shore-zone areas or resources at risk;
- contain oil that has already stranded at the shoreline to prevent remobilization of the oil; or
- prevent the oil from moving into an inlet or channel.

The decision-making process for developing appropriate strategies for achieving these objectives is described in Section 2.7. The strategies associated with shoreline protection objectives are shown in Table 3.1.

Options and Tactics

Eight groups of mechanical tactics can be used to achieve the shoreline protection objectives set for a specific location. The four on-water and four onshore groups of tactics that can be developed to meet the protection objectives are summarized below.

On-water tactics (Sections 3.2 to 3.5) are used to:

- contain and recover oil with booms, skimmers, or other techniques;
- redirect oil away from the shore with booms or other barriers;
- redirect oil towards a selected shoreline location(s) with booms for recovery by skimmers or other techniques; and
- exclude oil from shorelines and other areas with booms or other barriers.

Onshore tactics (Sections 3.6 to 3.9) are used to:

- contain, trap, or redirect oil using shore-seal booms for on-water recovery by skimmers or other collection techniques such as sorbents;
- contain and recover oil that washes ashore with barriers, berms, sorbents, or sumps;
- prevent oil from contacting the shoreline by using on-shore chemical, hydraulic, or physical barriers; and
- exclude oil from channels or inlets with shoreline booms, barriers, or dams.

The relationship between shoreline protection strategies and tactics is also shown in Table 3.2. In practice, two or more protection tactics or techniques are usually used to achieve the operational objectives.

Burning and **dispersants** can be used as shoreline protection options to reduce the threat of oiling or the amount of oil that could reach the shoreline. As these techniques are typically a component of the 'control-on-water' phase of a spill (Figure 2.1), they are not covered in this field guide, which focuses on mechanical strategies at or near the shoreline.

Techniques for containing submerged and sunken oil as part of a protection strategy are discussed in Section 4.19.

Shoreline protection strategies for specific tidal environments are described in Section 3.10. Estuaries, deltas, and tidal inlets are similar coastal environments characterized by a combination of tidal flow and/or river or tidal channels, which are critical factors when developing on-water strategies for shoreline protection. Information is provided about the characteristics and features of these environments that are relevant to development of these strategies.

Table 3.1 Marine Shoreline Protection Objectives and Response Strategies

Strategies	Objectives: Prevent contact between oil and shore	Minimize contact between oil and shore	Prevent alongshore movement of oil	Contain stranded oil at shoreline	Prevent oil movement into channel
Contain/recover oil on water	✓	✓	✓		✓
Alter direction of oil on water	✓	✓	✓		✓
Prevent oil movement into channel		✓	✓		✓
Trap or contain and collect oil at shoreline			✓	✓	✓
Prevent remobilization of oil			✓	✓	✓
Prevent overwash into backshore or lagoon		✓		✓	

Table 3.2 Marine Shoreline Protection Tactics and Response Strategies

	On-water Tactics				Onshore Tactics			
Strategies	Containment and recovery	Redirection away from shore	Redirection towards shore	Exclusion boom or barrier	Containment with shore-seal boom	Containment by barriers, berms, sorbents, or sumps	Exclusion by contact barrier	Channel exclusion by booms, barriers, or dams
Contain/recover oil on water	✓	✓		✓				
Alter direction of oil on water	✓	✓	✓	✓	✓		✓	✓
Prevent oil movement into channel	✓	✓	✓	✓				✓
Trap or contain and collect oil at shoreline			✓		✓	✓		
Prevent remobilization of oil						✓		
Prevent overwash into backshore or lagoon		✓			✓	✓		✓

3.2 ON-WATER CONTAINMENT AND RECOVERY

Objective

The objective of on-water containment and recovery is to prevent oil from reaching or making contact with a specific section of shoreline or vulnerable shore-zone resource. This is achieved by containment and recovery of the oil from the water surface in nearshore areas using conventional mechanical booming and skimming or other recovery tactics.

It is almost always easier, more efficient, less damaging to the environment, and considerably less expensive to remove the oil from the water surface than to clean or treat an oiled shoreline.

Description

Booms are used to surround or contain portions of a slick for mechanical recovery as shown in Figure 3.1. As shoreline operations are emphasized in this field guide, containment and recovery tactics are carried out in the nearshore zone, adjacent to the shoreline. Shallow-draft vessels are typically used for this type of operation. These vessels are equipped with:

- boom types suitable for the prevailing wave and current conditions; and
- skimmers or other recovery devices appropriate for the type(s) of oil to be recovered.

There are many manuals available that cover the standard operating procedures for booming, skimming, and oil storage or transfer. These are specialized activities that are best carried out by trained and experienced operators. For larger spills, these activities are usually managed and carried out by offshore recovery teams, rather than by the shoreline protection and cleanup teams.

Applications

The potential for recovering oil is high under favourable operating conditions. On-water containment and recovery activities can be used in any situation where it is safe and practical to recover the oil.

Constraints and Limitations

The primary limitation for using on-water tactics for shoreline protection is the limited window of opportunity. Constraints for operations include weather (visibility, wind, and temperature), waves and condition of surface currents, and water depth.

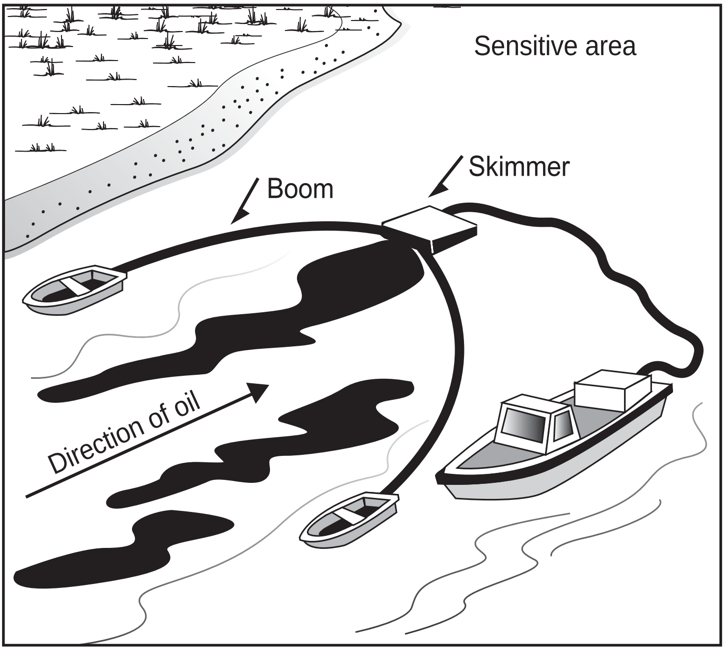

Figure 3.1 Nearshore On-water Containment and Recovery

3.3 ON-WATER REDIRECTION AWAY FROM SHORE

Objective

Booms or other barriers are deployed to redirect the oil on the water away from a specific section of shoreline or a specific vulnerable resource at risk.

Description

Redirection booming involves diverting the oil so that it moves in a different direction from that which it would follow naturally. This can be achieved either in nearshore areas or at the shoreline. Recovery may or may not be part of the strategy.

Booms can be deployed in a number of configurations to redirect oil including: (a) single, (b) cascading, (c) chevron, or (d) open chevron (Figure 3.2). The choice of the most appropriate configuration depends on:

- the size or area of the approaching slick;
- the amount of redirection necessary; and
- flow conditions (currents) in the deployment area.

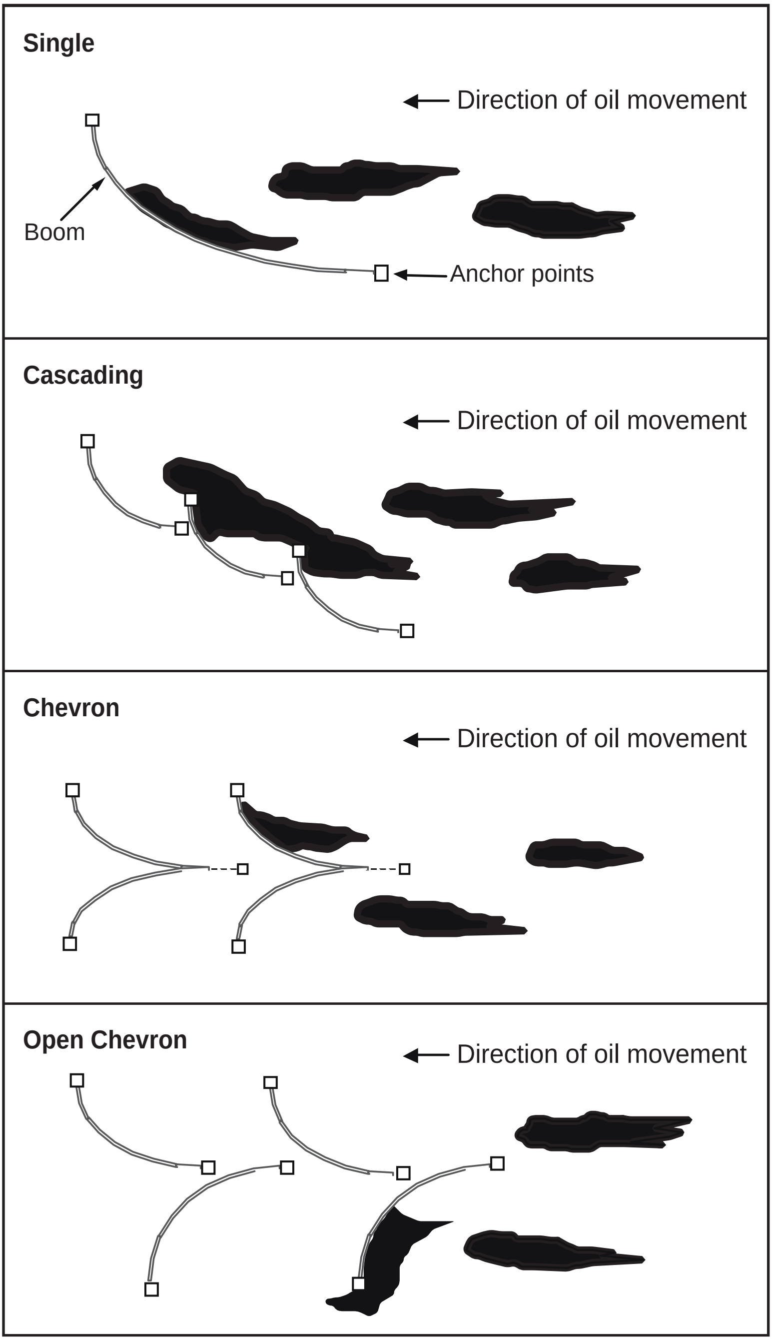

Figure 3.2 Boom Configurations for Redirecting Oil on Water

When boom is deployed at an angle to the shoreline in nearshore waters, the objective is to change the direction of oil movement rather than to place a barrier in the slick path to contain or control. A single boom can redirect oil over a swath that is equal to approximately ¼ to ½ of the boom length. To incrementally alter the location of the oil, multiple or cascading booms would be required if the slick width is greater than this length (the cascading configuration shown in Figure 3.2). It is usually easier to deploy and maintain several short sections of boom than a single, long section.

In higher flow conditions, redirection is usually more effective than exclusion booming which is discussed in Section 3.5, as boom(s) can be set at a higher angle. The higher deployment angle can redirect the oil seaward where it can be released without recovery as shown in Figure 3.3a or contained and recovered as shown in Figure 3.3b.

Applications

Redirection can be used to divert oil away from a vulnerable resource(s) at risk or towards a selected nearshore (on-water) location for subsequent collection and recovery. For example, oil approaching a marsh could be diverted seaward. From a protection viewpoint, this would prevent oil from entering and potentially damaging the marsh. From an operational viewpoint, (a) it is considerably easier to recover oil from the water surface than to remove oil from a marsh and (b) the marsh would not be damaged as a result of onshore treatment or cleanup operations.

This tactic is often used when current speeds or breaking waves preclude exclusion booming or when there is insufficient boom available for exclusion.

Constraints and Limitations

The effectiveness of nearshore booms is limited by current speed and breaking waves and by the accumulation or presence of floating debris and ice. The angle of deployment of booms is governed by the current speed. As the current speed increases, it becomes necessary to decrease the boom angle with respect to the shoreline, i.e., the boom angle becomes progressively parallel to the current direction to prevent splash-over, drainage, and entrainment (see Section 3.4 and Figure 3.6).

In most cases, a second boom or several layers of boom are required to ensure that no oil reaches a sensitive area(s) or resource(s) at risk.

Redirection of oil away from a section of shore without recovery may prevent contact with the oil at one location. The oil remains mobile, however, and may come into contact with the shoreline at another location, i.e., a less sensitive location, presumably with less impact.

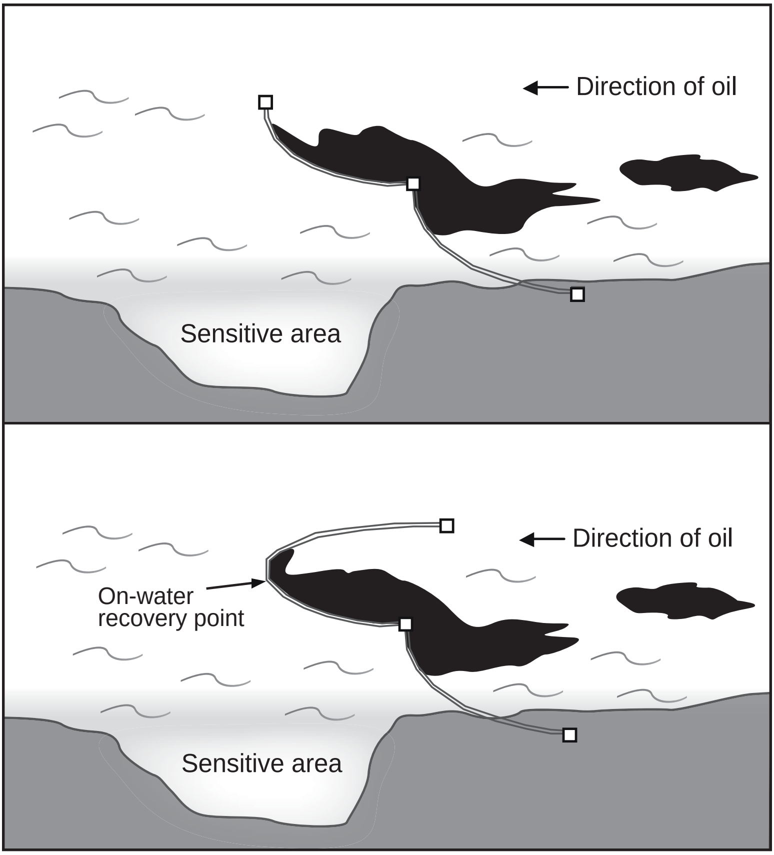

Figure 3.3 Nearshore Redirection Away from the Shore (a) without and (b) with Recovery of Oil

3.4 ON-WATER REDIRECTION TOWARDS SHORE

Objective

This tactic uses booms or other barriers to divert the oil on the water towards a pre-selected shoreline location for subsequent collection and recovery. This can be used to prevent oil from reaching a specific vulnerable down-drift section of shoreline or resource.

Description

Redirection booming involves diverting the oil either in nearshore areas or at the shoreline. Booms can be deployed in a number of configurations to redirect oil as shown in Figure 3.2. The most appropriate configuration depends on:

- the size or area of the approaching slick;
- the amount of redirection necessary; and
- flow conditions (currents) in the deployment area.

When boom is deployed at an angle in nearshore waters, the objective is to change the direction of oil movement rather than to place a barrier in the slick path to contain or control the oil. A single boom can redirect oil over a swath that is equal to approximately ¼ to ½ of the boom length. If the slick is wider than this length, multiple or cascading booms would be required to incrementally alter the location of the oil, as is shown in the cascading configuration in Figures 3.2 and 3.4. It is usually easier to deploy and maintain several short sections of boom than a single, long section.

In higher flow conditions, redirection is typically more effective than exclusion booming (see Section 3.5) as boom(s) can be set at a higher angle. At the shoreline, the higher deployment angle can redirect the oil to a selected location(s) where it can be collected and recovered.

Oil is redirected towards the shore usually in association with a containment and recovery activity (Figure 3.5) either on water, using skimmers or other recovery tactics, or at the shoreline, using trenches or sumps for example to prevent the oil from remobilizing (see Section 3.7).

Redirection can be used in combination with a shore-seal boom (Section 3.6) to minimize the amount of contact between the oil and the intertidal zone, by providing a seal at the land/water interface (Figure 3.4).

Applications

Redirection can be used to divert oil towards a location(s) where shoreline cleanup may be easier and/or more effective or to protect a specific down-drift vulnerable area(s) or resource(s) at risk. For example, oil approaching a marsh could be diverted towards a chosen landfall, such as a sand beach, that is up-current of the marsh. From a protection viewpoint, this would prevent oil from entering and damaging the marsh.

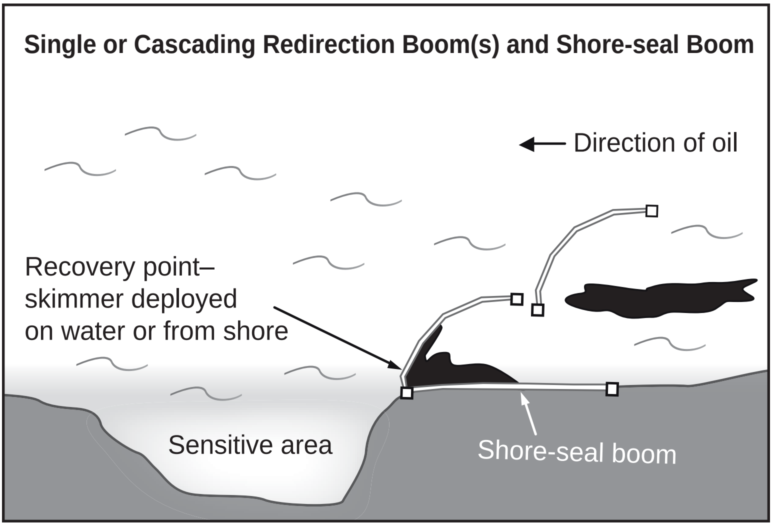

Figure 3.4 On-water Redirection of Oil Towards the Shoreline

Figure 3.5 Oil is redirected towards the shoreline during the 1999 *T/V Estrella Pampeana* spill, River Plate, Argentina.

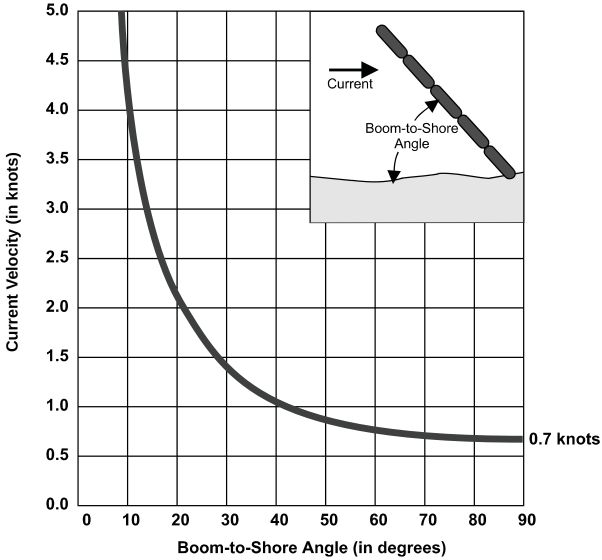

Figure 3.6 Shoreline Boom Deployment Angles

From an operational viewpoint, (a) the marsh would not be damaged as a result of treatment or cleanup operations, (b) it is considerably easier to clean a sand beach than a marsh, and (c) access and staging is usually easier from the beach. This technique can also be used up-drift of a location when current speeds or breaking waves preclude exclusion booming or when there is insufficient boom available for exclusion.

Constraints and Limitations

The effectiveness of nearshore booms is limited by current speed and breaking waves and by the accumulation or presence of floating debris and ice. In low current conditions, a boom can be deployed almost perpendicular to the shore to maximize the swath of oil that can be redirected. As current speed increases, it becomes necessary to decrease the boom angle with respect to the shoreline to prevent splash-over, drainage, and entrainment (Figure 3.6).

Even with a higher boom angle, entrainment is likely to occur if removal or recovery of the oil cannot keep pace with the oil accumulating against the apex of the boom and the shore. As the angle of deployment narrows with respect to the shoreline, the swath of oil that can be redirected decreases. More boom and possibly a cascading sequence of booms (Figure 3.4) may be required to redirect all of the slick towards the shore.

In most cases, second booms or several layers of boom are required to ensure that no oil reaches a sensitive area(s) or resource(s) at risk. In other words, the oil is redirected to a less sensitive location.

3.5 ON-WATER EXCLUSION BOOM OR BARRIER

Objective

Exclusion booms or barriers are used adjacent to the shoreline to prevent oil from coming in contact with a specific section of shore or a specific vulnerable resource at risk in the shore zone.

Description

This activity can include a number of nearshore, conventional booming strategies to provide a barrier around a resource at risk or across an embayment, e.g., a pocket beach, lagoon entrance, or river mouth. This is shown in Figure 3.7. Contact is prevented by forcing the oil to move in a different direction from what it would follow naturally. Recovery may or may not be part of the strategy.

Bubble barriers can be used to prevent oil from entering channels, such as sea water intakes or loading berths. These are fixed pipes laid on the channel bed through which air is pumped. These pipes may be several hundred metres long.

Textile barriers with long skirts can be used in low-energy environments to exclude oil from wetlands and reed beds, particularly in freshwater environments. Exclusion barriers can be deployed when flushing or washing wetlands and reed beds to contain released oil for recovery.

Applications

Exclusion booms can prevent oil from coming into contact with shorelines or from entering bays or other nearshore areas. If a resource such as an aquaculture site is located entirely in the nearshore zone, the exclusion boom can be deployed around part of the site to redirect oil away or to completely encircle the site to prevent contact (bottom, Figure 3.7). Aquaculture sites are usually fixed or anchored installations that may not be easily moved if they are within a spill path.

Constraints and Limitations

On open coasts, the wave height and velocity of the surface current control the effectiveness and feasibility of a proposed boom deployment. When current speeds or the size of the slick preclude the simple deployment of a boom across the path of a slick, the booms may have to be deployed at an angle (Figure 3.6) or in a cascading formation (Figure 3.2) to be effective.

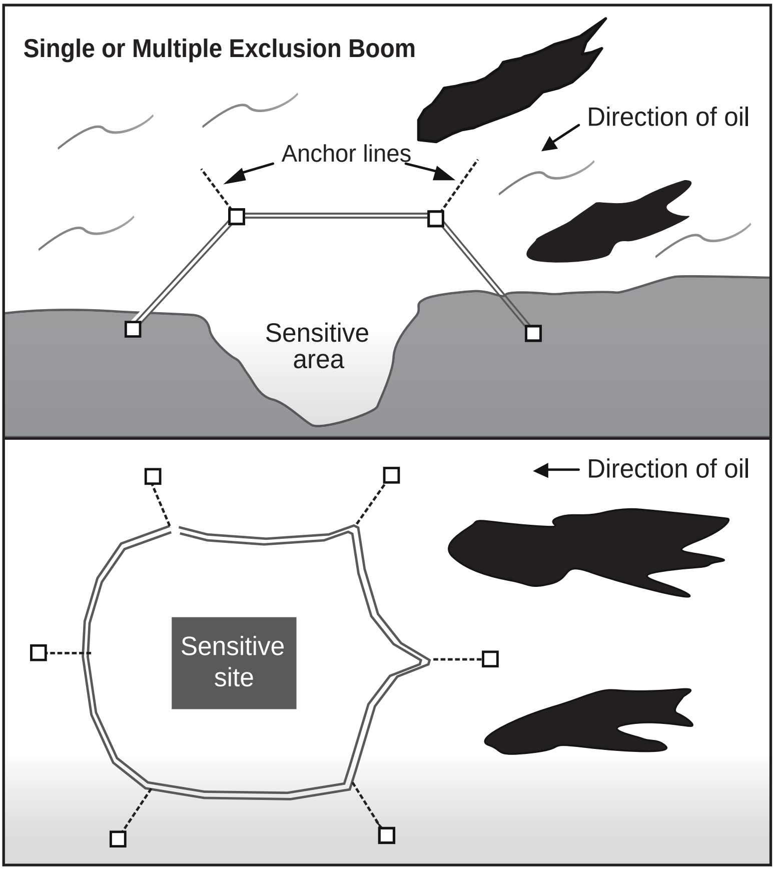

Figure 3.7 On-water Shoreline and Nearshore Exclusion Booms

The feasibility of exclusion booming may be limited by water depths and by the accumulation or presence of floating debris and ice. The size of the area to be protected by the booms may be a limiting factor.

A single boom may be effective in very calm waves and no or low current flow conditions. In most cases, a multiple set of booms is required to ensure exclusion, particularly with variable tidal currents.

Exclusion booms or barriers can prevent oil from contacting the shoreline or a resource at one location. Without recovery, however, the oil remains mobile and comes into contact with the shoreline at another location, presumably with a lesser impact.

3.6 ONSHORE CONTAINMENT WITH SHORE-SEAL BOOM

Objective

Shore-seal booms are used to contain and recover oil at the shoreline or to minimize the degree of contact between the oil and the intertidal zone by creating a barrier that can be effective with changing tidal or wind-driven water levels. This tactic may be used to prevent stranded oil from remobilizing and to prevent oiling or re-oiling at down-drift locations.

Description

Shore-seal boom, also known as shoreline boom, intertidal boom, and beach boom is designed to maintain a barrier against oil movement as the water level rises or falls. A shore-seal boom is shown is shown in Figure 3.8. The boom's water-filled lower chambers provide ballast and assume the contour of the shore when grounded. This same "skirt" presents a subsurface oil barrier when afloat as shown Figure 3.9. A similar type of boom can be fabricated on site by draping a sorbent roll over a conventional boom or a log boom. This has a similar design concept and may be effective in calm water conditions.

Shore-seal booms can be set perpendicular to (across) the shore to act as a barrier to the alongshore movement of oil (Figures 3.8 and 3.10) or deployed parallel to the water line to minimize contact between the oil and the shore or to prevent stranded oil from remobilizing (Figures 3.9, 3.11, and 3.23).

Applications

Apart from the primary application where tidal water levels change, this type of boom is useful in areas where the water level is relatively constant. The boom provides a seal at the land/water interface that is generally better than can be achieved by conventional booms, even in still or calm water conditions. When oil is directed towards a selected shoreline location(s) for collection and recovery using conventional boom (Figure 3.5), it would be appropriate to attach one section of shore-seal boom to provide a seal at the land/water interface to minimize contact with the shoreline.

Constraints and Limitations

This type of boom is relatively stable in shallow water due to the two water-filled chambers that sit below the waterline. It is susceptible, however, to rolling over, which renders it ineffective in the presence of breaking waves.

Grounded shore-seal boom cannot be repositioned when the ballast chambers are filled with water. Moorings must therefore be designed to allow the boom to move vertically but also to stay in place or have little lateral movement as the tidal level rises.

Figure 3.8 **Shore-seal boom deployed across the waterline acts as a barrier to alongshore movement of oil.**

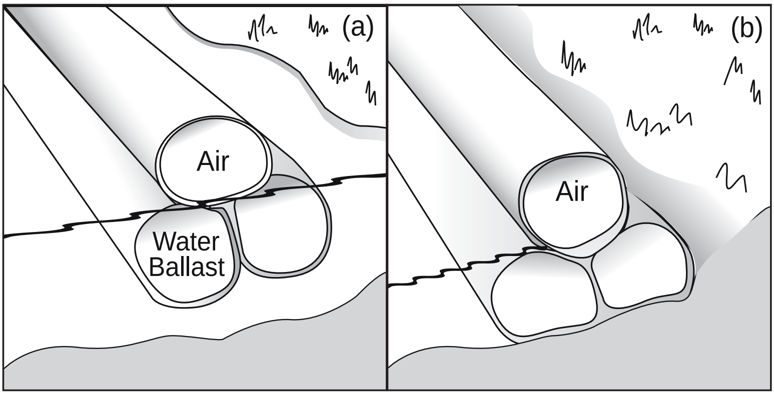

Figure 3.9 **Shore-seal boom is deployed at the shore-water interface, where water levels are expected to change (a) afloat and (b) aground.**

In cold temperatures, the water in the ballast chamber may freeze so that the ability to contour the shore zone is lost with the loss of flexibility of the seal.

The effectiveness of shore-seal boom is limited by current speed and the slope of the shoreline and by the accumulation or presence of floating debris and ice. Boom effectiveness decreases as the slope of the shore zone increases.

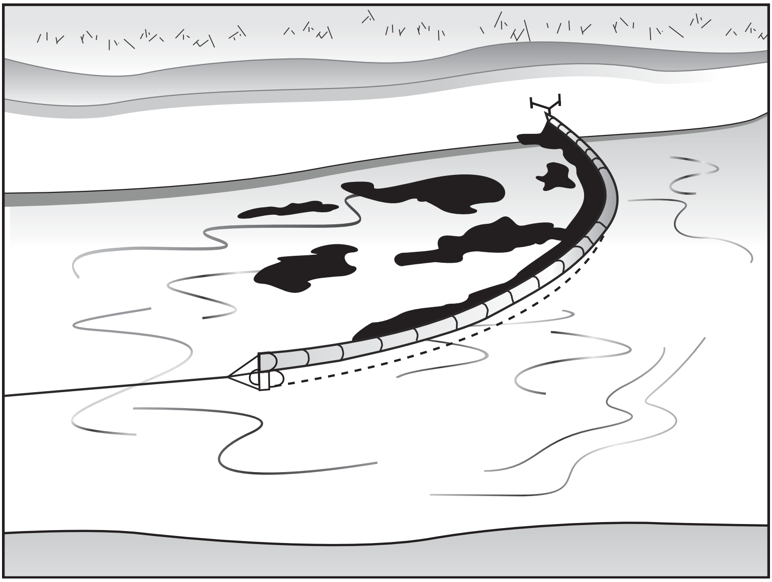

Figure 3.10 **A shore-seal boom can be deployed across the intertidal zone to prevent alongshore movement of oil and/or redirect and contain against the shoreline.**

Figure 3.11 **Oil is contained on or against the shoreline by use of boom.**

3.7 ONSHORE CONTAINMENT BY BARRIERS, BERMS, SORBENTS, OR SUMPS

Objective

Berms, sorbents, and sumps are used to contain oil on a beach for recovery as it comes ashore, to prevent remobilization of stranded oil, or to prevent waves from over-washing a beach and carrying oil into backshore areas.

Description

- **Berms** can be constructed on a beach parallel to the waterline to contain oil, with or without a ditch or trench to collect oil as it is washed ashore. This is shown Figures 3.12 and 3.13. If oil has stranded when water levels are high, i.e., during spring tides, a berm can be constructed near the lower limit of the oil to prevent the oil from being remobilized by wave action before cleanup can take place.
- **Ditches, trenches**, or **sumps** can collect oil as it is washed ashore for recovery by skimmers or other physical removal techniques. If oil has stranded when water levels are high, i.e., during spring tides, a ditch can be constructed near the lower limit of the oil to prevent the oil from being remobilized by wave action before cleanup can take place.
- **Sorbents** can be placed on a shore in the intertidal zone or near the high-water level to collect oil as it is washed ashore.
- **Barriers** or **dams** can be built across overwash channels to prevent oil from being carried by waves over a beach into a backshore lagoon or marsh as shown in Figure 3.14.

These protection barriers or collection systems are usually constructed using conventional earth-moving equipment, such as graders, front-end loaders, bulldozers, or backhoes.

Applications

Berms or barriers can prevent oil from stranding on the upper beach or being carried over a beach onto backshore areas. The berm or barrier should be constructed at or near the predicted upper high-tide level to catch oil as it is carried up a beach by breaking waves. Berms and barriers are particularly appropriate when low overwash channels provide an unobstructed pathway for waves to carry oil into sheltered backshore lagoons or marshes (Figure 3.14).

Earth-moving equipment can construct berms or ditches along long sections of beach in a short time. These may remain unmaintained for some time if constructed above the highest tide levels.

Oil that is collected in ditches, trenches, or sumps is easier to recover than oiled beach sediments. If recovered, this oil will not be remobilized or re-oil adjacent or down-drift shorelines.

If cleanup cannot take place before the stranded oil is remobilized, berms or ditches can be constructed near the lower limit of the oil, provided they would not be destroyed by wave action.

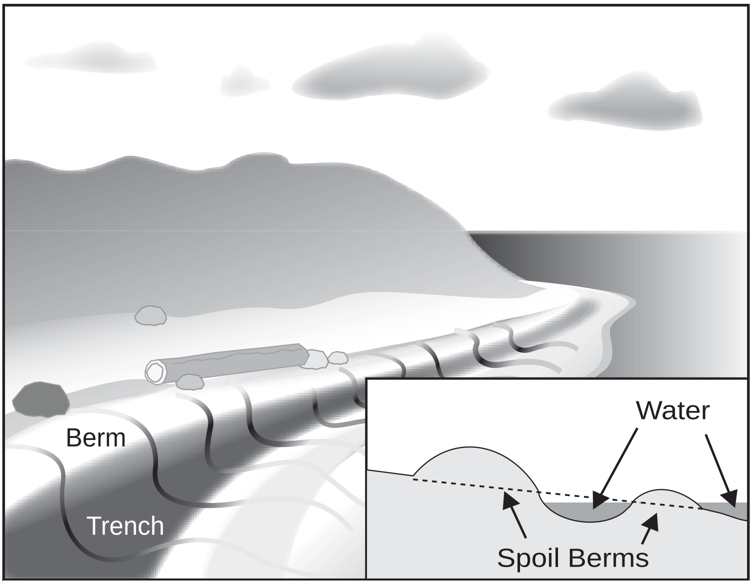

Figure 3.12 Beach Berm and Trench Parallel to the Shoreline

Constraints and Limitations

The feasibility and effectiveness of berms are limited by the size of the area to be protected and the time available to deploy equipment or to construct berms.

The berm should be at or above the anticipated highest tide level. If the barrier or berm is constructed too far down the beach face, then the effectiveness is compromised by breaking waves which may go over the berm. If it is located in an overwash channel that would be overtopped by high tide levels (Figure 3.14), it may be necessary to construct the berm or dam using sand bags or other more durable materials.

Berms or dams are more easily constructed on sand beaches that have an appropriate weight-bearing capacity for the required equipment. The ability of the equipment to operate is limited by the steep beach slopes and pebble/cobble size sediments found on other types of beaches.

Sorbents put on a shore and kept in place by stakes or other anchoring devices may require frequent change-outs. This tactic is typically labour-intensive and can generate a large volume of oily waste materials.

Depending on the character of the stranded oil and the sediment size, the trench or sump should be lined to prevent oil penetration into the sediments. Only weathered, viscous oils on fine-grained (sand) beaches will not penetrate. Lining also prevents swash action from mixing oil and sediment.

Figure 3.13 Digging a Collection Trench on a Sand Beach

Figure 3.14 Low Overwash Channel on a Sand Barrier Beach with a Lagoon in the Backshore

3.8 ONSHORE EXCLUSION BY CONTACT BARRIER

Objective

Specific vulnerable resources or small sections of shoreline can be protected from contact with oil by using a chemical or water barrier, or a physical barrier or cover placed over the shoreline.

Description

This tactic includes a number of options or techniques.

- **Flooding** (deluge) or **low-pressure washing** hoses are used to form a water barrier and simultaneously move oil away from the shoreline. These techniques are described in Sections 5.3.1, 5.3.2, and 5.3.3. This hydraulic approach keeps the shore wet when it would otherwise be dry and raises the water table in a beach to reduce the amount of oil that can penetrate the sediments. As oil is washed ashore, the water barrier prevents the oil from contacting the shore-zone materials and the down-slope water movement carries the oil towards the water line where it can be contained and recovered.
- A physical barrier, such as plastic sheeting, geotextile, or sorbent material, can prevent contact and protect underlying materials as shown in Figure 3.15. Generally, the barrier material is staked or held down by sandbags, cobbles, or other weights.
- Chemicals are applied to either a natural shoreline or manmade shoreline structures to form either a contact barrier or a surface that reduces the adhesion of oil. Shoreline cleaning agents, conventionally used to remove oil already stranded on the shoreline, are also used as an adhesion-inhibitor. These are decribed in Section 5.6.2.

Applications

The impact of this protection tactic is usually low, provided that the operational activities themselves do not affect the organisms or resources that are being protected.

Water or hydraulic barriers use pumps and hoses with a header placed above the high tide level. Nearshore and/or shore-seal booms can be used to contain the oil for recovery (see Section 3.6).

Physical barriers, such as plastic sheeting, rolls of sorbent materials, or other fabrics (usually called geotextiles), have been used on several spills. In these cases, extensive shoreline cleanup operations were prevented by the timely deployment of protective materials. This type of physical barrier is primarily used for riprap, harbours, docks, wharves, crib work, or other manmade structures where oil would likely be difficult to access or remove.

Figure 3.15 Contact Barrier Deployed Along a Permeable Manmade (Riprap) Shoreline

Many of these types of permeable structures act as reservoirs for the oil to slowly leach out if the shoreline is not protected or cleaned. This type of barrier also successfully prevents oil from coating the shore where logs, debris, or vegetation may be present. It is a slow and difficult process to clean up large oiled logs, particularly in remote areas.

When used as a pre-oiling protection tactic, chemical **dispersants** or **shoreline cleaning agents** are more effective for light and some medium types of oils. An advantage of this technique is that the agents dissolve in water and therefore do not require removal. This could be a disadvantage, however, as multiple applications may be necessary if the oil is still a threat after several tidal cycles. Due to concerns about using chemicals, this tactic is more appropriate for manmade structures such as piers and seawalls.

Constraints and Limitations

Flooding or water barriers involve the use of pumps and hoses that could require regular or continuous maintenance. This operation may have to be maintained for several days while oil is moving onto a shoreline.

The primary constraints for physical barriers are the time and resources required to cover long sections of coast. High winds and strong wave action could make deployment and maintenance difficult. Plastic sheeting can tear easily, whereas geotextiles are more resistant and sturdier.

Geotextile barriers have been deployed on open coasts where wave heights were up to 0.5 m and maintained a continuous protective barrier in areas with tidal ranges up to 5 m. Physical barriers are most suited to harbours and other manmade shorelines. It might not be practical to cover wide intertidal areas, except in very sheltered waters.

3.9 CHANNEL EXCLUSION BY BOOMS, BARRIERS, OR DAMS

Figure 3.16 Exclusion Boom Deployed Across a Channel

Objective

Oil is prevented from coming into contact with a specific section of shoreline or a vulnerable resource at risk by deploying a boom or constructing a barrier or dam in a small inlet, stream channel, canal, or ditch.

Description

This tactic includes the following options.

- **Booms** or **filter barriers** are deployed to contain oil on the water surface. These allow water to pass normally through the channel while preventing the movement of oil on the surface. Conventional booms or shore-seal booms can be anchored across the channel (Figure 3.16) or at an angle if required by the speed of the current flow (Figure 3.6). Barriers can be fabricated from available materials, such as fencing or nets, combined with sorbent materials as shown in Figure 3.17. Barriers in tidal channels should be designed to allow for the rise and fall of the water level and for current reversal.

Figure 3.17 Channel Barrier – Silt Screens

- **Dams** can be built using available materials, such as fill, planks, or sandbags. To avoid disrupting the local ecology, water flow should usually be maintained, particularly in streams and tidal environments. Single or multiple culverts, pipes, and siphons should be designed based on the lowest anticipated water level, flow volumes, and the potential for oil to build up against the dam and become entrained with the water passing through the pipe system. An earth dam with multiple siphon pipes is shown in Figures 3.18 and 3.19. Dams can be constructed quickly using earth-moving equipment, such as front-end loaders or bulldozers.
- **Bubble barriers** prevent oil from entering channels, such as sea water intakes or loading berths. Bubble barriers are fixed pipes laid on the channel bed and may be several hundred metres long.

Applications

Booms, filter barriers, dams, and bubble barriers prevent oil from entering backshore or backwater areas through narrow or small inlets, stream channels, canals, or ditches. This concept has also been used on a larger scale, for example, constructing a dam in a 500-m wide and 20-m deep tidal passage.

When necessary, water flow can be maintained using underwater pipes or underflow techniques. Examples of this are shown in Figures 3.18, 3.19, and 3.20. Allowance must be made for the reversals of current direction in tidal channels. This can be achieved by placing filter barriers made of sorbent material between two lines of staked wire or fencing as shown in Figure 3.17.

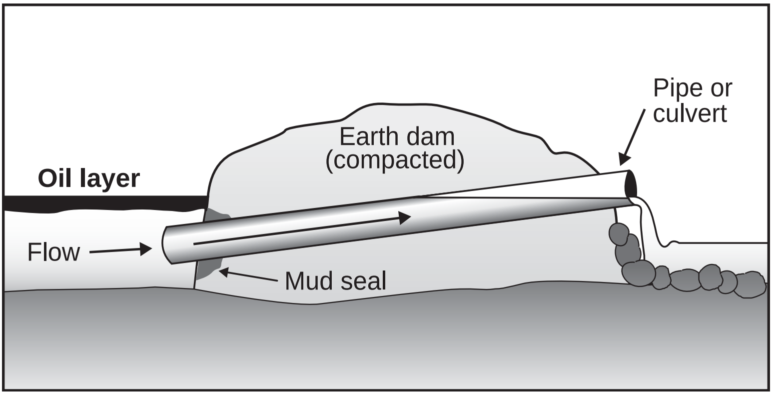

Figure 3.18 Channel Barrier – Underflow Dam

Constraints and Limitations

Selecting and designing practical and effective methods for excluding oil from channels are usually based on the width and depth of the channel and the water velocity. In areas where river or tidal flow is not an issue, blocking a channel, canal, or ditch without culverts or pipes can result in ponding from the backup of rainfall. Allowance should therefore be made for possible flooding.

The deployment and effectiveness of barriers and booms are limited by current speed, although well designed filter barriers are generally more effective in higher velocity currents than conventional booms. The effectiveness of booms or berms may be limited by breaking waves in the nearshore zone and by the accumulation or presence of floating debris and ice.

The effectiveness of this approach can be limited by the time available to deploy equipment or to construct dams or barriers.

Two or more barriers are often required as a single barrier may not be enough to exclude all the oil.

Exclusion booms or barriers may prevent oil from contacting the shoreline at one location but, without recovery of the oil, may result in contact at another location, where it presumably will have less impact, i.e., a less sensitive location.

Figure 3.19 Earth Dam with Multiple Siphon Pipes

Figure 3.20 Channel Barrier – Sand Bags, Wood, and Underflow Pipes

3.10 SHORELINE PROTECTION STRATEGIES FOR SPECIFIC TIDAL ENVIRONMENTS

Estuaries, deltas, and tidal inlets are similar coastal environments characterized by a combination of tidal flow and/or river or tidal channels. These are critical factors when developing on-water strategies for shoreline protection.

3.10.1 ESTUARIES

Estuaries are partially enclosed bodies of water in which fresh river waters mix with marine salt waters. Estuaries are a transition zone in which the salinity and water level are constantly changing as a result of tidal action. Estuaries are typically sheltered from open ocean waves and currents.

Estuaries are categorized on the basis of their dominant water circulation patterns.

- In a salt wedge estuary, the river outflow (freshwater) exceeds the marine input (saltwater). There is little mixing and a distinct density front is created at the surface where the fresh and salt water converge (Figure 3.21). As shown in Figure 3.22, this front creates a dynamic physical barrier that oil cannot cross. Such a front controls the transport of surface oil in estuaries. The location of a density front changes with the tides.
- In a stratified or vertically mixed estuary, density fronts are less important as the river output is less and turbulence induces more mixing.

River discharge varies seasonally. In winter, runoff and flow may be lower or even absent. With the onset of thaw in the upstream drainage basin, a period of high peak flow often coincides with the breakup of the river ice. Discharge then decreases through the summer.

Estuaries are typically very productive ecosystems and often include salt marshes and tidal flats that are priority protection areas. An on-water recovery protection strategy in an estuary is primarily an open-water operation that would be carried out by offshore recovery teams, rather than shoreline protection or shoreline cleanup teams.

On-water recovery can take advantage of the natural barriers created by density fronts where surface oil typically concentrates. Protection could involve the use of redirection boom, exclusion boom, or tidal channel barrier strategies deployed and maintained in areas with reversing tidal currents.

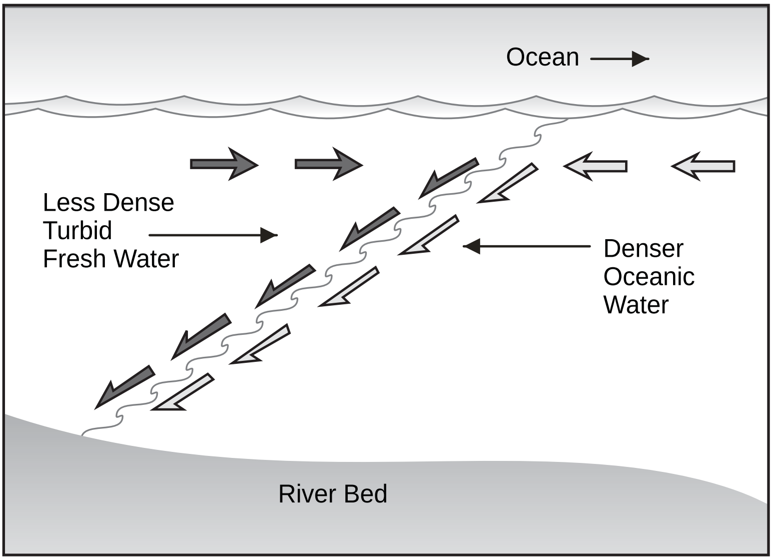

Figure 3.21 **A density front is created where sea water and fresh (low salinity) water converge. Arrows indicate direction of flow.**

photo credit: Elliott Taylor

Figure 3.22 **Oil is trapped at the density front. The turbid brackish water (left) is lighter in colour.**

3.10.2 DELTAS

Deltas are created by the accumulation of sediments at river mouths. They are dominated by freshwater outflow into the ocean and form at the coast where river flow slows down and can no longer transport all the sediments that are carried downriver.

Large deltas, such as the Fraser or Mackenzie River deltas, have multiple distributory channels and are navigable waterways. In such large deltas, the lower reaches of the river channels are typically tidal and therefore have the characteristics of an estuary.

Small deltas are common everywhere and form when waves or currents are unable to redistribute the sediment load offshore or alongshore and it is carried to the shoreline. Small deltas are particularly common in low wave-energy environments at the heads of bays and fjords.

The key factor to consider for developing a response strategy for an oil spill near a delta is that oil may enter the lower sections of the river channels with a flooding tide. This oil would eventually meet the seaward-moving fresh river water, generally at a density front as shown in Figure 3.22.

The following factors must be considered when dealing with a spill in the lower reaches of a river.

- Oil is moved downstream by unidirectional flow but reversal or upstream flow can occur in the lower sections of the channels when tides or a storm surge (meteorological tide) force water upstream.
- The oil/water flow is contained within individual channels except during the relatively short period of peak runoff.
- River banks and adjacent delta flats are usually water-saturated so that often oil will not readily stick to the sediments at the edges of the channels. If the sediments are well-sorted pebbles and cobbles, however, oil can easily and quickly fill the pore spaces between these sediment particles.
- The channels usually widen towards the river mouth so that current velocities slow down. It should therefore be easier to deploy deflection and diversion booms in these lower reaches of the river channels than farther upstream where the currents are stronger due to the more constricted flow.

- River discharge varies seasonally. Flow in winter may be very low or even absent. There is a period of high peak flow when the channel and upstream drainage basin begin to thaw that often coincides with breakup of the river ice. Discharge then decreases throughout the summer.
- Oil that is carried to the sea from a river spill is often contained within the density fronts that are common at the mouths of delta channels where the fresh river water converges with the denser saline ocean water. This natural, dynamic barrier may contain the oil and prevent it from spreading alongshore onto the adjacent marine shorelines.

Examples of possible dam barriers for use in channels are given in Section 3.9.

Examples of booming strategies for river and delta channels are shown in Figure 3.23.

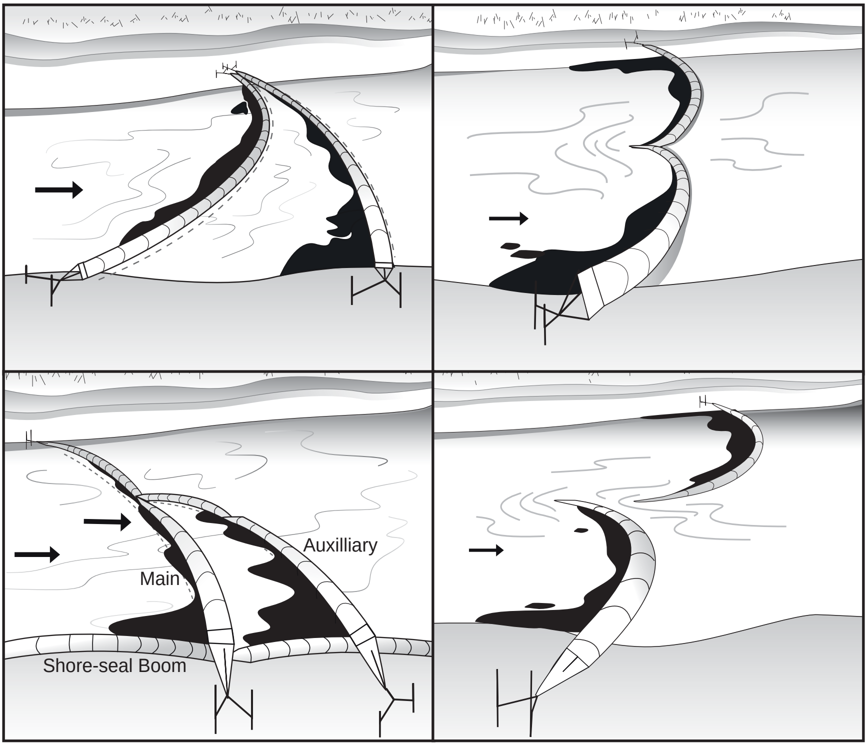

Figure 3.23 Channel Boom Deployment Strategies

3.10.3 TIDAL INLETS

Tidal inlets occur where water from a backshore lagoon or bay passes through a relatively narrow opening to the open sea. If the entrance to the lagoon or bay is wide, as in the case of most estuaries, the ebb and flow of the tide is physically unrestricted. Where a spit or barrier beach has grown across an embayment or estuary, however, a narrow opening or inlet is created through which the tidal waters must pass as they ebb and flow.

Physical Character

Inlets usually form on coasts when sediments build up and form a spit or barrier beach across a bay or estuary which changes the shape of the shoreline, as shown in Figure 3.24. Sediments are also redistributed in the nearshore areas adjacent to the inlet to form shoals and shallow areas that usually have a distinctive and recognizable pattern.

Due to the constricting effect of the inlet on the tide, current speeds are greatest in the narrowest part of the throat of the inlet. Sediments that are carried through the throat of the inlet by the ebbing or flooding tides are deposited as the current slows down after passing through the throat. This results in the formation of shoals or underwater deltas on either side of the inlet throat, as shown in Figure 3.25.

The ebb-tidal delta that is created on the ocean side of the inlet is usually entirely underwater, even at low tide, as these sediments are also reworked by wave action. This reworking by waves gives a typical rounded character to the outer part of the ebb delta. This is shown as the "swash platform" in Figure 3.25.

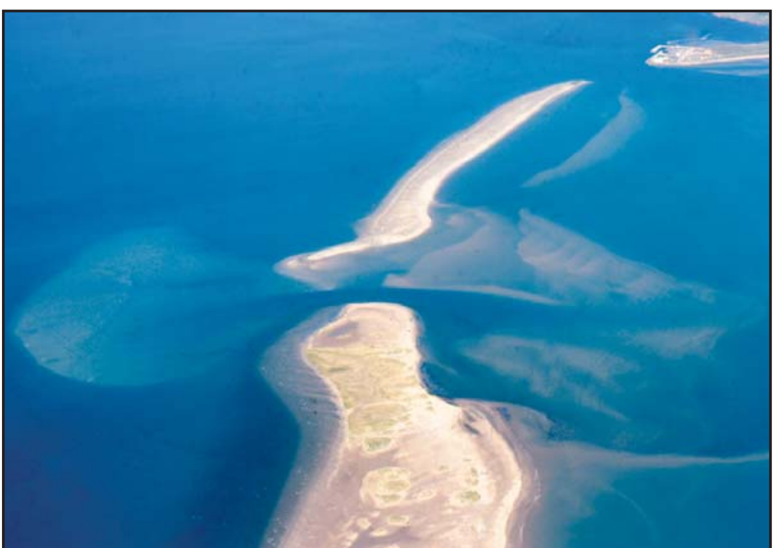

Figure 3.24 Aerial View of Tidal Inlets – Open Ocean to the Right

The flood-tidal delta that is created on the lagoon or bay side of the inlet is usually completely underwater at high tide, but largely exposed at low tide.

Not all inlets appear exactly as shown in Figure 3.25. On coasts with a dominant longshore drift of sediment in one direction, there may be barrier beaches that overlap in the inlet, creating a tidal inlet channel parallel to the coast. The same features of the tidal inlet are recognizable, although the deltas likely would be strongly skewed in the direction of the drift.

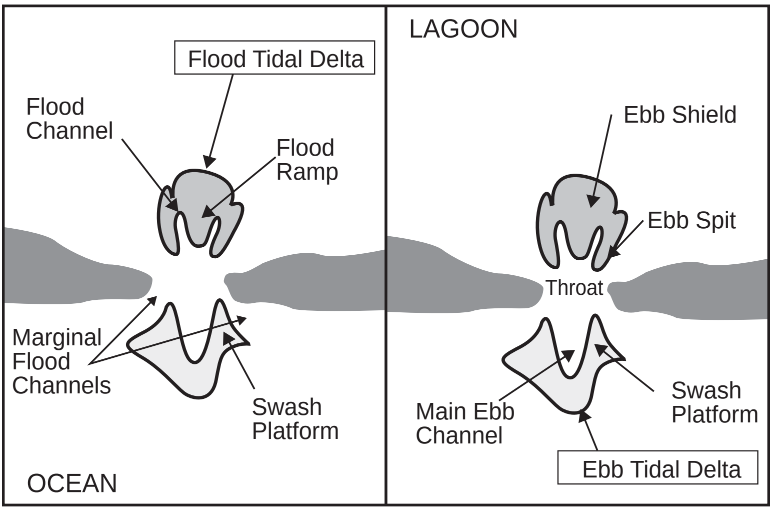

Figure 3.25 Features of Tidal Inlets

Tidal Currents

The pattern of tidal currents is partially controlled by the shape and character of the channels and shoals of the ebb and flood deltas. These effects are more important during the lower half of the tidal cycle when parts of the deltas are exposed or very shallow.

Current patterns at an inlet are controlled by the varying water depths and the outflow from the bay or lagoon. At the low-water slack, as the tide is turning from ebb to flood, the water in the lagoon or back bay often continues to drain out. If a large volume of water is entering the bay from rivers or if the narrowness of the inlet throat does not allow all the water to empty out of the bay in the available time, then this drainage continues after the tide has turned. If the bay cannot drain within the ebb time period, the water level on the bay side of the inlet is still higher than the water level on the ocean side during the early flood-tide stage.

The length of time that the ebb drainage encroaches into the flood tidal cycle is controlled by the amount of water that must drain through the inlet, combined with the narrowness of the throat of the inlet. The volume of water draining out of the inlet is a function of (a) the area and depth of the bay or lagoon, (b) the tidal range, and (c) the amount of river input.

If the amount of drainage is small or the inlet is wide, the drainage may not significantly affect the incoming flood tide. If the bay is not fully drained by the end of the slack period of low tide, the rising water level on the ocean side pushes the flood tide into the inlet. The ebb continues to run through the centre of the throat and the main ebb channel, draining the bay for as much as 1 or 2 hours while the flood attempts to enter the throat by one or both marginal flood channels. This is shown in Figure 3.26. This current pattern continues until the water levels in the bay and the ocean are equal, at which point the ebb drainage ceases and the flood tide is able to enter the inlet unimpeded.

The pattern of the currents through the tidal cycle can be summarized as a sequence of stages in which there is a distinct change in location, direction, or water movement.

- **Stage 1: Low Tide to Early Flood Tide**

  In the absence of an outflow from the bay through the inlet, the currents would normally be slack during the turn from the ebb to the flood tide. In reality, however, during this period of ebb drainage after the turn of the tide, there is a strong seaward flow (often referred to as a "tidal jet") in the central inlet throat and in the main ebb channel.

  At the same time, there is a landward flow toward and into the throat of the inlet in one or both of the marginal flood channels. At this tide stage when the water level is still relatively low, the main body of the flood delta (the flood ramp and the ebb shield in Figure 3.26) is exposed so that both the ebb drainage and the flooding currents must use channels on either side of the delta.

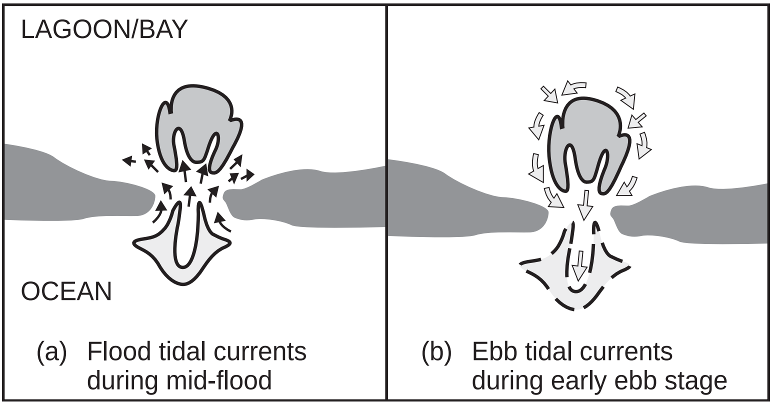

Figure 3.26 Tidal Inlets – Mid-flood and Early Ebb Currents

- **Stage 2: Mid-flood Tide to High Tide**

  After the ebb drainage finishes, when the water levels are the same on both sides of the inlet, there are only flood currents in the inlet system. The currents are initially confined to the channels on the margins of the flood-tidal delta and the maximum flood current speeds usually occur after mid-tide when the flow is still restricted by the flood tidal delta. This is shown in Figure 3.26(b). As the water level rises, the flood tidal delta is progressively submerged until water can flow completely across the entire delta, at which time the current is less restricted and the speed is slower.

- **Stage 3: Early to Mid-ebb Tide**

  As the tide turns, the tidal currents are initially slack for a period of several hours and then they reverse direction. If there is river drainage into the bay or lagoon, the currents flow seaward as these waters drain though the bay. The flood-tidal delta is submerged at this stage. The currents are strongest in the inlet throat (the "tidal jet"). This is shown in Figure 3.26(b).

- **Stage 4: Mid-ebb to Low Tide**

  As the water level falls, the flood tidal delta is progressively exposed until water can flow around the margins of the flood tidal delta only during the late-ebb stage. The speeds of the ebb currents usually increase as the tide falls and reach a maximum just before low tide as the outflowing waters become more and more restricted in the channels.

Response Strategies for Tidal Inlets

If the objective of a response is to prevent oil from entering or exiting a lagoon or bay through a tidal inlet, the feasibility of a protection strategy is affected by current speed, current direction, and water depth. Inlets are very dynamic environments in which all three of these variables change continuously.

The following must be considered when developing a practical strategy.

- Response actions will likely be least successful in the throat of the inlet as currents are always faster in this location.
- Current conditions and water depths change continually and quickly, usually within a matter of hours.
- For oil located in a bay:
  - redirection and/or recovery of oil during an ebbing tide is more likely to be successful on the bay side of an inlet as a confused sea often develops on the ocean side where waves and tidal currents interact;
  - ebb currents are likely to be strongest in a bay during the last hours before low tide.
- On the ocean side:
  - oil would be transported into the inlet near the shore in one or both of the marginal flood channels only during the initial stage of a flooding tide;
  - during a flood tide, after the ebb drainage ceases, redirection and/or recovery of oil is more likely to be successful on the bay side of an inlet where the waters are sheltered from wave action;
  - after the ebb drainage ceases, the flood tide would carry oil in the channels around the flood tidal delta;
  - flood currents are likely to be strongest during the 2-hour period after mid-tide.

Based on this knowledge, some possible strategies for redirection and recovery using nearshore (on-water) and shoreline booming tactics are shown in Figure 3.27.

- During Stage 1 – early flood, oil could be (a) redirected in marginal flood channels towards the shore for recovery or (b) away from the shore towards open water to bypass the inlet. In Figure 3.27, as the longshore drift is from the right, the strategy shown would be for oil being transported towards the inlet from this direction.
- By Stage 2, the focus likely shifts to a strategy of redirection towards the sheltered beaches on the backside of the barrier by deploying cascading booms in the channels in the lagoon.
- With the onset of the ebb (Stage 3), oil could be redirected away from the inlet throat, in the area of the shallow but submerged ebb shield and towards the back-barrier beaches.
- As the water level lowers with the tide, booming is feasible only in the channels (Stage 4).

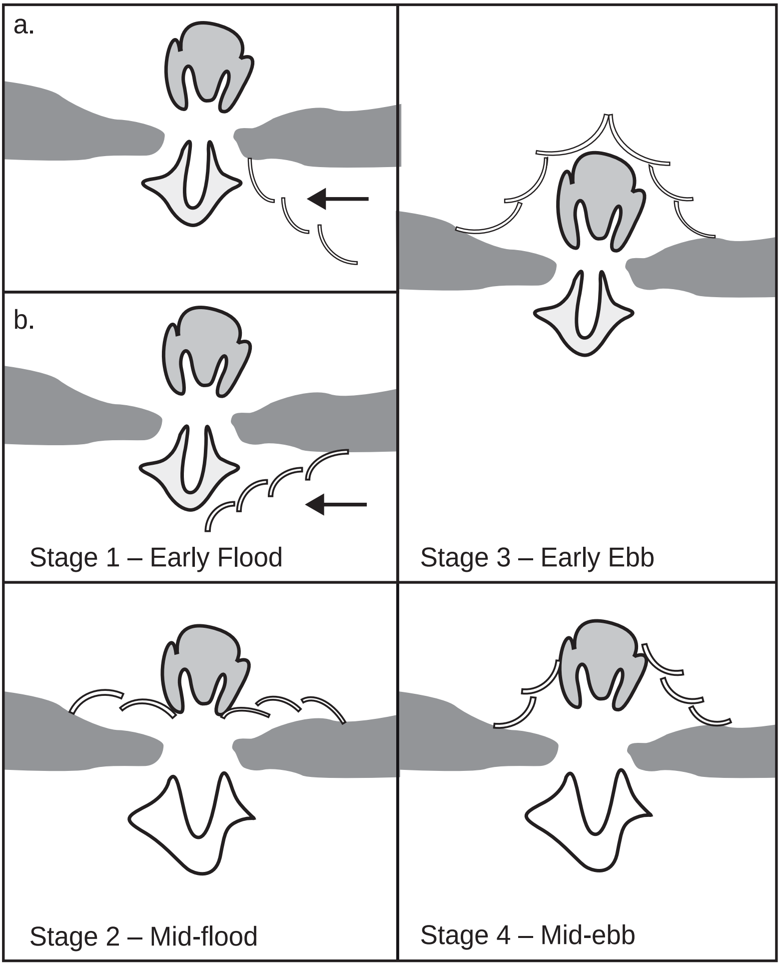

Figure 3.27 Tidal Inlets – Booming Strategies

4. Treatment Tactics for Different Types of Shoreline

4.1 INTRODUCTION

This section provides guidelines for selecting and applying appropriate response and treatment options for the basic types of shoreline along the marine coasts of Canada.

The types of shorelines referred to in this field guide follow the Environment Canada shoreline classification system used for both the Shoreline Cleanup and Assessment Technique (SCAT) and environmental emergency mapping (Sergy, 2008). These shoreline types and the sections in which they are discussed are listed in Table 4.1. On a more general level, regional shoreline characteristics of the coasts of Canada are described in Owens (1994).

Environment Canada's classification system is based primarily on a combination of the morphology and substrate character of the shoreline. In most cases, substrate is defined by the grain size (diameter) of the sediment.

Boulder	> 256 mm	Granule	2 to 4 mm
Cobble	64 to 256 mm	Sand	0.06 to 2 mm
Pebble	4 to 64 mm	Mud/Silt/Clay	< 0.06 mm

For comparison, 4 mm is about the width of a pencil, 64 mm is approximately the size of a tennis ball, and 256 mm is a little larger than a soccer ball (225 mm).

Flats, beaches, cliffs, platforms, and ramps are morphological characteristics of the shoreline type, with the differences based primarily on slope. Flats are almost level, less than 5°. Beaches vary from 5° to >35° but are most often in the lower half of that range. Cliffs range from very steep (35°) to vertical and platforms and ramps typically range from 5° to 35°.

Each of the sixteen types of shorelines are discussed in Sections 4.2 to 4.17 under the following headings.

- Definition
- Character
- Behaviour of Oil
- Sensitivity
- Summary of Tactics
- Precautions

Tactics are described in terms of those "preferred" or "possibly applicable for small amounts of oil" and for both surface oiling conditions and subsurface oiling conditions when this is appropriate. Use of the term 'preferred' means that those tactics are generally considered appropriate and are a practical option in comparison to other tactics. Appropriate is based on factors such as net environmental benefit, operational resources, efficiency, safety and waste generation. The actual determination of whether a tactic is appropriate is case-specific and conducted when planners evaluate the operational feasibility of proposed treatment strategies and tactics (see Figure 2.2)

Specific definitions of subsurface oil for different permeable substrate materials are provided in Owens and Sergy (2004a).

High tidal ranges and remote sites significantly influence the response strategies and treatment tactics selected for use. The same types of shoreline are found in either of these conditions. The adaptations that are required to deal with these conditions are discussed in Section 4.18.

Submerged and sunken oil in nearshore environments are discussed in Section 4.19 as these may be included within shoreline cleanup operations.

Table 4.1 Marine Shoreline Types

Section and Title		Environment Canada Shoreline Types
4.2	Bedrock Shoreline	Bedrock – Cliff/Vertical
		Bedrock – Sloping/Ramp
		Bedrock – Platform
4.3	Glacial and Solid Ice Shoreline	Glacier/Ice Shelf
		Seasonal Ice*
4.4	Solid Manmade Shoreline	Solid Manmade
4.5	Permeable Manmade Shoreline	Permeable Manmade
4.6	Sand Beach	Sand Beach
4.7	Mixed Sediment Beach	Mixed Sediment Beach
4.8	Pebble/Cobble Beach	Pebble/Cobble Beach
4.9	Boulder Beach	Boulder Beach
4.10	Mud Flat	Mud Flat
4.11	Sand Flat	Sand Flat
4.12	Mixed and Coarse Sediment Flat	Mixed Sediment Flat
		Pebble/Cobble/Boulder Flat
4.13	Marine Wetland – Salt Marsh	Wetland
4.14	Peat Shoreline	Peat Shoreline
4.15	Tundra Cliff Shoreline	Tundra Cliff – Ice-rich
		Tundra Cliff – Ice-poor
4.16	Inundated Low-lying Tundra Shoreline	Inundated Low-lying Tundra
4.17	Snow-covered Shoreline	Snow*

* Snow is included as a discrete type of shoreline although it is only applicable seasonally. Other winter ice shorelines (Ice Foot, Frozen Swash, Frozen Spray/Splash, and Grounded Ice Floes) are included in Section 4.3.

4.2 BEDROCK SHORELINE

Definition

Bedrock shorelines consist of impermeable outcrops of consolidated native rock.

Subtypes

Bedrock shorelines include cliffs, ramps, terraces, and platforms.

- **Bedrock cliffs** are sloped faces >35° with notches, caves, sea arches, and sea stacks created by erosion in some areas. A bedrock cliff is shown in Figure 4.1.
- **Bedrock ramps** are inclined slopes ranging from >5° to <35°.
- **Platforms** are almost horizontal, with an overall slope of <5°. Bedrock shorelines with ramps and horizontal platforms are shown in Figures 4.2 and 4.3.
- **Terraces** are characterized by step-like ramps or platforms.

Character

- Resistant bedrock outcrops, such as granites, are stable whereas non-resistant types of bedrock, such as the sandstone of Prince Edward Island, are easily abraded by waves and ice action. The surface may erode at rates of up to several centimetres a year.
- The surface can be irregular with numerous cracks, crevices, joints, and depressions.
- Sediment veneers may overlay bedrock platforms but the platforms are usually patchy and range from sand to boulders.
- Exposed or high wave-energy and sheltered lower wave-energy bedrock shorelines differ in terms of the character of the intertidal biological communities they support.
- Bedrock shorelines have a stable surface on which a zonation of plants and animals is common in the intertidal zone. Biological communities are usually more prolific in the subtidal or lower intertidal zones.
- On coasts where ice is common, there are few attached intertidal organisms due to the reduced growing season and ice abrasion. This is particularly true on exposed bedrock shorelines with steep slopes. As the biological community is usually scraped off the bedrock by ice every year, plants and animals survive only in cracks and crevices where they are protected.

Figure 4.1 Bedrock Cliff

Figure 4.2 Bedrock Ramp

Figure 4.3 Bedrock Platforms

Behaviour of Oil

- As bedrock is impermeable, stranded oil remains on the surface of the outcrop.
- Oil may pool in depressions on bedrock platforms, terraces, or ramps.
- Oil that collects in cracks and crevices may not be physically removed by wave and ice action.
- Oil is more likely to be deposited in the upper half of the intertidal zone. The lower tidal zones usually remain wet during low tidal water levels and have a biofilm that prevents adhesion of the oil.
- Oil often does not strand on exposed coasts due to wave reflection. If stranded, the oil may be rapidly washed off by wave action, i.e., in days to weeks.
- On exposed coasts, oil may be splashed above the limit of normal wave action.
- Oil that comes ashore in sheltered locations is likely to be deposited as a band on the upper intertidal zone near the last high-water level.
- Heavy oils or weathered crude oils can persist for months to years in sheltered locations as there is insufficient wave energy to remove them naturally.
- Even in sheltered locations, light oils are likely to be washed off a bedrock surface in a short time, i.e., in days to weeks.

Sensitivity

- On exposed coasts, plants and animals often inhabit cracks and crevices where they are protected from wave or ice action. These are the same locations where oil might be deposited and persist.
- On sheltered bedrock shorelines, sensitivity to oil can be high due to the combination of potential oil persistence and rich biological communities.
- Sensitivity varies with the intertidal zonation. Whereas oil is more likely to be deposited in the drier upper half of the intertidal zone, biological communities are typically more prolific in the lower intertidal zone.
- The lower half of intertidal bedrock outcrops usually stays wet, even when exposed, and has a biofilm so that oil often does not adhere to the bedrock surface or to plants.
  - Viscous or weathered oils can smother organisms in this zone but would otherwise have less impact than light products or fresh crudes on biological communities present in the lower intertidal zone.
  - Light products or fresh crude oils stranded in the upper half of the intertidal zone could flow downslope with a falling tide and affect biological communities in the lower tidal zones due to the higher concentrations of harmful components found in these types of oil.
- Overall, ice-scoured bedrock outcrops do not have extensive, diverse, or rich biological communities.
- Biological communities are more likely to be affected by large amounts of oil than by small oil concentrations and by light refined oils, such as diesel, than by heavy oil products (bunker fuels) or weathered crudes.

Summary of Tactics

Tactics for responding to oil on a bedrock shoreline are summarized in Table 4.2.

Preferred Response Options – Surface Oil

- **Natural recovery** is the preferred option on exposed high wave-energy coasts, particularly early in the open-water season. This option is less appropriate for heavy oils or weathered crude oils on a sheltered coast where the oil is likely to persist longer. Natural recovery may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- Natural recovery may be appropriate for volatile oils such as gasoline due to safety concerns caused by fumes, ignition, and flashback. If necessary, light or volatile oils can be removed using low-pressure, ambient-water washing, preferably carried out from a safe distance away.
- **Flooding** is appropriate for light or medium oils, but is of little practical value for very viscous or heavy oils.

Table 4.2 Summary of Tactics for Bedrock Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■	▪	▪
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■	▪	
Low-pressure warm/hot washing			■	■	■
High-pressure ambient washing			■	■	■
Manual removal		▪	▪	▪	▪
Vacuums		■	■	▪	
Vegetation cutting		▪	▪	▪	▪
Passive sorbents		▪	▪	▪	
Dispersants		■	■		
Shoreline cleaners		■	■		
Bioremediation		▪	▪		

■ Preferred option ▪ Possibly applicable for small amounts of oil

- **Physical washing** can be practical and efficient for removing oil from bedrock surfaces.
  - **Low-pressure, ambient-water washing** of light and some medium oils can minimize ecological impacts (see precautions below). If the water is deep enough, washing from a boat or barge prevents shore-zone organisms from being trampled. Removed oil should be contained and collected by booms and **sorbents** or skimmers.
  - **High-pressure, ambient-water washing** and **low-pressure, warm/hot water washing** can be useful for more viscous oils that cannot be removed by low-pressure, ambient-water washing.
- **Physical abrasion** of sedimentary bedrock may be used to accelerate erosion and sloughing off of the surface layer.
- **Manual removal** of all but volatile oils is recommended for small amounts of oil, but foot traffic should be controlled to minimize damage to organisms and habitats.

- Small amounts of oiled vegetation may be removed by **manual cutting**.
- **Hand-deployed vacuum systems** are effective for removing light oils such as diesel or medium/heavy oils collected in tidal pools and hollows. Foot traffic should be controlled to minimize damage to organisms and habitats. For safety reasons, this technique cannot be used to remove gasoline.
- **Sorbents** can be deployed to passively collect small amounts of light to heavy oils. Foot traffic should be controlled to minimize damage to organisms and habitats.
- **Dispersants** can be used on a flooding tide on those types of oil for which the product is designed, commonly light or medium oils. Dispersants can be effective for small amounts of oil if applied correctly.
- **Bioremediation** may be effective to remove oil residue and for bulk oil removal.

Typical Combinations of Response Tactics

- Oiled debris is removed manually, followed by manual removal using hand tools, vacuum, or sorbents in tidal pools.
- Flooding and ambient low-pressure washing are used along with collection and recovery.
- Shoreline cleaners are used with flooding and/or ambient low-pressure washing, followed by oil collection and recovery.

Precautions

- On steep bedrock outcrops, be very careful not to slip or fall, particularly on exposed shorelines (open coasts) where there is strong wave action or ice.
- In areas with plants (seaweeds) and animals (barnacles, mussels, etc.) in the shore zone, avoid washing oil from the upper to lower intertidal zones. The lower intertidal zones are often not oiled and cleanup can cause more damage if oil is washed downslope or if foot traffic leads to trampling. Avoid this potential damage by working only during the upper half of the tidal cycle (during the flooding tide from mid-tide to high-tide and during the ebb to mid-tide) when the lower tidal zones are always under water.
- The biological effects of high-pressure water washing (including steam cleaning and sandblasting) must be considered, as these tactics can remove healthy organisms. Spot washing may be used to remove oil if no organisms are present or if the oil has already smothered or killed the biological community. Even if the oil has killed them, removing plants and animals may delay recolonization due to changes in habitat.
- Avoid spraying freshwater on intertidal communities.
- Avoid excessive vegetation cutting as this may kill the plants and remove the protective cover for smaller organisms and wildlife.

4.3 GLACIAL AND SOLID ICE SHORELINE

Definition

This type of shoreline is composed of ice that occurs where glaciers or ice shelves reach the coast, permafrost is exposed, or solid seasonal ice forms as a layer on the shore.

Note: This section addresses only the 'ice' component of the shoreline. On shorelines with seasonal ice, the ice forms on the surface of the sediment or bedrock in the form of frozen swash or spray or an ice foot. In these situations, both the surface layer of ice and the underlying geological substrate of the shoreline (as addressed in other sections) are considered when planning a response. Oil behaviour and the selection of treatment strategies also take into account whether the underlying sediments are frozen or not frozen.

Subtypes

Shoreline conditions vary according to the source of the ice as described here.

- Glaciers that reach the coast create an ice shoreline, as shown in Figure 4.4. Glaciers can 'calve' as ice breaks off the glacier front to form tidewater glaciers. The ice front of a slow moving or retreating glacier may melt without calving.
- Ice shelves are present on coasts in the Canadian Arctic Ocean where ice sheets extend over the sea and float on the water. The ice shelves range in thickness from a few hundred metres to over 1000 metres.
- Shorefast ice (or an "ice foot") forms on arctic shorelines and most shorelines on the Atlantic coast each winter. The seaward edge of the ice foot is often a vertical or steep face.
- Frozen wave splash, spray, or swash can form a coat of ice on an intertidal or backshore surface. This is shown in Figure 4.5.
- Ice floes of various sizes can be stranded on a shore. These originate from the breakup of sea ice or from calving tidewater glaciers.
- Fresh water flowing downslope from the backshore towards the intertidal zone can freeze and may mix with the sea water ice of an ice foot or frozen splash and spray.
- Erosion of the tundra can expose permafrost at the shore.
- Ice can form within a beach when water freezes in the interstitial spaces of sediments.

Character

- Ice is impermeable.
- Solid ice can be associated with the formation of an ice-foot, tidewater glaciers, an ice shelf, or exposed permafrost. A coat or thin layer of ice can form on any substrate material if the air temperature is below freezing even if the temperature of the sea water is above freezing.
- Ice surfaces range from an eroding face on a calving tidewater glacier ice front, a thin sheet of frozen spray, or a melting exposed permafrost surface or thawing ice foot.
- Shore-zone ice ranges from a vertical face to a low-angle slope.

Behaviour of Oil

- Oil behaves differently on the various forms of shoreline ice depending on the character of the surface or texture of the ice, which are linked to the temperature of the air-ice boundary.
- The presence of an ice foot or a frozen layer of ice prevents oil from making contact with the shoreline substrate.
- Oil washed onto the exposed surface of the ice is not likely to adhere except when the air temperature is below freezing.
- During freeze-up, oil on the shore or stranded on the shore-zone ice during a period of freezing temperatures can become covered and encapsulated within the ice.
- During a thaw cycle or if the surface of the ice is melting and wet, oil is unlikely to adhere to the ice surface and will remain on the water surface or in shore leads. Oil may be splashed over the ice edge or stranded above the limit of normal wave action. The stranded oil can then be incorporated into the shore-fast ice if temperatures fall below freezing again.
- If oil becomes stranded on the substrate in between ice floes and on the floes themselves, its behaviour would be influenced by a combination of ice and that substrate material.
- Ice in beach sediments, either frozen interstitial or groundwater, can prevent the penetration of stranded oil.

Sensitivity

- Ice surfaces do not support significant plant or animal life.
- Marine mammals may use the edge of the ice to haul themselves out of the water.

Figure 4.4 Glacial Ice Shoreline

Figure 4.5 Variations of Seasonal Ice Shorelines – Frozen Spray and Frozen Swash in the Intertidal (lower right) and Supratidal Zone (upper left)

Summary of Tactics

Tactics for cleaning oil from glacial and solid ice shorelines are summarized in Table 4.3.

Preferred Response Options – Surface Oil

- As ice shorelines are not sensitive, oil removal tactics on the ice itself do not usually have significant environmental effects.
- **Natural recovery** is the preferred option on exposed coasts. This option is less appropriate for heavy oils or weathered crudes on a sheltered coast where the oil is likely to persist longer. It may not be appropriate immediately before freeze-up as the oil could become encapsulated by the ice and potentially remobilized during the next thaw. When there is no physical energy to remove the oil, natural recovery does not take place until spring melt and breakup.
- Natural recovery is the safest option for volatile and light oils such as gasoline. This type of oil can also be removed by one of the physical washing techniques, preferably from a safe distance as fumes, fire, and flashback are risks to consider.
- **Flooding** or **low-pressure ambient-water washing** are practical and efficient for removing low to medium viscosity oil on shore-fast ice if the adjacent sea is ice-free and air temperatures are above freezing. The oil can be flushed onto the surface of the water for containment and recovery. This washing option can minimize ecological impacts that might result if stranded oil remobilized. Washing from a boat or barge is preferred if the water is deep enough. The edges of shore-fast ice are often steep so that washing from a boat or barge may be the only practical option.
- **High-pressure, ambient-water washing** and **low-pressure, warm/hot water washing** may be useful for more viscous oils that cannot be removed by low-pressure, ambient-water washing.
- **Manual removal** of medium and heavy oils is recommended for small amounts of oil, but safety is a primary concern on slippery ice surfaces.
- **Mechanical removal** may be efficient in some circumstances where equipment is available and can be deployed safely.
- **Sorbents** can be deployed to collect small amounts of low to medium viscosity oils.
- **Vacuums** can be used to collect light and medium viscosity oils. For example, rope mops can be deployed using cranes to sweep ice surfaces or to collect oil from pools, cracks, or crevices.
- **Burning** of pooled or collected oil on the ice surface is applicable for all but the most viscous oils.
- As it is important to minimize the generation of waste in remote areas, removing the oiled ice in combination with melting and then collection of the oil or direct burning may be the preferred option.

Table 4.3 Summary of Tactics for Glacial and Solid Ice Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	▪		
Flooding	■	■	▪		
Low-pressure ambient washing	■	■	■	▪	
Low-pressure warm/hot washing			■	■	
High-pressure ambient washing				▪	▪
Manual removal		▪	▪	▪	▪
Vacuums		■	■	▪	
Mechanical removal		■	■	■	■
Passive sorbents	▪	▪	▪		
Burning	■	■	■	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Preferred Response Options – Subsurface Oil

- Oil may be encapsulated on an ice surface by freezing wave spray. The oil/ice can be removed as blocks using chain saws or mechanical cutters, e.g., "Ditch Witches".

Precautions

- Be very careful not to slip and fall on ice.

4.4 SOLID MANMADE SHORELINE

Definition

These shorelines consist of manmade (anthropogenic) structures that are composed of impermeable materials.

Subtypes

- Solid manmade features and structures vary greatly in design, form, and material. They include structures for moorage (docks, wharfs, and marinas), protected anchorages (breakwaters), commercial activities, and backshore protection (seawalls).
- This type of shoreline includes historic structures and archaeological or historic sites in the intertidal or backshore areas.

Character

- Solid manmade structures have stable, impermeable surfaces consisting of a wide range of materials such as concrete, metal, plastic, and wood. The surface of each of these materials is different in texture and roughness.
- The structure may present a vertical face, such as a dock or wharf or be sloped, as a solid sea wall. Examples of solid manmade structures are shown in Figure 4.6.

Behaviour of Oil

- Solid manmade structures are considered to be impermeable. Oil would coat the surfaces or penetrate a few millimetres in open grain woods or concrete.
- These structures are built of a wide range of materials, each of which has a different surface texture and roughness. The adhesion potential will vary with the type of oil and the material. For example, one type of oil may not stick to a smooth, sloping metal surface, but may stick to a vertical, rough concrete surface.
- Oil generally behaves in a similar way on solid manmade structures as on bedrock shorelines, as both are impermeable.
- Oil is more likely to be deposited in the upper half of the intertidal zone. The lower tidal zones usually stay wet and often have a biofilm.
- Often oil does not strand on exposed coasts due to wave reflection. If stranded, the oil may be washed off rapidly by wave action, i.e., in days to weeks.
- Oil may be splashed above the limit of normal wave action on exposed coasts.
- Oil that comes into sheltered locations is likely to be deposited as a band near the last high-water level on the upper intertidal zone.
- In sheltered locations, because of the relatively low wave-energy conditions, heavy oils or weathered crudes may persist for months or years as there is insufficient energy to remove these types of oil naturally.
- Even in sheltered locations, light oil will probably be washed off a solid manmade surface in a short time, ranging from hours to days.

Figure 4.6 **Solid Manmade Shorelines – Concrete Seawall and Boat Ramp**

Sensitivity

- Manmade historic, cultural, and archaeological structures typically have a high social value and are assigned a high sensitivity. They may be relatively fragile in the context of intrusive treatment tactics. Both oil and the methods used to remove it can deface or alter the physical integrity of such structures.
- Most other solid manmade structures are relatively low in sensitivity, although their importance and priority will vary with location and human use, e.g., outer breakwater structures compared to inner harbour recreational areas.
- As moorings, docks, and seawall walkways are frequently used by people, there is a high potential that people will come in contact with the oil.
- Biota attached to these structures are usually treated as less sensitive than those on bedrock shorelines. There are usually fewer biological communities on solid manmade structures than on bedrock shorelines as many have smooth surfaces and/ or are vertical so there is less intertidal area for colonization.
- Fish may frequent the waters in the shade and shelter at the base of structures such as seawalls, docks, and wharves.
- On coasts where ice is common on water or on shore, the biological community is usually scraped off the surface every year, so that plants and animals can only survive in cracks and crevices where they are protected. As a result, ice-scoured solid surfaces do not have extensive, diverse, or rich biological communities.

Summary of Tactics

Tactics for cleaning oil from solid manmade shorelines are summarized in Table 4.4.

Preferred Response Options – Surface Oil

- Historic structures, particularly those made of wood or stone, must be treated as a special case to minimize physical damage or degradation. These types of structures should be cleaned only after appropriate consultation with federal and/or provincial agencies and subject matter experts. Non-aggressive, labour-intensive manual methods are typically used to clean oil from historic structures.
- **Natural recovery** is preferred for low human use areas or on high-wave energy exposed coasts. This option is less appropriate for heavy oils or weathered crude oils on a sheltered coast where the oil is likely to persist longer or for structures with high human use. Natural recovery may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- Natural recovery may also be a good choice for light, volatile oils such as gasoline due to safety concerns related to fumes, ignition, and flashback. If necessary, volatile or light oils can be removed by using one of the ambient-water washing techniques, preferably from a safe distance.
- **Physical washing** can be practical and efficient for oil on solid manmade shorelines.
- **Low-pressure, ambient-water washing** of light and some medium oils can minimize ecological impacts (see below for applications to avoid). As manmade surfaces are often steep, washing from a boat or barge is preferred if the water is deep enough. Removed oil should be contained and collected by booms and sorbents or skimmers.
- **High-pressure, ambient-water washing** and **low-pressure, warm/hot water washing** may be useful for more viscous oils that cannot be removed by low-pressure, ambient-water washing.
- On surfaces where no organisms are present, such as ice-scoured manmade surfaces, **high-pressure washing techniques, steam cleaning,** or **sandblasting** may be appropriate.
- **High-pressure, warm/hot water washing** techniques with the spray nozzle held only 10 cm from the oiled surface have been used successfully to remove viscous oils on historic stonework and plaster.
- **Manual removal** of all but volatile oils is recommended for small amounts or small areas of oil.

Table 4.4 Summary of Tactics for Solid Manmade Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■	▪	▪
Low-pressure ambient washing	■	■	■	▪	▪
Low-pressure warm/hot washing	■	■	■	■	■
High-pressure ambient washing			■	■	■
High-pressure warm/hot washing			■	■	■
Steam cleaning			▪	▪	▪
Sandblasting				▪	▪
Manual removal		▪	▪	▪	▪
Passive sorbents	▪	▪	▪	▪	
Dispersants		■	■		
Shoreline cleaners		■	■		

■ Preferred option   ▪ Possibly applicable for small amounts of oil

Special consideration should be given to historic structures to avoid damage or degradation.

- **Sorbents** can be deployed to passively collect small amounts of low to medium viscosity oil.
- **Dispersants** and **shoreline cleaners** can be used on oil types for which the product is designed and are effective for small amounts of oil if properly applied. Note that government approval is typically required for use of dispersants and shoreline cleaners.

Typical Combinations of Response Tactics

- Shoreline cleaners can be combined with flooding or low-pressure washing to remove and collect the oil.

Precautions

- Avoid all unnecessary access to oiled manmade historic, cultural, and archaeological structures until there is a special treatment plan.
- Control civilian access on oiled mademade structures to avoid tracking and spreading the oil.
- On steep manmade structures or those with shelves, be extremely careful to avoid falls and slips, particularly on open coasts where there is strong wave action or ice.
- If there are plants, e.g., *Fucus sp.* and animals, e.g., barnacles and mussels, in the intertidal zone, avoid washing oil from the upper into the lower intertidal zones. These lower intertidal zones often are not oiled and more damage can be caused if oil is washed downslope during cleanup. This can be avoided by working only during the upper half of the tidal cycle (the flooding tide from mid-tide to high-tide and the ebb to mid-tide) when the lower tidal zones are always under water.
- Avoid high-pressure, warm/hot water washing (including steam cleaning and sandblasting) if there are healthy organisms in the area. When organisms are present, these techniques may be of value for spot washing if the oil has already smothered or killed the biological community. Removing the plants and animals, even if they have been killed by the oil, may delay recolonization due to habitat modification.

4.5 PERMEABLE MANMADE SHORELINE

Definition

These shorelines consist of manmade (anthropogenic) features and structures that are composed of permeable material(s).

Subtypes

- Permeable manmade features and structures include a wide range of designs, such as berms, breakwaters, bulkheads, cribwork, dikes, gabion baskets, piers, seawalls, rip-rap, and artificial islands. They also include shore land extensions, landfill, and areas filled for flood control. Examples of permeable manmade structures are given in Figure 4.7.
- This type of shoreline includes historic structures and archeological or historic sites, for example, cobble fish weirs.

Figure 4.7 Permeable Manmade Shorelines: cobble fish weir archeological site (top photo), gabion baskets (middle photo), and a cobble/boulder seawall (bottom photo)

Character

- Permeable manmade structures are composed of various sizes of materials with open spaces between the materials leaving them permeable to oil and water penetration.
- Materials include sand, pebbles, boulders, concrete blocks, crushed rock, sand bags, soil, tires, or pre-cast interlocking concrete shapes.

Behaviour of Oil

- Oil behaves in a similar way on manmade permeable structures as on shorelines with natural sediments. This is a function of the size of the material which is described in Sections 4.6 through 4.9. For example, permeable shorelines made up of large quarried rock, that is more than 256 mm in size, are similar to boulder shorelines and gabion baskets of cobble and pebble are similar to pebble/cobble shorelines.
- Manmade materials, such as fill or concrete forms, are no different than naturally occurring materials in terms of how the oil behaves.

Sensitivity

- Manmade structures of historic, cultural, and archeological value are considered to be highly sensitive. They may be relatively fragile in the context of intrusive treatment tactics. Both oil and the methods used to remove it can deface or alter the physical integrity of such structures.
- Permeable manmade structures are built primarily to stabilize the shoreline, act as sea defences, or protect docks and harbours. They are generally not considered to be sensitive except when they are historically significant or have been constructed to provide a specific artificial biological habitat.
- Biological productivity is typically higher on permeable manmade shorelines than on solid manmade shorelines as the open pore structure provides additional habitat.
- Structures in zones of high human use present a high potential for human/oil interaction.
- As these structures are stable, they may provide habitats similar to those of the natural base materials. In particular, they may provide a substrate for a similar type of biological colonization as occurs on bedrock, mixed, pebble/cobble or boulder sediment shorelines as discussed in Sections 4.2, 4.7, 4.8, and 4.9.

Summary of Tactics

Preferred Response Options

- Preferred response options for removing surface and subsurface oil from permeable manmade shorelines are related to the size of the material in the structure and follow the recommendations and guidelines presented in Sections 4.6 to 4.9 which address those types of materials.
- More aggressive treatment strategies and tactics can be considered for manmade structures than for a natural beach consisting of the same material.
- For smaller, heavily oiled structures, such as a cobble-filled gabion basket, it may be more cost- and time-efficient to remove and rebuild the structure than to attempt to clean it.
- Historic structures are usually made of wood or natural or worked stone. They must be treated as a special case to minimize physical damage or degradation. Such structures should be cleaned only after appropriate consultation with federal and/or provincial agencies and subject matter experts. Non-aggressive, labour-intensive manual methods are typically used to clean historic structures.

Precautions

- Avoid large-scale removal of coarse (large-sized) materials as this is not usually practical. If such materials are removed, they should be replaced immediately. Coarse materials/sediments could provide a strong armour layer and would probably not be replaced naturally. Removal without replacement could therefore lead to shoreline retreat in the form of erosion.
- Generally avoid washing oil from oiled into unoiled zones, particularly in areas that are colonized with plants and animals.
- Avoid flushing techniques that only move the oil deeper into the shoreline sediments or permeable materials of the structure, unless they also flush the oil out for recovery. Warm or hot water could temporarily mobilize viscous oil that would then penetrate more deeply into the substrate material. The loss of heat as the oil moves through the material or sediments or as it makes contact with cool or ambient groundwater may cause the oil to be redeposited at a deeper level within the permeable materials of the structure.

4.6 SAND BEACH

Definition

A sand beach is composed of sand with grains ranging from 0.0625 to 2.0 mm in diameter. There may also be small amounts (less than 10%) of granules, silts, or clay.

Subtypes

Sand beaches are subdivided based on the dominant size of the sand.

- **Coarse-sand beaches** have larger grains of sand (0.5 to 2 mm in diameter) and usually have steeper slopes and poorer weight-bearing capacity.
- **Fine-sand beaches** (grain size less than 0.5 mm) have a flatter slope and are typically more compacted and provide better traction and higher weight-bearing capacity.

An oiled sand beach is shown in Figure 4.8.

Character

- Very dynamic, mobile, unstable surface layer.
- Even a relatively low level of wave action, e.g., waves 10 to 30 cm high, can easily change the surface level on a sand beach by as much as 10 cm in one tidal cycle.
- During storms, large waves can lower or raise a beach surface by as much as 1.0 m in a few hours. These processes can result in erosion, mixing, or burial of stranded oil.
- On exposed coasts, beaches are typically narrower and elevations lower during winter months as sediment is redistributed to the adjacent nearshore zone, with a buildup of intertidal sediments by constructive wave action in spring and summer months.
- Sediment supply to sand beaches is highly dependent on local source and supply conditions.
- Most types of vehicles usually have good traction on sand beaches. Traction can be a problem in the lower intertidal zone due to water-saturated sediments or above the normal intertidal zone because of soft wind-blown sands. Reducing tire pressure partially compensates for low weight-bearing capacity.
- Slopes are typically 5° to 20° but can vary from less than 5° to 35°.

Behaviour of Oil

- Permeable for some medium and all light oils.
- As pore spaces are small, medium and heavy oils are not likely to penetrate more than 25 cm.

Figure 4.8 Sand Beach with Dark Patches of Oil in Supratidal Zone

- Burial and/or mixing of oil can occur easily and quickly. On exposed coasts, sand is very mobile and even in sheltered areas, the gentle shifting of the surface layer may cover the oil.
- Light oils can readily penetrate a medium- or coarse-grained sand beach and mix with groundwater. Light oils can also be re-floated and transported by changing tidal water levels.
- Oil is less likely to stay stranded in the lower intertidal zones as these remain wet due to backwash and groundwater flowing out of the beach. All but highly viscous or dense oils would be re-floated and carried up the beach by a rising tide and will then concentrate on the upper beach.

Sensitivity

- The biological productivity and sensitivity of sand beaches are relatively low. Exposed and semi-exposed sand beaches are dynamic and support only a few species of mobile, burrowing animals.
- Biological productivity increases in protected, low wave-energy environments which tend to have a higher organic component.
- Sand beaches are common resting or foraging habitats for shorebirds.
- Public and private beaches provide waterfront access to people. Seasonal recreational human use significantly increases sensitivity and the potential for people coming into contact with the oil.

Summary of Tactics

Tactics for cleaning oil on sand beaches are summarized in Table 4.5.

Preferred Response Options – Surface Oil

- **Natural recovery** is recommended for small spills of light oils on exposed coasts and in remote areas.
- **Flooding** can remove light and medium oils. Effectiveness decreases as the viscosity of the oil increases.
- **Manual removal** is preferred for most oils, as little unoiled material is removed. Effectiveness decreases as the area of oiled sediments increases.
- **Mechanical removal** is often appropriate for long sections of beach with high concentrations of oil on the surface of the beach.
  - Graders are the preferred heavy equipment as they scrape up only a thin layer of oiled sand.
  - Front-end loaders have a less accurate depth of cut and bulldozers are a last resort.

  Factors to be considered when comparing the selection of manual and/or mechanical removal techniques include:
  - size of the area to be cleaned;
  - access to area;
  - time available for cleanup; and
  - amount of oiled sediment that must be handled, transferred, and disposed of.
- **Sorbents** can be useful to collect oil as it washes ashore, although their effectiveness decreases as oil volumes increase. Use of large amounts of sorbent material can create a waste disposal problem.
- **Wet and dry mixing** and **sediment relocation** accelerate the weathering and removal of oil in sediments. Sediment relocation in particular may be an important polishing step for stained sands that remain after other treatment to remove bulk oil has been completed. Wet mixing has been used successfully to separate and recover oil from sands.

Typical Combinations of Response Tactics

- Flooding or floating oil into lined collection trenches or sumps, followed by recovery with vacuums or skimmers;
- Manual or mechanical removal followed by mixing or sediment relocation.

Table 4.5 Summary of Tactics for Sand Beach

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	□				
Manual removal		□	□	□	□
Vacuum		■	■		
Mechanical removal		■	■	■	■
Passive sorbents		□	□		
Mixing – dry		■	■	■	
Mixing – wet		■	■	□	
Sediment relocation		■	■	■	
Bioremediation		□	□		
Oil in the subsurface sediments					
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal			□	□	□
Mechanical removal		□	□	□	□
Mixing – dry		■	■	■	
Mixing – wet		■	■	■	
Sediment relocation		■	■	■	
Bioremediation		□	□	□	

■ Preferred option □ Possibly applicable for small amounts of oil

Preferred Response Options – Subsurface Oil

- **Flooding** and **low-pressure ambient-water washing** can remove light subsurface oils. Effectiveness decreases as viscosity, penetration, or depth of burial of oil increase.
- **Manual removal** is preferred for medium and high viscosity oils, as little unoiled material is removed. For a buried layer of oil, the clean overlying sediment should be removed and replaced to minimize sediment removal and waste generation. Efficiency decreases as the area of oiled subsurface sediments increases and as the depth of oil penetration or burial increases.
- **Mechanical removal** may be an option on long sections of beach with high concentrations of subsurface oil. Removing subsurface oil can involve large volumes of material with low concentrations of oil. Clean overlying sediment should be removed and segregated from deeper oily sediment.

  Graders are the preferred heavy equipment if the oil is not deep as they scrape only a thin layer of oiled sand. Front-end loaders have a less accurate depth of cut and bulldozers are a last resort. When selecting manual and mechanical removal techniques, the following factors must be considered:

  - size of the area to be cleaned;
  - time available for cleanup; and
  - amount of oiled sediment that must be handled, transferred, and disposed of.
- **Wet and dry mixing** and **sediment relocation** accelerate weathering and removal of oil by water and physical abrasion. Sediment relocation in particular may be an important polishing step for stained sands that remain after other treatment to remove bulk oil has been completed.

Precautions

- Avoid removing too much sediment as natural replacement rates are slow in many areas. Excessive removal could lead to erosion.
- Avoid mixing clean and oiled sediments. In particular, avoid mixing oil into clean subsurface sediments except as a planned strategy of mixing or sediment relocation.
- Concentrations of oil in the sediment are typically low. Removing the sediment generates a large volume of lightly oiled waste, which then requires transfer and disposal.
- Avoid spillage from graders. If more than one machine is used, generate separate windrows rather than try to move sand successively up a beach.
- Avoid tracking oil into clean areas. With both vehicles and personnel, always work from a clean area towards an oiled area to avoid cross-contamination.
- During manual cleanup, avoid over-filling collection bags or containers in order to minimize spillage and to prevent bags or containers from breaking.

4.7 MIXED SEDIMENT BEACH

Definition

A mixed sediment beach is composed of sand plus any combination of granules, pebbles, and/or cobble.

- Sand is 0.0625 to 2.0 mm in diameter, granules are 2 to 4 mm in diameter, pebbles range from 4 to 64 mm in diameter, and cobbles range from 64 to 256 mm in diameter. For comparison, 4 mm is about the width of a pencil, 64 mm is approximately the size of a tennis ball, and 256 mm is a little larger than a soccer ball (225 m) or a basketball (240 mm).
- The interstitial spaces (voids) between the coarse pebble/cobble fractions are in-filled with sand or granules as shown in Figure 4.9. This important characteristic distinguishes a mixed sediment beach from a pebble/cobble beach.
- Although mixed sediment beaches are sometimes called 'gravel beaches', the term is non-standard and is used to describe various other types of sediment shorelines.

A mixed sediment beach is shown in Figure 4.10.

Subtypes

- Mixed sediment beaches are sometimes subdivided due to differences in oil penetration and treatment tactics selected. The subtypes are:
  - **fine-mixed** (sand/granule/pebble) and
  - **coarse-mixed**, which includes larger cobble material.
- In delta environments, the channel margins or mid-channel bars are frequently characterized by pebble and cobble sediments from which most of the sand has been washed out to leave a coarse-sediment surface layer that is underlain by mixed sediment. The sand and other fine sediments tend to accumulate in areas where the currents are slow.
- On low-lying arctic tundra shores, wave action may push sand or gravel deposits on to the backshore. These "perched beaches" rest directly on the vegetation or on a peat mat which is often exposed on the seaward face of the beach ridge.

Character

- The surface layer often consists predominantly of coarser sediments (pebbles and cobbles) with increasing amounts of sand and granules in the subsurface.
- There is often a steep section in the upper half of the intertidal zone and the coarse sediments provide poor traction for vehicles and sometimes for workers.
- The lower intertidal zone is often predominantly sand.
- Supply of the coarse sediments to this type of beach is usually a very slow process. In most cases, coarse sediments that are removed are replaced only at a very slow rate, i.e., decades, or not at all.

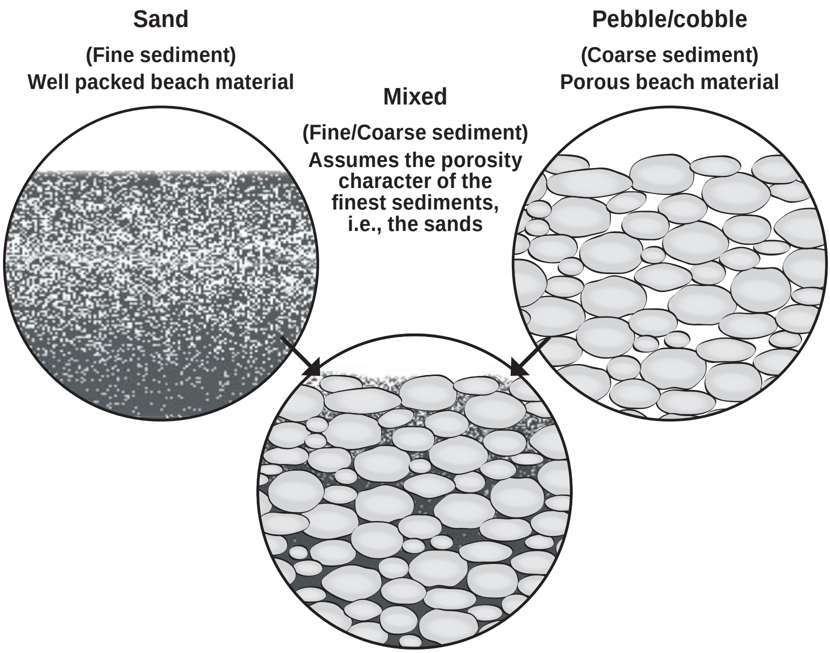

Figure 4.9 **The interstitial spaces between the coarse pebble/cobble fractions are in-filled with sand or granules in a mixed sediment beach.**

Figure 4.10 A mixed sediment beach is composed of sand plus any combination of granules, pebbles (bottom right), or cobbles (upper left).

Behaviour of Oil

- The coarse fractions (pebbles and cobbles) are in-filled with the finer sands and granules. How the oil behaves is determined more by these finer fractions.
- From an oil fate perspective in terms of penetration, retention, and persistence, this type of beach is similar to a sand beach or sand/granule beach.
- From a response operations perspective in terms of weight-bearing capacity and cleanup techniques, this type of beach is more like a pebble/cobble beach.
- Oil residence time or persistence is primarily a function of the type of oil, the depth of penetration or burial of the oil, and wave-energy levels on the beach.

- Depth of oil penetration is primarily a function of the viscosity of the oil. Depth of burial or reworking of oiled sediments is primarily a function of wave-related beach erosion and recovery processes.
- These beaches are permeable only for some medium oils and all light oils.
- Light oils can readily penetrate a medium- or coarse-grained sand beach and mix with groundwater and/or be transported by changing tide levels.
- Medium or heavy oils penetrate through the mixed sediments less readily than on a coarse sediment beach. Oil that does penetrate, however, is more likely to persist in the subsurface of a mixed sediment beach.
- Oil is less likely to stay stranded in the lower beach zones as these remain wet due to wave action and groundwater flowing out of the beach. All oils except those that are highly viscous or dense would be refloated and carried up the beach by a rising tide. As a result, oil is more likely to concentrate on the upper intertidal zone.
- The frost table in a beach acts as a lower limit for oil penetration into the sediments. In arctic and subarctic regions, during the first weeks of summer after the ice foot or fast ice melts, the depth of thaw ranges from only a few centimetres to 0.5 m. As the summer progresses and the ice in the beach melts, the depth to the frost table increases to as much as 1.0 m or more by mid- to late August. The frost table moves closer to the surface again with the onset of freezing temperatures.
- Asphalt pavements commonly form in upper- or supra-intertidal zones where weathered medium and heavy oils create a stable oil-sediment conglomerate.
- Usually only the surface layer of sediments is reworked by normal wave action. Oil that penetrates below the surface may not be physically reworked except during infrequent, high-energy storms.

Sensitivity

- Sensitivity of a mixed sediment beach to oil and to treatment is low to medium. As few animals or plants can survive the continuous reworking of the coarse sediments, exposed or semi-exposed beaches support little life, particularly in the upper intertidal zone.
- The most common biota are burrowing or mobile species.
- Sensitivity is higher in the lower sections of the beach or in sheltered wave environments that tend to be more stable and where organisms are more likely to be present.

Summary of Tactics

Cleanup tactics of oil on mixed sediment beaches are summarized in Table 4.6.

Preferred Response Options – Surface Oil

- **Natural recovery** may be an acceptable option for small spills, low to medium viscosity oils, or on exposed coasts, and/or in remote areas. It may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- **Flooding** is a non-intrusive technique that can wash mobile and/or light oil from surface sediments for collection. Effectiveness decreases with increasing viscosity and stickiness of oil.
- **Low-pressure, ambient-water washing** can flush mobile oil from surface sediments for collection. This is more effective for viscous oils than flooding, but effectiveness decreases with increasing viscosity and stickiness of oil.
- **Manual removal** can minimize the amount of oiled and unoiled sediment that is recovered and can be appropriate for removing surface oiled sediments. This technique can be used to remove patches of asphalt pavement, tar patties, and small-size oiled debris. It becomes less practical as the amount of oiled shoreline or sediment increases. Pointed shovels are more effective than straight-edge shovels for removing oiled sediments on mixed sediment beaches.
- **Mechanical removal** is effective for large volumes of most oils. Equipment that removes as little unoiled sediment as possible is recommended. Because of the generally poor weight-bearing capacity of this type of sediment, front-end loaders may be the first choice, with backhoes as an alternative. In most cases, a coastal geologist should be consulted to determine how much material can be safely removed from a mixed-sediment beach without having to replace sediment.
- **Vacuums** are useful where oil has pooled on the beach surface.
- **Sorbents** can be useful for recovering small amounts of light and medium oils.
- **Mechanical mixing** can be used, particularly for light or medium oils.
- **Sediment relocation** is appropriate on exposed or semi-exposed coasts after any mobile oil has been removed or for small amounts of oiled sediment. This approach minimizes the possibility of erosion. This technique depends on the availability of wave energy to abrade, redistribute, and replace the sediments or on the presence of fines (clays and silts) to remove oil.

Typical Combinations of Response Tactics

- **Flooding** with trenches or sumps to collect oil that is floated can be combined with **vacuum systems** to recover the oil.
- **Sediment relocation** can be followed by **mechanical mixing**. **Bioremediation** can also be used as a final polishing tactic.

Table 4.6 Summary of Tactics for Mixed Sediment Beach

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	▪	■	■		
Manual removal		▪	▪	▪	▪
Vacuum			■	■	
Mechanical removal		■	■	■	■
Passive sorbents		▪	▪		
Mixing – dry		■	■	■	
Mixing – wet		■	■	▪	
Sediment relocation		■	■	■	
Bioremediation		▪	▪		

Oil in the subsurface sediments	Volatile	Light	Medium	Heavy	Solid
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal			▪	▪	▪
Mechanical removal		■	■	■	■
Mixing – dry		■	■	■	
Mixing – wet		■	■	■	
Sediment relocation		■	■	■	
Bioremediation		▪	▪	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Preferred Response Options – Subsurface Oil

- **Flooding** and **low-pressure ambient-water washing** can remove volatile and light subsurface oils. Effectiveness decreases as the viscosity, penetration, or depth of burial of the oil increase.
- **Manual removal** is applicable for small amounts of medium and heavier oils, as only a small amount of unoiled material needs to be removed. For a buried layer of oil, the clean overlying sediment should be removed and replaced to minimize sediment removal and waste generation. Efficiency decreases as the area of oiled subsurface sediments increases and as the depth of penetration or burial of the oil increases.
- **Mechanical removal** can be an option for long sections of beach with high concentrations of subsurface oil. Removing subsurface oil can involve large volumes of material with low concentrations of oil.

  Because of the generally poor weight-bearing capacity of this type of sediment, front-end loaders may be the equipment of choice, with a backhoe as an alternative. In most cases, it is appropriate to consult a coastal geologist to determine how much material can be safely removed from a mixed-sediment beach without having to replace sediment.
- When selecting manual and mechanical removal techniques, the following factors must be considered:
  - size of the area to be cleaned;
  - time available for cleanup; and
  - amount of oiled sediment that requires handling, transfer, and disposal.
- **Mechanical mixing** (wet or dry) and **sediment relocation** accelerate weathering and removal of oil by water and physical abrasion. Sediment relocation, in particular, may be an important polishing step for stained sediments that remain after other treatment to remove bulk oil has been completed. **Bioremediation** can also be used as a final polishing tactic.

Precautions

- Excessive removal of coarse sediments is probably the greatest concern on this type of beach as natural replacement rates are usually very slow and can take decades. This can lead to the beach retreating or eroding.
- As concentrations of oil in sediment are usually very low, mechanical or manual tactics for removing sediment generate large volumes of waste that contain relatively small amounts of oil.
- If there are attached animals or plants in the unoiled lower tidal zones, avoid spreading oil into those areas when flushing or relocating sediment.
- Avoid flushing techniques that only move the oil deeper into the sediments without flushing the oil out of the beach for recovery. Warm or hot water may temporarily mobilize viscous oil which could then move downslope or deeper into the beach. The loss of heat as the oil moves through the beach or makes contact with cool or ambient groundwater may cause the oil to be re-deposited at a lower level within the beach.

4.8 PEBBLE/COBBLE BEACH

Definition

A pebble/cobble beach is clearly dominated by either pebbles or cobbles or a combination of both. Pebbles are 4 to 64 mm in diameter and cobbles range from 64 to 256 mm in diameter.

The interstitial spaces between individual pebbles or cobbles are relatively open and not in-filled with finer material as shown in Figure 4.9. This important characteristic distinguishes a pebble/cobble beach from a mixed sediment beach.

These beaches may include small amounts of sand, e.g., less than 10%. Granules (2 to 4 mm diameter) are usually included in the pebble category. This shoreline type has also been described as a 'coarse sediment beach'.

Subtypes

- This shoreline type includes pebble beach, cobble beach, or pebble/cobble beach.
- A pebble/cobble beach may have a bimodal sediment character with sand dominant in the lower intertidal zone.

A pebble beach is shown in Figure 4.11 and a cobble beach in Figure 4.12.

Character

- Pebble/cobble beaches are very permeable and have a dynamic, mobile, unstable surface layer.
- Boulders may be scattered on the beach surface.
- On exposed coasts, pebble/cobble beaches are typically characterized by a steep section in the upper half of the intertidal zone that provides poor traction for vehicles and sometimes for cleanup workers.
- Sediment supply to this type of beach is usually very slow. It may take decades for sediment that is removed to be replaced.
- The slopes on pebble/cobble beaches range from 5° to 35°.

Figure 4.11 Pebble Beach

Figure 4.12 Cobble Beach

Behaviour of Oil

- Subsurface oiling is typical because pebble/cobble beaches are permeable to all types of oil, except those of a semi-solid nature.
- Due to the size of the material, oil-in-sediment amounts (by weight or by volume) are usually very low, often less than 1% unless the oil is pooled or very thick.
- Oil residence time or persistence is primarily a function of the type of oil, the depth of penetration, retention factors, and wave-energy levels on the beach.
- Depth of oil penetration is a function of the viscosity of the oil and the size of the sediment. The larger the particle size, the easier it is for oil to penetrate. As retention is relatively low, however, mobile oil can be flushed naturally from these coarse sediments.
- Light or non-sticky oils can be easily flushed out of the surface or subsurface sediments by tidal pumping.
- Oil is less likely to remain stranded in the lower intertidal zone as this area remains wet due to backwash and groundwater flowing out of the beach. All but highly viscous or dense oils would be refloated and carried up the beach by a rising tide. Oil is therefore more likely to concentrate on the upper beach.
- Only the surface layer of sediments is usually reworked by normal wave action. Oil that penetrates below the surface may not be physically reworked except during infrequent, high-energy storms or run-off events.
- On a bimodal beach, where there are two different physically separated sediment distributions, then oil would be stranded only in the upper, coarse sediment tidal zones. Where sand is present in the lower intertidal zone, the finer sediments are typically water-saturated.

Sensitivity

- Sensitivity to oil and treatment activities is low to medium. As few animals or plants can survive the continuous reworking of the mobile surface sediments, exposed beaches support little life, particularly in the middle and upper intertidal zones.
- Sediments in the lower sections of the beach or those in sheltered wave environments tend to be more stable and organisms are more likely to be present in this zone. Habitat and protection are provided within the interstitial spaces of larger materials such as cobbles.

Summary of Tactics

Cleanup tactics for oil on pebble/cobble beaches are summarized in Table 4.7.

Preferred Response Options – Surface Oil

- **Natural recovery** is preferred, particularly for small spills of light oils, on exposed coasts, and/or in remote areas. It may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- **Flooding** is a non-intrusive technique that can flush mobile oil from surface sediments for collection. Effectiveness decreases with increasing viscosity and stickiness of the oil.
- **Low-pressure, ambient-water washing** can flush mobile oil from surface sediments for collection. Although this is more effective for viscous oils than flooding, effectiveness decreases with increasing viscosity and stickiness of the oil.
- **Manual removal** can minimize the amount of oiled and unoiled sediment that is collected and can be appropriate for removing surface oiled sediments. It is appropriate for removing patches of asphalt pavement, tar patties, and small amounts of oiled debris, but the practicality decreases as the amount of oiled shoreline or oiled sediment increases. Pointed shovels are more practical than straight-edge shovels for removing oiled pebbles and cobbles.
- **Mechanical removal** is effective for recovering a large volume of semi-solid oil. Equipment that removes as little unoiled sediment as possible is recommended. Because of the generally poor weight-bearing capacity of this type of sediment, front-end loaders are often the equipment of choice, with a backhoe as an alternative. In most cases, it is appropriate to consult a geologist to determine how much material can safely be removed from a pebble/cobble beach without having to replace sediment.
- **Sorbents** could be useful for recovering small amounts of light, medium and heavy oils.
- **Mechanical mixing** is most appropriate for light and medium oils in surface sediments. This tactic can be combined with **sediment relocation**.
- **Sediment relocation** is appropriate on exposed coasts after any mobile oil has been removed. It is also useful for small amounts of oiled sediment. This approach minimizes the possibility of erosion. Sediment relocation depends on the availability of mechanical wave energy to abrade, redistribute, and replace the sediments. Sediment relocation in low wave-energy environments requires mechanical energy or the presence of fines (clays and silts) to remove oil.

Table 4.7 Summary of Tactics for Pebble/Cobble Beach

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	▪	■	■		
Manual removal		▪	▪	▪	▪
Mechanical removal		■	■	■	■
Passive sorbents		▪	▪	▪	
Mixing – dry		■	■	■	
Mixing – wet		■	■	▪	
Sediment relocation		■	■	■	
Shoreline cleaners		▪	▪		
Bioremediation		▪	▪		
Oil in the subsurface sediments					
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal			▪	▪	▪
Mechanical removal		■	■	■	■
Mixing – dry		■	■	■	
Mixing – wet		■	■	■	
Sediment relocation		■	■	■	
Bioremediation		▪	▪	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Typical Combinations of Response Tactics

- Removal of oiled debris can be followed by manual removal, vacuums, or use of sorbents on surface oil patches.
- Flooding and low-pressure washing are a good combination.
- Sediment relocation can be followed by mixing and/or bioremediation.

Preferred Response Options – Subsurface Oil

- **Flooding** is a non-intrusive technique that flushes mobile oil from subsurface sediments for collection. Effectiveness decreases with increasing viscosity and stickiness of the oil and its depth of penetration.
- **Low-pressure, ambient-water washing** flushes mobile oil from subsurface sediments for collection. While this is more effective for viscous oils than flooding, effectiveness decreases with increasing viscosity, stickiness, and depth of penetration of the oil.
- **Manual removal** minimizes the amount of oiled and unoiled sediment collected and could be used to remove small amounts of subsurface oiled sediments. This tactic is not very practical for deeply penetrated or buried oil. Practicality decreases as the volume of oiled shoreline or oiled sediment increases and as the depth of penetration or burial of the oil increases. Pointed shovels are more practical than straight-edge shovels for removing oiled pebbles and cobbles.
- **Mechanical removal** can be effective for recovering a large volume of semi-heavy subsurface oil. Equipment that removes as little unoiled sediment as possible is recommended. Because of the generally poor weight-bearing capacity of this type of sediment, front-end loaders are the equipment of choice, with a backhoe as an alternative. In most cases, it is appropriate to consult a geologist to determine how much material can be safely removed from a pebble/cobble beach without having to replace sediment.
- **Mechanical mixing (wet or dry)** is appropriate for light and medium oils in subsurface sediments. This tactic can be used in combination with **sediment relocation**.
- **Sediment relocation** is also useful for small amounts of oiled subsurface sediment and minimizes the possibility of erosion. Sediment relocation depends on the availability of mechanical wave energy to abrade, redistribute, and replace the sediments. Sediment relocation in low wave-energy environments requires mechanical energy or the presence of fines (clays and silts) to remove oil.

Precautions

- Excessive removal of sediment is probably the greatest concern on this type of beach as it usually takes decades for sediments to be replaced. Avoid excessive removal of sediments as this can cause the beach to retreat or erode.
- As oil-in-sediment concentrations are usually very low, mechanical or manual sediment removal tactics generate a large volume of waste that contains a relatively small amount of oil.
- If attached animals or plants are present in unoiled lower intertidal zones, avoid spreading oil into these areas when flushing or relocating sediment.
- Avoid flushing techniques that only move the oil deeper into the sediments without flushing the oil out of the beach for recovery. Warm or hot water may temporarily mobilize viscous oil that could then migrate more deeply into the beach. The loss of heat as the oil moves through the beach or as it makes contact with cool or ambient groundwater may cause the oil to be redeposited at a lower level within the beach.

4.9 BOULDER BEACH

Definition

A boulder beach has an unconsolidated accumulation of boulders in the shore zone. Boulders are more than 256 mm in diameter, a little larger in size than a basketball (240 mm). A useful rule of thumb to differentiate between boulders and bedrock outcrops is that boulders typically are less than 4 m in size.

Character

- Boulder beaches are highly permeable.
- The boulders provide a stable surface layer that can be moved only by ice, humans, and extreme wave conditions.
- The subsurface of boulder beaches often consists of pebble/cobble material.
- Boulder beaches frequently give way to mud or sand tidal flats in the lower intertidal zone.

Behaviour of Oil

- Oil stranded on the upper exposed surfaces of the boulders behaves similarly to oil on bedrock.
- Oil has easy access through the large spaces between the individual boulders, thus coating the inner protected faces of the boulder surface and penetrating into underlying sediments. An oil-covered boulder beach is shown in Figure 4.13.
- Oil residence time or persistence is primarily a function of the type of oil and wave-energy levels. Persistence of oil varies greatly between exposed boulder surfaces and protected crevice and subsurface locations.
- Light or non-sticky oils may be easily flushed out of the sediments on the surface or subsurface by tidal pumping.

Sensitivity

- This type of beach is stable and the boulders provide different types of wave exposures and habitats for biological growth. The outer surfaces provide habitat similar to that on bedrock, whereas the large spaces between boulders are more sheltered, shaded, and damp, providing a more favourable habitat. Productivity and sensitivity of biological growth can be relatively high, except in areas where boulders are abraded or moved by ice action in winter.
- Similar to bedrock, sensitivity for large boulders varies in the different intertidal zones.

Figure 4.13 Heavily Oiled Boulder Beach

Summary of Tactics

Tactics for cleaning up oil on boulder beaches are summarized in Table 4.8.

Preferred Response Options – Surface Oil

- The outer exposed surfaces of boulders are similar in some ways to a bedrock outcrop and can be cleaned using similar techniques.
- The inner protected surfaces of the interstitial spaces are very difficult to access and the options for oil removal are limited.
- In most cases, all but surface oil would be difficult to recover and **natural recovery** is a preferred option, particularly for small amounts of oil. Natural recovery may not be appropriate for any pooled oil immediately before freeze-up as the oil would be encapsulated by ice and could remobilize during the next thaw.
- **Flooding** washes mobile oil from surface and subsurface sediments for collection. The effectiveness of flooding decreases with heavier oils as they are more viscous and sticky.
- **Low-pressure, ambient-water washing** can be used to flush mobile oil from surface and subsurface sediments for collection. This is more effective than flooding for heavy oils, but effectiveness decreases as the oil becomes more viscous and sticky.
- If oil can be removed from the difficult-to-access inner surfaces by **washing**, this should be done before the oil weathers and decreases the effectiveness of removal.
- **Manual removal** could be used to remove patches of surface asphalt, tar patties, and small areas of viscous oil, but the practicality decreases as the amount of oiled shoreline increases.
- **Mechanical removal** of oiled boulders may be used for smaller boulders or small areas of boulders where oil must be removed from the inner surfaces. In all cases, the boulders removed must be replaced with clean boulders. This can be either new boulders from off-site sources or the same boulders can be replaced after cleaning off the oil.
- **Sorbents** may be useful for recovering small amounts of light, medium and heavy oils on exposed surfaces. For small areas of boulder beach, sorbent materials (pads, pillows, etc.) can be stuffed into cracks and interstitial spaces to prevent oil penetration.
- **Bioremediation** could be used as a final polishing tactic if the nutrients can be applied in an efficient manner to ensure that they come into contact with the residual oil.

Table 4.8 Summary of Tactics for Boulder Beach

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	□	■	■		
Manual removal		□	□	□	□
Mechanical removal		□	□	□	
Passive sorbents		□	□	□	
Shoreline cleaners		□	□		
Bioremediation		□	□		
Oil in the subsurface sediments					
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Mechanical removal		□	□	□	□
Bioremediation		□	□	□	

■ Preferred option □ Possibly applicable for small amounts of oil

Typical Combinations of Response Tactics

- Removal of oiled debris is followed by manual removal of surface oil.
- Shoreline cleaners are combined with flooding and/or ambient low-pressure washing and oil collection and recovery.
- Flooding and low-pressure washing and/or manual removal are followed by natural removal of residual oil that is inaccessible.

Preferred Response Options – Subsurface Oil

- There are relatively few options for treating subsurface oil on a boulder beach and often little can be done practically to recover or treat heavy or semi-heavy oils that penetrate into the large interstitial spaces.
- In many cases, **natural recovery** may be the only practical option.
- **Flooding** can be used to wash mobile oil from subsurface sediments for collection. The effectiveness of flooding decreases, however, with heavier oils (increasing viscosity and stickiness), and depth of penetration.
- **Low-pressure, ambient-water washing** can be used to flush mobile oil from subsurface sediments for collection. This is more effective for heavy oils than flooding, but effectiveness decreases with increasing viscosity, stickiness, and depth of penetration.
- If oil leaching is a concern, the boulders could be lifted out mechanically, either from the land side or from a barge, the subsurface oil removed or treated, and the boulders replaced.
- **Sorbent materials**, such as pads and pillows, can be stuffed in cracks to prevent oil from penetrating into the structure, although this is fairly labour-intensive.
- **Bioremediation** could be used as a final polishing tactic if the nutrients can be applied in an efficient manner to ensure that they come into contact with the residual oil.

Precautions

- In most cases, it is not practical or effective to remove boulders from this type of shoreline. Boulder-size sediments could form a strong armour layer and in most cases would not be replaced naturally. Therefore, avoid removal without replacement as it could lead to retreat of the beach in the form of erosion.
- If there are attached animals or plants in unoiled lower tidal zones, avoid flushing or washing techniques that spread oil onto those areas.
- Avoid flushing techniques that only move the oil deeper into the sediments without flushing the oil out of the beach for recovery. Avoid washing with warm or hot water as this could temporarily mobilize viscous oil that would then penetrate more deeply into the beach sediments. The loss of heat as the oil moves through the beach or as it makes contact with cool or ambient groundwater may cause the oil to be redeposited at a lower level within the beach.

4.10 MUD FLAT

Definition

Mud flats have a level or low angled sloping surface dominated by very fine sediments – typically mud, silt, and clay with grain sizes smaller than 0.0625 mm in diameter. This may or may not include organic detritus and/or small amounts of sand.

Character

- Mud flats:
  - are always flat with low-angle slopes (less than 5°);
  - are usually wide, but range from a few metres to hundreds of metres in width;
  - are generally water-saturated and not permeable; and
  - have a mobile surface layer.
- Mud flats are usually located adjacent to low-lying areas, lagoons, estuaries, and river mouths (deltas) as shown in Figure 4.14. They are most frequently located in sheltered wave-energy environments.
- They are typically drained by steep-sided creeks or channels which could hinder access.
- Mud flats can be found in conjunction with boulder flats and marshes. They are often located in the lower intertidal zone and give way to a beach or marsh in the upper intertidal and supratidal zones.

Behaviour of Oil

- Mud flats are frequently water-saturated at or just below the surface of the sediments. The potential for natural penetration of oil is usually limited, although light oils can mix with the water in the sediments.
- Mud flats generally have a low weight-bearing capacity for both personnel and vehicles. As a result, oil is easily driven into or mixed with subsurface sediments where it may persist for long periods of time, i.e., years to decades.
- All but highly viscous oils would be refloated and carried landward by a rising tide. Oil is therefore more likely to concentrate on the upper tidal zones or on the crests of dry ridges rather than on the lower, water-wet, or water-saturated areas.
- Heavy viscous oils can be buried in mud flats by storm activity.

Figure 4.14 Mud Flat

- Oil may enter the subsurface through cracks in the mud or the holes of burrowing animals such as clams and worms and may persist for up to years.
- The surface layer of a mud flat with a high tidal range or high energy currents, e.g., Bay of Fundy or Ungava Bay, can be very dynamic. Elevation may change by several centimetres during a tidal cycle or after periods of wind-generated wave action. Most mud flats are in low wave zones, however, where there is little physical movement below the active surface layer.

Sensitivity

- Sensitivity to oil and treatment activities ranges from medium to high. Mud flats are usually very productive biological habitats with many burrowing animal species, such as snails, worms, and clams. These organisms are often a food source for shorebirds and humans.
- Due to their low weight-bearing capacity, muddy habitats are very sensitive to any activities that mix oil deeper into the sediments where it will persist.
- These shorelines are important bird habitats and are frequently used by migrant species.
- On contact with animals and birds, the impact of nonpersistent oils could be immediate and heavier oils could fill burrows and smother organisms.
- Mud flats most typically have a high sensitivity but low vulnerability to spilled oil.

Summary of Tactics

Tactics for cleaning up oil from mud flats are summarized in Table 4.9.

Preferred Response Options – Surface Oil

- In practical terms, there are limited options for removal of oil in this type of shoreline environment. Care must be taken to ensure that response activities do not cause more ecological damage than the oil. To avoid driving oil into the subsurface, less intrusive strategies are preferred. These include **herding**, **flooding** or **washing**, and collection using **sorbents** or **vacuums**.
- **Natural recovery** is the preferred option where this choice exists.
- **Flooding** or **low-pressure ambient temperature water washing** can be used to flush oil for on-water recovery.
- **Manual techniques** using rakes or picking up by hand could be used for smaller amounts of heavy oil.
- **Sorbents** could be used for passive collection of light and medium oils.
- If the mud is soft, foot traffic should be controlled to minimize negative effects. If necessary, boardwalks or wide foot gear such as snowshoes can be used to avoid trampling oil into the sediments.
- **Mechanical wet mixing** depends on suitable weight-bearing capacity and has been used effectively to release and recover oil in mud flats.
- **Barges** or **flat-bottomed boats** can be used to support operations and personnel. These can provide a form of transport in unforeseen conditions, such as an unexpected surge condition.

Preferred Response Options – Subsurface Oil

- **Manual removal** may be possible if staged from an independent weight-bearing surface or if the weight-bearing capacity of the mud allows, as might be the case on a dried mud flat.
- **Mechanical wet mixing** depends on weight-bearing capacity and has been used effectively to release and recover oil in the sediments of mud flats.

Table 4.9 Summary of Tactics for Mud Flat

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■	■	
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal			▪	▪	▪
Vacuums		■	■		
Passive sorbents		▪	▪	▪	
Mixing – wet		■	■	▪	
Oil in the subsurface sediments					
Manual removal		▪	▪	▪	▪
Mixing – wet		■	■	▪	

■ Preferred option   ▪ Possibly applicable for small amounts of oil

Precautions

- Plan operations in the shore zone to deal with the changing water levels. Factor in actual as well as predicted water level conditions. Although predicted tides are accurate at a particular site, the effects of wave action, and winds which cause surges or set-downs, can significantly and rapidly alter water levels in these flat-angle environments.
- The weight-bearing capacity of a mud flat may vary from one place to another. Some areas may not support the weight of a person or vehicle.
- Avoid mixing oil into sediments. Subsurface oil could persist for a very long time, i.e., years. Disturbing sediment can have an impact even in the absence of oil, so all movement of both personnel and vehicles in oiled and unoiled areas must be carefully controlled.

4.11 SAND FLAT

Definition

Sand flats have a level or low angled sloping surface in which the dominant sediment is sand with a grain size ranging from 0.0625 to 2.0 mm in diameter.

Character

- Sand flats:
  - are flat with low-angle slopes (<5°);
  - are usually wide, but range from a few metres to hundreds of metres in width;
  - contain finer sediments, such as mud, silt, and clay; and
  - have a very dynamic, mobile, and unstable surface layer.
- Sands flats are differentiated from:
  - sand beaches by almost level slopes and less well drained sediments;
  - mud flats by a significant component of sand; and
  - mixed sediment flats by not having significant amounts of coarse sediments (granules, pebbles, and cobbles).
- Sand flats are usually located adjacent to low-lying areas, lagoons, estuaries, and river mouths (deltas).
- The weight-bearing capacity of sand flats is variable but often low and trafficability of sand flats is typically poor for vehicles.
- Migrating waves or ripples of sand are often found on sand flats. Moving sediment can change the level of the surface by several centimetres during a single tidal cycle or after wind-generated wave action.

Two examples of sand flats are shown in Figure 4.15 and 4.16.

Figure 4.15 Aerial View of Sand Flat

Figure 4.16 Sand flats are almost level.

Behaviour of Oil

- Sand flats do not fully drain at low tide and many sections are water-saturated at or just below the surface of the sediments. The potential for oil penetration is therefore limited, although low-viscosity oils can mix with the waters in the sediments.
- All but highly viscous or dense oils would be refloated and carried landward by a rising tide. Oil is therefore more likely to concentrate on the upper tidal zones or on the crests of dry sand ridges rather than on the lower, water-wet or water-saturated areas.
- The frost table acts as a lower limit for oil penetration into the sediments. In arctic and subarctic regions during the first weeks of summer after the ice foot or fast ice melts, the depth of thaw may range from only a few centimetres to 0.5 m. As the summer progresses and the ice in the sediments melts, the depth to the frost table increases to as much as 1.0 m or more by mid- to late August. The frost table moves closer to the surface again with the onset of freezing temperatures.
- Oil can become buried in sand flats, but only if it is highly viscous or dense.
- Oil driven or mixed into subsurface sediments by vehicles or cleanup or which penetrates to the subsurface through the holes of burrowing animals may persist in the subsurface sediments for long periods, i.e., years.

Sensitivity

- Sensitivity to oil and treatment activities is low to medium. Sand flats provide habitat for a relatively high number of burrowing animals. Biological productivity is usually lower than in mud flats but higher than sand beaches.
- In many areas, these shorelines are an important bird habitat in summer as migrant species feed on zooplankton, insects, larvae, and worms.
- The impact of non-persistent, light oils could be immediate on contact with animals and heavier oils could fill animal burrows and smother organisms.

Summary of Tactics

Preferred options for cleaning up oil on sand flats are summarized in Table 4.10.

Table 4.10 Summary of Tactics for Sand Flat

	Volatile	Light	Medium	Heavy	Solid
Oil on the surface					
Natural recovery	■	■	■		
Flooding	■	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■		
Mechanical removal			■	■	■
Passive sorbents		▪	▪	▪	
Mixing – dry		■	■		
Mixing – wet		■	■	▪	
Oil in the subsurface sediments					
Manual removal		▪	▪	▪	▪
Mechanical removal			■	■	■
Mixing – dry		■	■		
Mixing – wet		■	■		

■ Preferred option ▪ Possibly applicable for small amounts of oil

Preferred Response Options – Surface Oil

- From an operations standpoint, the cleanup of oil stranded on sand flats is difficult when the weight-bearing capacity of the sand flat is low. Care must be taken that response activities do not cause more damage than the oil.
- **Natural recovery** is the preferred option if possible, particularly for small amounts of oil. It may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and could remobilize during the next thaw.
- **Flooding** can be used to flush oil onto the water surface for collection.
- **Sorbents** may be effective for low- or medium-viscosity oils.

- **Manual removal** or **vacuums** can be used for small areas of oil and vacuums may be effective for oil pooled or collected in natural depressions. If necessary, boardwalks or wide foot gear such as snow shoes should be used to prevent trampling oil into the sediments.
- Highly viscous oils can be removed mechanically when the weight-bearing capacity allows safe access.
- Oil can be trapped or contained on shore using trenches and ditches and collected on a falling (ebb) tide.
- **Mechanical wet mixing** has been used effectively to release and recover oil on sand flats if the weight-bearing capacity of the sediment allows.

Preferred Response Options – Subsurface Oil

- **Manual removal** may be possible if the weight-bearing capacity allows, as might be the case on a dry sand flat.
- **Mechanical removal** can be applicable for recovering large amounts of higher viscosity oil when weight-bearing capacity is not an issue.
- **Mechanical wet mixing** has been used effectively to release and recover oil on sand flats if the weight-bearing capacity of the beach is sufficient.

Precautions

- Plan operations in the intertidal zone to take into consideration the changing water levels. Although predicted tides are accurate at a particular site, the effects of winds and wave action can alter actual water levels.
- Surges (higher water levels – on the southern coast of the Beaufort Sea, these are associated with strong winds from the west) or set-downs (lower water levels associated with strong winds from the east on the southern coast of the Beaufort Sea) are common in all coastal environments. Factor actual rather than predicted conditions into schedules and work plans.
- The weight-bearing capacity of a sand flat can vary from one place to another and may not support the weight of a person or vehicles in some areas.
- Use barges or flat-bottomed boats to support operations and personnel. These can ground when tides or water levels fall and be refloated by the flood tide and provide a form of transport in unforeseen conditions, such as an unexpected surge condition.
- Avoid mixing oil into sediments. If this happens, subsurface oil could remain for a very long time, i.e., years. As disturbing sediment can have an impact even in the absence of oil, carefully control all movement of personnel and vehicles in both oiled and unoiled areas.

4.12 MIXED AND COARSE SEDIMENT FLAT

Definition

This shoreline type is a tidal flat composed of sand mixed with any combination of coarse sediments such as granules, pebbles, and cobbles (sand is 0.0625 mm to 2.0 mm in diameter, granules are 2 to 4 mm, pebbles are 4 to 64 mm, and cobbles range from 64 to 256 mm). For comparison, 4 mm is about the width of a pencil, 64 mm is approximately the size of a tennis ball, and 256 mm is a little larger than a soccer ball (225 m) or a basketball (240 mm). This type of shoreline is sometimes referred to as "gravel flats".

A typical coarse sediment flat is shown in Figure 4.17.

Subtypes

- This type of shore includes both mixed and coarse sediment flats where the distribution of sand and coarse sediments varies greatly.
  - On mixed sediment flats, the coarser pebble/cobble fractions are in-filled with sand or granules.
  - On coarse sediment flats, there is a distinct surface layer of coarse sediment without the sand infill.
- Mixed and coarse sediment flats are sometimes located in conjunction with mud and/or boulder flats.

Figure 4.17 Mixed Coarse Sediment Flat

Character

- Mixed sediment flats are typically wide but can range from a few metres to hundreds of metres in width. As with all tidal flats, the slope is low-angle (less than 5°).
- These flats are similar to a mixed sediment beach or pebble-cobble beach in terms of sediment composition, but the slope is almost level and the water table is higher.
- The surface layer often consists predominantly of coarser sediments (pebbles and cobbles) with increasing amounts of sand and granules in the subsurface. The thickness of the coarse surface layer may vary.
- Boulders may be scattered over the surface of the beach.
- The coarse sediment surface provides poor traction and uneven terrain for vehicles and sometimes for workers.
- In most cases, it takes a very long time, i.e., decades or not at all, for sediment to be replaced. There may be an exception when mixed-sediment flats have formed in deltas where coarse sediments are replenished by river transport to the shore zone.

Behaviour of Oil

- On a coarse-sediment flat with a pebble/cobble surface layer, oil behaves similarly as on a pebble/cobble beach. These sediments are permeable to all but the semi-solid oils and subsurface oiling is likely. Oil readily penetrates the coarse fraction until it hits the water table or a subsurface layer of sand or mixed sediment.
- On a mixed sediment flat, as the coarse surface fractions, i.e., pebbles and cobbles, are in-filled with finer sands and granules, oil behaviour is determined more by these finer fractions. In terms of oil behaviour, a mixed sediment flat is similar to a sand flat and is permeable to all light oils and some medium oils.
- Oil residence time or persistence is primarily a function of the type of oil, depth of oil penetration or burial, and wave-energy levels on the beach.
- Depth of oil burial or reworking of oiled sediments is primarily a function of wave-related processes.
- Normal wave action usually reworks only the surface layer of sediments. Oil that penetrates below the surface may not be physically reworked except during occasional high-energy storms.
- Within the coarse fractions, the potential for natural flushing of any oil is relatively high. Within the mixed sediments, however, the possibility of natural flushing is lower. If medium or heavy oils penetrate mixed sediments, a long retention time can be expected.
- Light oils are mobile and can mix with groundwater and/or be transported by changing tidal water levels.

- Oil is less likely to stay stranded in the lower elevation zones as these are typically water-saturated. As all oils except those that are highly viscous or dense would be refloated by rising water levels, oil is more likely to concentrate on the upper flats or bank zone.
- The frost table in sediments acts as a lower limit for oil penetration into the sediments. During the first weeks of summer in arctic and subarctic regions after the ice foot or fast ice melts, the depth of thaw varies from a few centimetres to 0.5 m. As the ice in the sediments melts, the depth to the frost table increases to as much as 1.0 m or more by mid- to late August. The frost table moves closer to the surface again with the onset of freezing temperatures.
- Asphalt pavements commonly form when weathered medium and heavy oils create a stable oil-sediment conglomerate.

Sensitivity

- Sensitivity to oil and treatment activities is medium to medium-high.
- Biological productivity varies but is frequently higher than on mixed sediment or pebble/cobble beaches. Detritus levels are likely to be higher and wave energy lower, providing a more stable substrate.
- In many areas, these shorelines may be an important bird habitat in summer as migrant species feed on zooplankton, insects, larvae, and worms.
- The impact of non-persistent, light oils could be immediate on contact with animals and heavier oils could fill animal burrows and smother organisms.

Summary of Tactics

Tactics for cleanup of oil in mixed and coarse sediment flats are summarized in Table 4.11.

Preferred Response Options – Surface Oil

- For response operations, this type of flat is similar to a pebble/cobble beach in terms of weight-bearing capacity and cleanup techniques.
- **Natural recovery** is a preferred option, particularly for small spills of light oils or on exposed coasts and/or in remote areas. Natural recovery may not be an appropriate choice immediately before freeze-up, however, as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- **Flooding** is a non-intrusive technique that flushes mobile oil from surface sediments for collection. Effectiveness decreases as the oil becomes more viscous and sticky.

Table 4.11 Summary of Tactics for Mixed and Coarse Sediment Tidal Flats

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	▪	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■	▪	
Mechanical removal		■	■	■	■
Passive sorbents		▪	▪	▪	
Mixing – dry		■	■	■	
Mixing – wet		■	■	■	
Bioremediation		▪	▪		
Oil in the subsurface sediments					
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal			▪	▪	
Mechanical removal		■	■	■	
Mixing – dry		■	■	■	
Mixing – wet		■	■	■	
Sediment relocation		■	■	■	
Bioremediation		▪	▪	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

- **Low-pressure, ambient-water washing** flushes mobile oil from surface sediments for collection. Although this technique is more effective than flooding for viscous oils, effectiveness decreases with increasing viscosity and stickiness.
- **Manual removal** minimizes the amount of oiled and unoiled sediment collected and may be appropriate for removing oiled sediments from the surface, patches of asphalt pavement, tar patties, and small amounts of oiled debris. The practicality decreases as the amount of oiled shoreline or oiled sediment increases. Pointed shovels are more practical than straight-edge shovels for removing oiled pebbles and cobbles.
- **Mechanical removal** is effective for recovering large amounts of oil. Equipment that removes as little unoiled sediment as possible is recommended. Because of the generally poor weight-bearing capacity of this type of sediment, **front-end loaders** are the equipment of choice, with a **backhoe** as an alternative. In most cases, it is appropriate to consult a geologist to determine how much material can be removed safely from a pebble/cobble beach without having to replace sediment.
- **Sorbents** may be useful for recovering small amounts of light and medium oils.
- **Mechanical mixing (wet or dry)** can accelerate weathering and removal of oil by water and physical abrasion.

Typical Combinations of Response Tactics

- Manual removal and vacuums can be combined with use of sorbents on surface oil patches.
- Flooding can be combined with low-pressure washing.
- Mixing can be followed by bioremediation.

Preferred Response Options – Subsurface Oil

- **Flooding** or **low-pressure, ambient temperature water washing** flushes mobile oil from subsurface sediments for collection. Effectiveness decreases with increasing viscosity, stickiness, and depth of penetration of the oil.
- **Manual removal** minimizes the amount of oiled and unoiled sediment collected and is appropriate for removing small amounts of subsurface oiled sediments. This tactic is less appropriate for deeply penetrated oil or buried oil and becomes less practical as the amount of oiled shoreline or oiled sediment increases. Clean overlying sediment should be removed and replaced to minimize waste generation. Pointed shovels are more practical than straight-edge shovels for removing oiled pebbles and cobbles.
- **Mechanical removal** is effective for recovering large amounts of semi-heavy subsurface oil. Equipment that removes as little unoiled sediment as possible is recommended. Because of the generally poor weight-bearing capacity of this type of sediment, **front-end loaders** are the equipment of choice with a **backhoe** as an alternative. In most cases, it is appropriate to consult a geologist to determine how much material can safely be removed from a pebble/cobble beach without having to replace sediment.
- **Mechanical mixing** or **sediment relocation** are appropriate for low and medium viscosity oil in subsurface sediments, possibly followed by **bioremediation**.

Precautions

- Excessive removal of sediment can lead to erosion. This is probably the greatest concern in this type of tidal flat environment, as natural replacement rates are usually very slow and can take up to decades.
- Concentrations of oil in sediment are usually very low, which means that mechanical or manual sediment removal tactics generate a large amount of waste that contains a relatively small amount of oil.
- If attached animals or plants are present in unoiled lower intertidal zones, avoid spreading oil onto those areas when using flushing or sediment relocation techniques.
- Avoid flushing techniques that only move the oil deeper into the sediments without flushing the oil out of the sediments for recovery. Warm or hot water may temporarily mobilize viscous oil that could then migrate more deeper into the subsurface sediments. The loss of heat as the oil moves through sediments or makes contact with cool or ambient temperature groundwater may redeposit the oil at a lower level within the sediments.

4.13 MARINE WETLAND — SALT MARSH

Definition

A salt marsh is a coastal zone that is covered at least once a month by salt or brackish water at high tide and that supports significant (more than 15%) non-vascular, salt-tolerant plants such as grasses, rushes, reeds, and sedges.

Subtypes

- The primary type of marine wetland is a **salt marsh**. Other marine wetlands include **mangroves**, which are found in more tropical locations, and **supratidal meadows**. This section focuses on salt marshes.
- Salt marshes vary significantly in terms of species composition, substrate character, and size. This variance is found between separate marshes and within the zones of an individual marsh.

Character

Salt water marshes are common in sheltered wave-energy environments, such as estuaries, lagoons, deltas, or behind barrier beaches. Marshes usually:

- develop above the high tide level and are only flooded during spring high tides or wind-driven surges;
- support a stable cover of surface vegetation and root system, the leafy portion of which dies back during winter months;
- vary significantly in terms of species composition between marshes;
- have distinct zones of different vegetation types (within any one marsh) that are arranged in parallel or concentric patterns in response to gradients of water depth;
- have an anoxic mud substrate;
- have muddy tidal creeks that drain during ebbing tides;
- may be fringed by intertidal mud or sand tidal flats; and
- are characterized by a surface accumulation of organic matter deposited in water, although inorganic sediments dominate the substratum.

Behaviour of Oil

- Oil can impact the (exterior) fringe of a marsh during lower tide/water levels or can be deposited on higher interior meadow areas during periods of spring tides or higher water levels. Fringe oiling may be washed by subsequent tides and weathered more rapidly, depending on energy levels. Oil would weather slowly in the meadow area, where there is little or no current and wave action.

Figure 4.18 Salt Marsh

- Most types of oil readily adhere to and are retained on the stems and leaves of vegetation. An oiled band forms when floating oil comes in contact with the stems of plants. The width, i.e., vertical height, of this oiled band depends on changes in water levels while the oil is mobile on the water surface. The water level varies with the tidal stages or due to wind effects.
- Oil may or may not adhere to the sediments. Light oils can penetrate into marsh sediments or fill animal burrows and cracks. Medium to heavy oils tend to pool on the sediments, frequently creating a tenacious tarry surface cover as they weather. Due to the low level of wave energy, the oil may persist for very long periods. The fine mud substrate prevents penetration but the oil could smother plants and animals.
- The upper leafy portion of marsh vegetation (including oiled vegetation) typically dies seasonally and is returned to the ecosystem.
- In winter months, the frost table limits the depth to which oil can penetrate.
- Natural recovery rates vary depending on the type of oil, total area affected, oil thickness, plant type, growth rates, and season during which the oiling occurred. Recovery may take as little as a few years after light oiling but can take decades in extreme circumstances such as extensive, thick deposits of viscous oil.

Sensitivity

- Salt marshes are extremely productive ecosystems. They are important to large migratory bird populations, fisheries, and resident fauna.
- Marshes are considered highly sensitive both in terms of plant and animal life and because the physical integrity of the marsh system is susceptible to physical changes or disturbance.
- Populations of birds, biological productivity, and sensitivity vary with the seasons.

Summary of Tactics

Cleanup tactics for oil in a salt marsh are summarized in Table 4.12.

Each distinct marsh warrants an individualized treatment plan based on the physical and biological character of the marsh, and on circumstances of the spill, such as oiling conditions, time of year, size of spill, type of oil, location, and usage of area. Due to multiple sensitivity issues, whether related to species or habitats, it is often essential to evaluate the net environmental benefit in order to select appropriate tactics and determine how they are used. A specialist may be required to provide judgement calls in this regard.

Preferred Response Options – Surface Oil

- **Natural recovery** is a preferred option, particularly for small amounts of surface oil. Factors influencing the selection of options include:
  - the rate of natural recovery;
  - the possible benefits of a response to accelerate recovery; and
  - any possible damage or delays in recovery that response activities may cause.

  Natural recovery may not be appropriate near the time of freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- Response activities are best carried out from a boat or using boardwalks or mats to minimize the trampling of plants.
- **Flooding** and **washing techniques** that herd oil into collection areas without extensively disturbing the vegetation cover are preferred cleanup techniques.
- **Low-pressure, ambient-water washing** removes light or medium oils without causing damage, particularly if the operation is carried out from a boat and/or crane and does not require foot or vehicle traffic on the marsh.
- For small amounts of oil, **sorbents** can be placed on the fringe of the marsh to collect oil and can be deployed and retrieved without accessing the surface of the marsh.
- Small amounts of oil can also be removed manually using boardwalks or mats to avoid damaging plants and root systems.

Table 4.12 Summary of Tactics for Salt Marsh

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■	□	
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		□	□	□	□
Vacuums		□	□		
Vegetation cutting		□	□	□	□
Passive sorbents		□	□	□	
Burning	■	■	■	■	
Oil in the subsurface sediments					
Natural recovery	■	■	■		
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal		□	□	□	□

■ Preferred option   □ Possibly applicable for small amounts of oil

- **Vacuums** can be used to remove pooled oil in depressions.
- **Vegetation cutting** has selected application. Oiled plant stems can be cut to remove the threat of sticky oil to marsh birds and animals. The effects of cutting to the plant community should be considered. Cutting is generally less harmful to plants if done late in the growing season or in the winter die-back season. Operations are best carried out from a boat or using a boardwalk to minimize the amount of trampling.
- **Burning** is effective if the potential damaging effects on plants or animals outweigh the risks associated with the continued presence of the oil, for example to birds and other wildlife. If burning is carried out, root systems should be protected by a layer of water.
- Generally, treatment activities are less likely to damage plants and root systems in late fall during the die-back phase or in winter when the substrate is frozen.

Preferred Response Options – Subsurface Oil

- **Natural recovery** is the preferred option, particularly for small amounts of subsurface oil as removal activities would likely delay recovery.
- **Flooding** and **low-pressure ambient-water washing** can flush mobile oil from the subsurface and herd oil into collection areas without extensively disturbing the vegetation cover.
- Treatment activities are less likely to damage plants and root systems in winter months during the die-back phase and when the substrate is frozen.
- Small amounts of oil can be removed manually.

Precautions

- Most activities that involve traffic on or through a marsh would delay natural recovery. Trampling of an oiled marsh can drive the oil deeper into the sediments, increasing the persistence of oil and damage to the plants from contact with the oil. Trampling of vegetation without oil also directly impacts the vegetation. Offset the effects of trampling by using boardwalks or mats, limiting the number of people and their access, and creating restricted pathways that can be restored by replanting after the cleanup.
- Cutting of oiled plant stems during the early or active growing season could affect the plants and should only be considered if leaving the oil would threaten other resources, such as migratory or nesting birds.
- Avoid burning if the lower stems and roots of a plant are dry and therefore not insulated from the heat.
- Removing sediment or mixing or disrupting the root systems, such as compacting with machinery or trampling by workers, can significantly delay recovery. Use sediment removal techniques only if it is expected to take decades for the marsh to recover.

4.14 PEAT SHORELINE

Definition

The dominant substrate of this type of shoreline is 'peat' – a spongy, compressible, fibrous material that forms from the incomplete decomposition of plant materials. The peat deposits may occur as a mat on a beach or a mobile slurry. This shoreline is common along low-lying or sheltered arctic coastlines but is also found in lower latitudes near coastal peat outcrops.

A peat shoreline is shown in Figure 4.19.

Character

- Peat layers that are relatively dry are soft and spongy, but peat can behave like a semi-solid or liquid due to its high water content (80 to 90% by weight).
- Peat has very poor weight-bearing capacity due to it low cohesion.
- Peat is eroded from tundra cliffs, which make up about 50% of the southern coast of the Beaufort Sea, or from coastal peat bogs, for example, in the southern Miramichi Bay area of the Gulf of St. Lawrence. Eroded peat tends to accumulate primarily in low-energy, sheltered areas, which is where spilled oil is also likely to accumulate.
- The quantity of inorganic material in peat is often either very low or completely absent.
- Peat mats are either wet or dry ("dewatered"), erode easily, and are redistributed by wave or current action.
- Peat slurry, which may look like "coffee grounds", occurs in the water, often at the edge of the beach or shore. It consists of thick mats of suspended peat that are more than 0.5 m thick and 5 to 10 m wide.
- Peat deposits can rest on other substrates, such as a sand beach or low-lying tundra.
- Shallow nearshore water may limit access to the site by water and make land access and possibly temporary roadways necessary.

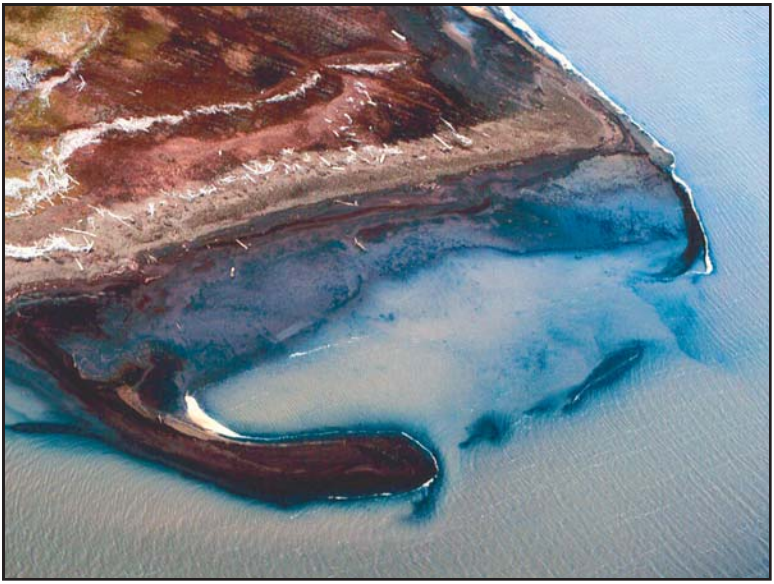

Figure 4.19 Peat Shoreline

Behaviour of Oil

- Heavy oils do not penetrate far into a peat mat, even if the mat is dry or dewatered, but may be buried or become mixed with peat where it is reworked by wave action.
- Volatile and light oils penetrate into peat more easily than heavier oils. If oil penetrates into the peat mat, relatively little recoverable oil may remain on the surface. Dry peat can hold large amounts of oil, i.e., 1 to 5 kg of oil/per kg of dry peat.
- Oils that make contact with peat slurry are likely to be mixed and remain so, especially in the low wave-energy areas where these slurries typically accumulate. The slurry has a similar effect to that of a loose granular sorbent and partially contains the oil and prevents it from spreading.

Sensitivity

- Although not typically an important biological habitat, peat shorelines are potential bird-feeding areas.

Summary of Tactics

Tactics for responding to both surface and subsurface oil on a peat shoreline are summarized in Table 4.13.

Preferred Response Options – Surface Oil

- **Natural recovery** is often the least damaging alternative for treating light and moderate oiling in inaccessible areas. Peat shorelines generally erode at rates of more than 1 m/year and oil is likely to have a short residence time in these areas. Natural cleaning may not be appropriate near the time of freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- **Low-pressure, ambient-water flooding and/or washing** can raise the local water table to float oil and peat downslope into a boomed area for collection. This tactic would probably erode large quantities of peat for subsequent transport and disposal. Customized net panels in shore-fast booms would help retain oiled peat slurries.
- **Vacuum systems**, combined with **booms** and **skimmers**, can recover deep pools of mobile oil, if the oil is not too full of debris or too viscous. Vacuum systems that can be quickly deployed are particularly appropriate for thick pools of oil stranded in lagoons or among slumped tundra blocks on beaches.
- **Nets** with a mesh finer than 1 cm can contain and collect oil mixed in a peat slurry. Nets or wire mesh can be rigged onto the bucket of a front-end loader to lift the oiled slurry out of the water, either from a barge or at the water's edge from the shoreline.
- **Rope mops** could be used to recover free oil in peat slurries when oleophilic disc skimmers cannot be deployed or are not effective.
- **Sorbents**, such as peat itself, are effective for fresh crude oil and product. The most effective technique in a peat-rich environment might be to use natural peat as a sorbent and remove the most heavily oiled fraction. Peat is more effective as a sorbent on fresh crude oil and fuels than on aged oils. Peat becomes less oleophilic when wet. Loose natural sorbents are harder to recover than the oil alone but, in peat-dominated areas, there may be no additional impact in failing to recover all the sorbents, provided that peat moss is used and that the most severely oiled patches of oiled peat are recovered.
- Small amounts of peat and peat slurries can sometimes be **manually removed**. Peat could be stacked and dewatered before being moved off site or to a disposal site.
- The most oiled portions of peat mats could by removed by raking and then applying **mixing** or **sediment relocation** to any remaining materials to accelerate physical and biological cleaning processes. If necessary, boardwalks or wide foot gear such as snow shoes can be used to avoid trampling oil into the peat.

Table 4.13 Summary of Tactics for Peat Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■		
Mechanical removal		■	■	■	■
Passive sorbents		▪	▪	▪	
Mixing – dry			▪		
Mixing – wet		■	■	▪	
Sediment relocation			■		
Oil in the subsurface sediments					
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		▪	▪	▪	▪

■ Preferred option ▪ Possibly applicable for small amounts of oil

Preferred Response Options – Subsurface Oil

- **Low-pressure, ambient-water flooding and/or washing** is used to flush light products into a boomed area for collection. This tactic would probably erode large quantities of peat, which would subsequently require transport and disposal. Customized net panels in shore-fast booms can help to retain oiled peat slurries.
- Peat and peat slurries can be **manually removed** to clean up subsurface oil under some conditions.
- The most oiled subsurface portions of peat mats can be removed by raking and then mixing any remaining materials to accelerate physical and biological cleaning processes.

Precautions

- Avoid trampling vegetation and using heavy machinery as this will likely incorporate the oil deeper into the peat. The weight-bearing capacity of peat shores is low during the open-water season, but increases after freeze-up. For summer cleanup, crews should use plank walkways or snowshoes to minimize damage and trampling.
- Although they are recommended tactics, manual oil removal, recovery of sorbents, and washing will probably promote foot traffic in peat areas.
- When the peat is found in association with tundra (which is a living plant community), minimize removal of substrate and cropping of vegetation unless it is very heavily oiled. If peat on sediment is removed, pick up only the top 2 to 5 cm, if possible.
- Avoid raking loose sorbents or peat onto living bog plants.
- Use only low-pressure flushing techniques to minimize the erosion of peat.
- Avoid burning peat or oiled debris near living plant communities.
- Avoid drainage and nutrient application on low-lying peat shorelines during cleanup as this reverses the conditions required for peat formation.

4.15 TUNDRA CLIFF SHORELINE

Definition

Tundra cliffs are an erosional feature on arctic coasts. They are composed of a tundra (vegetation) mat that usually overlies peat and exposed ground ice with varying combinations of mixed sediment layers.

Subtypes

- Ice-rich tundra cliffs are a unique type of arctic shoreline, primarily composed of the tundra mat, peat, and ice with relatively little sediment. An ice-rich tundra cliff is shown in Figure 4.20.
- Ice-poor tundra cliffs (Figure 4.21) are unconsolidated sediment cliffs with an overlying surface layer of tundra vegetation and peat. There may be minor interstitial ice in the cliff face.

The behaviour of oil and response options for ice-poor tundra cliffs are similar to those described in the earlier sections for the type of sediment supplied to the shore zone by cliff face erosion; typically sand, mixed sediment or mud (sections 4.6, 4.7, 4.10, and 4.11). The following information therefore focuses on oil behaviour and response options for ice-rich tundra cliffs where relatively little sediment is supplied to the shore zone from erosion.

Character

- Ice-rich tundra cliffs are distinct and different from cliffs formed by eroding unconsolidated sediment, which are predominantly exposed sediment which may have peat or exposed ice in the upper sections.
- As the cliff face retreats due to wave action or as thermal erosion 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 of more than 4.0 m/year (1.0 to 1.5 m/open-water month).
- Cliffs range from less than 1 m to as much as 5 or 10 m high in some cases. The cliff face is usually either exposed ground ice (permafrost) or deposits of slumped peat and tundra. Despite 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 alongshore (see Section 4.14).
- As tundra cliffs are often undercut and are naturally unstable, safety is a primary concern during operations on these shorelines.

Behaviour of Oil

- Oil washed up onto exposed ground ice is unlikely to stick and will flow down the face of the ice unless air temperatures are below freezing.
- If the peat is in the form of fragmented or slumped blocks, oil may pool in the spaces within and between the blocks. This is likely to occur at the top of a beach where both oil and peat blocks tend to accumulate.
- Oil may be splashed over a low cliff onto the tundra surface where it can persist beyond the reach of wave or water action. Sediment is often deposited on the tundra, sometimes as “perched beaches”, on exposed coasts during periods of storm wave action or wind surges.
- Oil would usually not persist for long due to natural erosion. Oil on the cliff or the slumped tundra blocks, that also erode rapidly, would be reworked and remoblilized by wave action.

Sensitivity

- The overlying tundra vegetation is composed of living plants and is sensitive to trampling and disturbance.
- Exposed ground ice surfaces do not support plant life.

Figure 4.20 Ice-rich Tundra Cliff

Figure 4.21 Ice-poor Tundra Cliff

Summary of Tactics

Cleanup tactics for oil on a tundra cliff shoreline are summarized in Table 4.14.

Preferred Response Options – Surface Oil

- **Natural recovery** is the preferred response option due to the rapid natural erosion of ice-rich tundra cliffs. Oil on the cliff face, at the top edge of a cliff, or in the tundra and peat deposits at the base of a cliff will probably be naturally removed within weeks provided that the oil is not stranded at the onset of freeze-up. Natural recovery may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- During periods of little wave action in the open-water season, the cliffs retreat as a result of warm air melting the exposed ice. At these times, oil removed from an eroding cliff by melting ice could be contained at the base of a cliff by a **berm** or **passive sorbents**.
- Oil could be washed from the cliff face by **low-pressure ambient temperature water washing** and contained and collected at the base of a cliff by a berm or **passive sorbents**. Note: Consider the safety aspects of washing noted under Precautions.
- **Manual removal** of oil or oiled tundra/peat at the base of a cliff is practical for small amounts of oil.
- **Mechanical removal** using a large or small front-end loader is more practical for larger amounts or oil or oiled material.
- **Mixing** and **sediment relocation** can be considered if these actions disperse oil without re-oiling the site of oiling adjacent areas.
- Oil that has splashed over the cliff onto the top of a tundra surface is above the normal limit of wave action and is treated in the same manner as an on-land spill.

Precautions

- As erosion of the cliffs by natural processes is normal, cleanup activities such as low-pressure washing that cause additional erosion of the cliff face are not considered to be damaging. Any erosion caused by cleanup should be minimized, however, as the vegetation on the tundra is a living community.
- Tundra cliffs are an eroding and often unstable coastal feature. Block falls, slumping, and mud flows are potential safety hazards during any response operations, particularly when cliffs are higher than 2 m. These events may occur suddenly and without warning.

Table 4.14 Summary of Tactics for Tundra Cliff Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding		■	■	■	
Low-pressure ambient washing	■	■	■		
Manual removal			▪	▪	▪
Mechanical removal		■	■	■	■
Passive sorbents		▪	▪	▪	
Mixing – dry		■	■	■	
Sediment relocation		■	■	■	

■ Preferred option ▪ Possibly applicable for small amounts of oil

- Flushing or washing activities may trigger unexpected block falls, slumping, or mud flows.
- Restrict activities to the base of the cliff whenever possible to prevent trampling or other damage to the tundra surface.
- In many areas, the beaches that front a tundra cliff are very narrow or absent so there may be little working area or room to stage equipment.
- Select cleaning techniques that minimize erosion. Although this is unlikely to cause significant environmental damage, the vegetation on the tundra is a living community.

4.16 INUNDATED LOW-LYING TUNDRA SHORELINE

Definition

This is a type of arctic shoreline characterized by very low-lying coastal tundra that is flooded or inundated by marine waters during spring high tides or wind-induced surges (Figure 4.22). In some locations, subsidence has resulted in permanent inundation of coastal tundra. This type of shoreline is dominated by vegetation, although it is not strictly a marine wetland.

Character

- Many sections of the southern coast of the Beaufort Sea are very low-lying. These areas are often "drowned" or flooded by the sea due to subsidence resulting from natural melting of the ground ice (permafrost) or from regional geological subsidence.
- Low-lying areas not normally in the intertidal zone are frequently inundated by salt water during spring high (tidal) water levels or by wind-induced (meteorological) surges. Strong westerly winds on the southern coast of the Beaufort Sea can raise the normal water levels by a metre or more and inundate these low-lying areas so that oil is stranded several hundred metres "inland". The landward limits of past surge events are usually marked by logs or debris lines.
- The shorelines of these low-lying areas are often complex and convoluted, consisting predominantly of a combination of vegetated flats, peat mats, brackish lagoons, and small streams. Any vegetation is salt-tolerant and may be more adapted to drier conditions than the aquatic plants of arctic salt marshes.
- These areas can include subsiding tundra or vegetated river banks and deltas. Areas of flooded tundra polygons have a complex configuration of interconnected ridges with pools that contain decomposing vegetation.
- During the summer, the sediments and/or peat deposits are often water-saturated so that oil may be restricted to surface areas only.
- Wave action may push sand or gravel deposits on to the backshore. These "perched beaches" rest directly on the vegetation or peat mat which is often exposed on the seaward face of the beach ridge. These are treated as either sand beaches (Section 4.6), mixed sediment beaches (Section 4.7), or pebble/cobble beaches (Section 4.8), depending on their character.
- Shallow nearshore water may limit access to the site by water and make it necessary to access the site by land and possibly to build temporary roadways.
- The complicated character of the shoreline and the presence of many water-saturated sections may make it difficult to access and move on the land.

Figure 4.22 Inundated Low-lying Tundra Shoreline

Behaviour of Oil

- The tundra has a vegetated soil or peat surface that resists penetration by heavy oil. Heavy oils can persist, however, when buried by sediments or peat deposits.
- Light oil and light refined products can penetrate the soil, especially when the soil is dry.
- Residence times for oil on untreated tundra may increase as both the viscosity of the oil and the water content of the tundra decrease.
- Complete removal of the oil by natural processes may be delayed until a storm surge.

Sensitivity

These shorelines are sensitive to trampling and vehicle traffic during the open-water season and are important bird habitats during the arctic summer.

Summary of Tactics

The preferred tactics for responding to oil on a low-lying tundra shoreline are summarized in Table 4.15.

Table 4.15 Summary of Tactics for Inundated Low-lying Tundra Shoreline

Oil on the surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	■		
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■	■	
Vegetation cutting		▪	▪	▪	▪
Passive sorbents		▪	▪	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Preferred Response Options – Surface Oil

- **Natural recovery** is often the least damaging alternative for treating light and moderate oiling, particularly where access is limited or difficult, as is often the case with this type of shoreline. This may not be appropriate immediately before freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.
- **Low-pressure, ambient water flooding and/or washing** could raise the local water table to float and direct oil towards a boomed area for collection.
- Pools of mobile oil can be recovered using **vacuum systems** combined with **booms and skimmers** if the oil is not too full of debris or too viscous. Quickly deployed vacuum systems are particularly appropriate for thick pools of oil stranded in lagoons or ponds.
- **Rope mops** can be particularly useful and could be used to recover free oil on water surfaces or from the surface of water-saturated sediments where vacuum or disc skimmers cannot be deployed or are not effective. Vertical rope mops could be deployed from cranes or similar equipment.

- **Manual tactics** using shovels or rakes could be used in small, heavily oiled areas.
- Oiled vegetation could be cut, preferably only on dry tundra surfaces.
- Surface disturbance is minimized if treatment is done during winter months when the surface material is frozen.
- **Sorbents** are effective for fresh crude oil and petroleum products. The most effective technique in a peat-rich environment might be to use natural peat as a sorbent and remove the most heavily oiled fraction. Peat is more effective on fresh crude oil and fuels than on aged oils. Dry peat should be used as peat moss becomes less oleophilic when wet. While loose natural sorbents are less easy to recover than the oil alone, in peat-dominated areas, there may be no additional impact if all of the peat is not recovered as long as the most severely oiled patches of peat are recovered.

Precautions

- Avoid trampling vegetation and using heavy machinery as this is likely to incorporate oil more deeply into sediments. The weight-bearing capacity of these low-lying areas is usually low during the open-water season, but increases after freeze-up. In summer, cleanup crews could use boardwalks or snowshoes to minimize damage and trampling.
- Where the tundra (which is a living plant community) has been oiled, minimize substrate removal and vegetation cropping unless they are very heavily oiled. If vegetation and sediment are removed, only the top 2 to 5 cm of oiled surface should be picked up if possible to avoid root damage.
- Avoid raking and trampling oil on to living plants.
- Minimize intrusive physical damage to the tundra by using only low-pressure hydraulic washing techniques.
- Avoid burning close to living plant communities.

4.17 SNOW-COVERED SHORELINE

Definition

A snow-covered shoreline can be any shoreline type with seasonal snow that is layered on top of the sediment or bedrock of the intertidal zone.

Note: Only the snow component of the shoreline is dealt with in this section. In response planning, this snow component is combined with the character of the underlying geological substrate to determine response options. The shore zone, interstitial waters, and the shore-water interface can be frozen or unfrozen, depending on air and water temperatures.

Character

- The character of the snow surface can be highly variable, ranging from:
  - fresh powder with a soft surface or drifting snow;
  - a loose granular surface that results when powder or packed powder thaws then refreezes and re-crystalizes or from an accumulation of sleet;
  - a hard, dry, crusty surface; or
  - wet slush.
- As snow accumulates in depth over time, it is common to find a vertical variation in density and porosity. Typically, this steady accumulation is interrupted by the effects of freeze-thaw cycles and wind. As the air temperature oscillates around the freezing point, layers of ice are generated as snow melts during warm daylight temperatures and freezes at night when temperatures drop below zero. If this freeze-thaw cycle is accompanied by precipitation, a range of features can form that may include alternate layers of snow and ice.

Figure 4.23 Snow-covered Shoreline

- Wind action can strip the loose crystals on the surface to expose denser layers of snow below.
- Blown, powdery snow accumulates in hollows, depressions, or wind shadows.
- Snow accumulates on another substrate so that, in practice, both the layer of snow and the underlying substrate of the shoreline are considered in response planning.
- How the oil behaves and the treatment strategies used also depend on whether the underlying sediments are frozen or not frozen.

Behaviour of Oil

- The behaviour of oil on a snow-covered shore depends on:
  - the type of snow (fresh, compacted, or containing ice layers);
  - the air temperature; and
  - the surface character of the shore (flat or sloping).
- If a spill is on the surface of the snow, oil that is above its pour point migrates vertically and horizontally. Oil migrates horizontally from a spill at the base of the snow cover. Oil that is below its pour point could penetrate minimally and run off laterally across the snow's surface.
- Oil usually penetrates rapidly into the snow column but may be hindered by layers of ice in the snow column that have formed as a result of the freeze-thaw process.
- As light oil can migrate laterally tens or hundreds of metres within snow, it may be difficult to detect. Dogs have been used to successfully locate subsurface oil in snow.
- Snow is a good natural oil sorbent. The oil content may be very low (less than 1%) in the case of light oils or if the oil has spread over a wide area.
- The proportion of oil to snow depends on the type of oil and the character of the snow. Snow absorbs more medium crude oils than light products. For example, one cubic metre (m^3) of snow can absorb up to 200 L of light oil and as much as 400 L of medium oil.
- Oil content is lowest on firm, compacted snow surfaces in below-freezing temperatures and highest for fresh snow conditions.
- Oil causes snow to melt. Crude oils cause more melting but spread less than gasoline, which spreads faster in snow and over a larger area. Light oils, such as diesel, can move upslope in snow through capillary action as they spread.
- Fresh snow blowing over oil tends to stick to the oil and migrate down into it, which increases the amount of material to be recovered.

Sensitivity

- The snow layer itself is not considered to be a sensitive environment.
- When selecting oil removal tactics, the nature and sensitivity of the underlying sediment or bedrock substrates must be considered.

Summary of Tactics

The preferred tactics for responding to oil on a snow-covered shoreline are summarized in Table 4.16.

Preferred Response Options

- **Natural recovery** is usually preferred for light oils that will evaporate during thaw periods unless the oil spill is close to sensitive habitats or populated areas.
- If the adjacent sea is ice-free and air temperatures are above freezing, **flooding** or **low pressure ambient-water washing** may be practical to flush the oiled snow onto the water surface for containment and recovery.
- **Manual removal** with shovels and rakes may be appropriate for small amounts of surface or subsurface oil, but becomes less practical as the amount of oiled area and the volume of oiled snow increases.
- Light and medium oil pooled on the surface of a snow-covered area or collected in **trenches** or by **containment berms** can be recovered by **vacuum systems**.
- On flat surfaces or if a mechanical arm can reach the oiled area, **mechanical techniques** can be used to scrape snow-covered areas for removal and disposal. These techniques could include melting to separate the oil and snow or **burning**.
- **Sorbents** could be used to remove light or medium oil on the surface, but are less effective as the oiled area or volume of oiled snow increases or in low temperatures that cause the oil to either reach its pour point or fall below it.
- **Sediment relocation** of oiled supratidal snow to the intertidal zone may be appropriate for small or large amounts of light or medium oils. Wave energy levels in the intertidal zone would quickly weather the oil. Oil could be recovered by following sediment relocation with **wet mixing** and **containment and recovery**.
- Pooled oil on the snow surface, oil that is contained by berms, or oiled snow that is collected and piled in a suitable location can be removed by **burning**. This may be suitable in remote areas where minimizing waste is an important consideration.

Table 4.16 Summary of Tactics for Snow-covered Shoreline

Oil on the snow surface	Volatile	Light	Medium	Heavy	Solid
Natural recovery	■	■	▪		
Flooding	■	■	■		
Low-pressure ambient washing	■	■	■		
Manual removal		▪	▪	▪	▪
Vacuums		■	■		
Mechanical removal		▪	■	■	■
Passive sorbents	▪	▪	▪		
Mixing – wet		■	■	▪	
Sediment relocation		■	■	▪	
Burning	■	■	■	▪	
Oil below the subsurface sediments					
Natural recovery	■	■	▪		
Flooding	■	■			
Low-pressure ambient washing	■	■			
Manual removal		▪	▪	▪	▪
Vacuums					
Mechanical removal		▪	■	■	■
Passive sorbents	▪	▪	▪		
Mixing – dry		■	■	▪	
Mixing – wet		■	■		
Sediment relocation		■	■	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

4.18 SHORELINES WITH HIGH TIDAL RANGES AND SHORELINES IN REMOTE AREAS

An oil spill in an area with a high tidal range or in a remote location will significantly change the response strategies and in turn the selection of treatment tactics. The same types of shoreline described earlier in this field guide are found in both high tidal range areas and those in remote locations. This section focuses on ways to adapt to these conditions.

4.18.1 SHORELINES WITH A HIGH TIDAL RANGE

Definition

This section deals with cleaning up and protecting any type of shoreline with a very high tidal range (more than 4 m) and/or a very wide intertidal zone. Refer to Sections 4.10, 4.11, and 4.12 for specific information about the different substrates found in the various types of tidal flats, i.e., mud flats, sand flats, and mixed and coarse sediment flats.

Character

High tidal range usually means that the environment has strong tidal currents and a very wide intertidal zone that is exposed at low tide. These coastal characteristics significantly affect how stranded oil is handled. Tidal range is not the only factor that determines the width of the intertidal zone as low slopes combined with tidal ranges of more than 2 m can produce a similar effect, for example on the coasts of the Northumberland Strait. This section focuses on coasts with either a high tidal range (more than 4 m) or low slopes with tidal ranges of 2 to 4 m.

The following regions in Canada have a high tidal range (more than 4 m):

- northern British Columbia (Prince Rupert);
- the Bay of Fundy in western Nova Scotia; and
- southeastern Baffin Island, Hudson Strait, and northern Labrador.

Regions with low slopes and mean tidal ranges of 2 to 4 m include:

- the southeast coast of Labrador; and
- the St. Lawrence estuary.

Response Considerations

- The exposure of a wide intertidal zone to oil as it washes ashore could cause the oiling of a large surface area. The rising (flood) tide can cover the intertidal zone very rapidly, particularly where slopes are low or flat. Land-based operations in the intertidal zone must be scheduled to take into account the possibility of rapidly changing water levels.

- Although predicted tides are accurate at a particular site, the effects of winds and wave action can alter actual water levels. As surges (higher water levels) or set-downs (lower water levels) are common in all coastal environments, actual rather than predicted conditions must be factored into schedules and work plans.

- Where appropriate, barges or flat-bottomed boats can be used to support operations and personnel. These can be grounded on the falling tide and will refloat on the flood tide. These boats have the added advantage of providing transport in unforeseen conditions, such as during an unexpected surge.

- Often, tidal flats do not fully drain by low tide so that the presence of surface water may prevent persistent medium- or high-viscosity oils from adhering to the sediments. These oils may then be remobilized by the rising (flood) tide. Nonpersistent or low-viscosity oils may mix with the water. In both cases, the oil tends to be carried landward, except where strong offshore or alongshore winds counteract the effect of the onshore (flood) current. Due to their viscosity and density, heavy weathered oils may not be remobilized and could be submerged by the rising (flood) tide.

- Shoreline booms or nearshore booms will probably not be very effective in areas with high tidal ranges, strong tidal currents, and rapid changes in water levels. **On-water protection** tactics are the preferred strategy as nearshore protection tactics are less likely to be effective.

4.18.2 SHORELINES IN REMOTE AREAS

Definition

Remote areas are defined as locations with little or no local infrastructure to support spill response operations. A relatively high level of logistical support is required for a shoreline treatment program. Shoreline treatment activities are conducted from temporary onshore or floating offshore/nearshore staging areas that accommodate personnel and equipment overnight.

Response Considerations

Spill response operations in remote locations must be considered in terms of access and logistical support. Response strategies for shorelines therefore focus on tactics that:

- limit the need for extensive equipment and personnel resources; and
- minimize the generation of waste.

With these two constraints in mind, the initial response objective should be to use **on-water containment and recovery strategies** to prevent oil from reaching shorelines where cleanup would be required. The remoteness factor likewise limits this option. If control on water is not feasible or practical, then the preferred shoreline treatment strategies are to:

- allow **natural oil removal** or recovery processes to the extent possible; and/or
- utilize **in-situ treatment** of oil so that environmental recovery is accelerated without the requirements for a labour-intensive effort or managing large amounts of heavy or liquid waste materials.

The basic tactics of in-situ treatment are **mixing, sediment relocation, burning** (particularly logs and debris), **dispersants**, and **bioremediation**. These are discussed in Section 5.

If an in-situ option is not applicable, then one of the other alternatives for the type of oiled shoreline should be evaluated with emphasis on logistics and waste management/disposal requirements. Types of waste and relative volumes of waste that can be generated by the different treatment techniques are discussed in Section 5.7 of this field guide.

4.19 NEARSHORE SUBMERGED AND SUNKEN OIL

Definition

Oil that reaches a body of water either floats, submerges, or sinks depending on the density of the water and the oil. The term 'submerged oil' is used to define neutrally buoyant oil that is suspended in the water below the surface, either throughout the water column or just above the bottom. 'Sunken oil' refers to oil that accumulates on the seafloor.

Submerged oil should not be confused with 'overwashed oil' near the surface of the water column, which is temporarily entrained by wave action or with sunken oil that is denser than the body of water but lifted into suspension by currents or turbulence. In both cases, the oil returns to the surface or the bottom when the mixing energy decreases.

Formation and Behaviour of Submerged and Sunken Oil

A number of factors can cause oil to submerge or sink.

- The initial density of some heavy or semi-solid oils could be greater than that of the sea water.
- Some oils that initially are less dense than sea water can lose their light components to natural weathering processes so that their density becomes the same as or greater than that of sea water.
- Oils that mix with suspended sediments in the surf zone can sink as the density increases as sediments are incorporated. As some products are close to the density of sea water, e.g., No. 6 fuel oil and Bunker C, only a relatively small increase in density is necessary to effect this change.
- Stranded oils are often mixed with shoreline sediment by wave or tidal action in the intertidal zone which increases the oil's density. If that oil-sediment mixture is then refloated by the rising tide, for example, it can be carried into the nearshore waters and submerge or sink.
- Some products are a blend of refined oils. If the blend separates after spilling, the density of the heavier component may be higher than that of sea water and it may submerge or sink.
- Emulsification of oil by physical mixing changes the density of the oil.

Sunken oil ranges from small tar balls to larger masses or mats. The 'oil' can be any combination of petroleum products, water, sediments, detritus, or vegetation. Sunken oil temporarily entrained in the water column is transported by the local currents.

Oil rises in the water column or from the sea bed under a variety of conditions. The sand may separate from the oil by gravity if that oil has not weathered to the point where the changes in viscosity prevent this process, e.g., it has become semi-heavy.

Seasonal or even daily changes in water temperature could change the viscosity and/or temperature of the oil. A change in water density where cold and warmer water meet, where fresh and salt water meet, or where surface ice melts on sea water could cause oil to rise or become submerged.

Detection of Submerged and Sunken Oil

The character of submerged oil greatly affects the ability to accurately assess the location and scale of the problem. Oil in the water column, particularly in the form of submerged droplets, is more difficult to detect than a large patch of oil resting on a sandy bottom in shallow water.

In favourable, clear water conditions, oil patches can be seen and identified to depths of up to 30 m from an aircraft, or with glass-viewing boxes from a boat, or by a diver. Diver observations are more accurate but are limited by depth, range (area), and safety considerations.

In general, these observations are made more difficult, however, by the colour of bottom sediments, fine sediments dusting over the sunken oil causing it to blend with the bottom sediments, or the presence of coarse-sediment patches, bedrock outcrops, or bottom vegetation.

Remote detection methods can be considered when visual observations are not feasible. These include remote-sensing techniques (geophysical, sonar, or acoustic), bottom-sampling devices (grab or core samplers), or remote-operated vehicles with a video system.

Recovering Submerged or Sunken Oil

Very few techniques are practical for recovering submerged nearshore oil. Towed nets may be effective depending on the viscosity of the oil and the mesh size of the net. "Snare curtains" have been used successfully but are usually relatively small, i.e., a few metres deep and wide. These may be effective on a site-specific basis to protect intakes or small channels.

It is more difficult to recover sunken oil than oil on the surface because:

- it may not be possible to see or pinpoint the location of the oil during the recovery activity;
- the oil can be relatively mobile; and
- recovery methods may involve collecting large volumes of water with the oil.

Techniques that may be appropriate for recovering submerged oil include manual recovery, the use of pumps and vacuums, nets, or dredging.

Manual recovery with nets, rakes, sieves, or stabbing devices may be practical for viscous or semi-solid oil in shallow water (less than 2 m). This is shown in Figure 4.24 where sunken oil is shovelled out of shallow water. Similarly, small amounts of viscous or semi-heavy oil can be manually recovered by divers. Snares may be useful where they can recover oil.

Vacuum systems can be used for oil that can be pumped (hand-held pumps in water up to 2 m deep or diver-held pumps in water up to 30 m deep). Vacuum systems include a mesh or filter(s) or a decanting process to separate oil and/or organic materials from the water.

Limitations

Manual techniques are limited by the area that can be efficiently covered and by visibility. In deeper water or with greater amounts of oiling, these manual recovery tactics rapidly become less effective. Vacuums and pumps recover large volumes of oil-water that must be transferred, stored, and separated.

Concentrations of submerged oil are typically very low and recovery is generally not practical.

Manual vacuum/pumping or using nets to recover the oil are generally not practical for large amounts of sunken oil on a sea or river bed in water more than 2 m deep. Commercially available dredge or pump systems may be the only practical solution for recovery. These recovery techniques generate large amounts of sediment and water that require appropriate storage and separation facilities.

Figure 4.24 Manual Recovery of Sunken Oil

5. Shoreline Treatment Tactics

5.1 INTRODUCTION

This section describes the different types of tactics and techniques used to treat or clean oiled shorelines. Shoreline treatment operations are conducted to accelerate the removal of oil and the recovery of the oiled area or to prevent stranded oil from remobilizing and possibly oiling or re-oiling adjacent sections of shoreline. Specific treatment strategies and tactics are selected based on the objective of the operation within a given shoreline segment. This objective is in turn directly related to the endpoints or cleanup standards defined by the spill management team.

It can be useful to first apply one broad primary objective to each individual shoreline segment or group of segments. This determines the overall level of effort required within an oiled area. Primary objectives include the following:

- Allow the oiled shore zone to recover naturally.
- Restore the oiled shore zone to its pre-spill condition.
- Accelerate the natural recovery of the oiled shoreline.

Within the context of the primary objective, one or more of the following secondary objectives may or may not apply when it comes to implementing treatment activities in a segment.

- Minimize remobilization of stranded oil.
- Restore the shoreline with minimal removal of material.
- Minimize damage to intertidal biota, dunes, or marsh systems.

With rare exceptions, the following universal objectives apply to all response operations.

- Avoid causing more damage to the shore zone than the oil would cause by itself.
- Use available resources in a safe, efficient, and effective manner.
- Minimize the generation and handling of waste materials.

The decision-making process for developing appropriate strategies to meet treatment objectives is described in Section 2 of this field guide. The treatment objectives can be achieved by implementing a number of specific operational strategies that include:

- monitor;
- act quickly to remove oil before it is reworked and/or buried;
- remove bulk oil and allow residue to degrade;
- minimize waste generation by using in-situ techniques;
- give preference to manual treatment techniques;
- develop a specific marsh treatment strategy; and
- use backshore riprap treatment tactics.

The relationship between objectives and response strategies is shown in Table 5.1

Table 5.1 Marine Shoreline Cleanup Objectives and Response Strategies

Strategies	Natural recovery	Restore to pre-spill condition	Accelerate natural recovery	Restore with minimal material removal	Minimize remobilization	Minimize operational damage
Monitor	✓					
Remove oil before reworked/buried		✓		✓	✓	
Remove bulk oil – leave residue to degrade			✓	✓	✓	✓
Minimize waste – use in-situ tactics			✓	✓		✓
Manual treatment tactics preferred			✓	✓		✓
Marsh treatment strategy			✓			✓
Backshore riprap tactics			✓	✓		

Shoreline Response Tactics

Twenty shoreline response tactics are described in this section. These tactics are grouped on the basis of the primary treatment strategy and are listed in Table 5.2. Each tactic group has a reference number, noted in brackets after the name of the tactic, that is used throughout this section.

Shoreline treatment or cleanup tactics should be compatible with the character of the shore zone and with the oiling conditions, i.e., the type and amount of oil. The various types of shoreline and the appropriate options for responding to an oil spill on a particular type of shoreline are discussed in Section 4.

All options except natural recovery require some form of intrusion on the ecological character of the shoreline that is being treated or cleaned. The relative impact of each option on the various types of shorelines is summarized in Table 5.3. The impact is the same regardless of the type or volume of oil involved in a spill.

Treating an oiled shoreline usually involves a phased approach with separate strategies, tactics, and endpoints for each phase. A typical sequence involves:

1. initial removal of bulk oil or oil that can be removed easily or would easily be remobilized;
2. removal of the residual coat or stain if this residue poses an environmental threat or concern; and
3. a completion phase in which sediment is replaced or staging areas, roads, fences, etc. are restored or repaired.

Although each of the twenty tactics listed in Table 5.2 is described separately in this field guide, in practice two or more are usually combined to achieve the treatment objectives. The tactics are grouped into five categories that reflect the general treatment strategy. Within these categories, the objective of each treatment tactic is defined and the tactic is described under the headings of description, applications, and constraints and limitations.

The types and amounts of waste generated by the different treatment options are briefly described. This is particularly critical to the shoreline treatment decision-making process as the amounts of waste generated by an operation are determined by the treatment endpoints and treatment tactics rather than by the actual amount of spilled or stranded oil.

This section is organized in the following manner:

Natural Recovery is discussed in Section 5.2
Physical Methods – Washing in Section 5.3
Physical Methods – Removal in Section 5.4
Physical Methods – In-situ Treatment in Section 5.5
Chemical and Biological Treatment in Section 5.6
Waste Generation in Section 5.7

Table 5.2 Shoreline Response Tactics

Natural Recovery	(1)
Physical Methods	
Washing	
Flooding	(2)
Low-pressure, ambient water wash	(3)
Low-pressure, warm/hot water wash	(4)
High-pressure, ambient water wash	(5)
High-pressure, warm/hot water wash	(6)
Steam cleaning	(7)
Sandblasting	(8)
Removal	
Manual removal	(9)
Vacuums (a) onshore and (b) nearshore	(10)
Mechanical removal	(11)
Vegetation cutting	(12)
Passive sorbents	(13)
In-situ Treatment	
Mixing (a) dry and (b) wet	(14)
Sediment relocation	(15)
Burning	(16)
Chemical and Biological Treatment	
Dispersants	(17)
Shoreline cleaners	(18)
Solidifiers	(19)
Bioremediation	(20)

Table 5.3 Summary of the Relative Impact of Response Tactics on Different Shoreline Types*

	Bedrock	Manmade solid/ice	Sand beaches	Mixed sediment	Pebble/Cobble beaches	Boulder beaches	Sand tidal flats	Mud tidal flats	Marshes	Peat	Low-lying inundated tundra	Tundra cliffs
Natural recovery	—	—	—	—	—	—	—	—	—	—	—	—
Flooding	●	●	●	●	●	●	●	●	●	●	●	●
Low-pressure, ambient wash	●	●	◒	◒	◒	●	○	○	●	●	●	●
Low-pressure, warm/hot wash	◒	●	○	◒	◒	◒	○	○	○	○	○	●
High-pressure, ambient wash	●	●	○	○	○	◒	○	○	○	○	○	○
High-pressure, warm/hot wash	◒	●	○	○	○	◒	○	○	○	○	○	○
Steam cleaning	◒	●	○	○	○	○	○	○	○	○	○	○
Sandblasting	○	◒	—	—	—	—	—	—	—	—	—	—
Manual removal	●	●	●	●	●	●	◒	○	○	○	○	●
Vacuums	●	●	●	●	●	●	◒	◒	◒	●	●	●
Mechanical removal	—	—	◒	◒	◒	◒	◒	○	○	◒	○	◒
Vegetation cutting	◒	●	—	—	—	◒	—	○	○	—	◒	—
Passive sorbents	●	●	●	●	●	●	●	●	●	●	●	●
Mixing	—	—	◒	◒	◒	—	◒	○	○	○	○	●
Sediment relocation	—	—	◒	◒	◒	—	○	○	○	○	○	●
Burning	●	●	◒	◒	◒	◒	○	○	◒	○	○	—
Dispersants	●	●	●	●	●	●	—	—	○	○	○	●
Shoreline cleaners	●	●	●	●	●	●	—	—	◒	—	—	●
Solidifiers	●	●	●	●	●	●	◒	◒	◒	●	●	●
Bioremediation	●	●	●	●	●	●	●	●	●	○	●	●

●	=	Low potential impact
◒	=	Medium potential impact
○	=	High potential impact
—	=	Not applicable

* modifed from API/NOAA, 1994

5.2 NATURAL RECOVERY (TACTIC GROUP 1)

Objective

The objective of natural recovery is to allow the oiled shoreline to recover without intervention by leaving the stranded oil to natural weathering and oil removal processes.

Description

Information on the oiling conditions, the coastal processes and physical character of the shoreline, and the resources at risk must be assessed in order to evaluate the probable consequences of allowing the oil to be naturally removed or to degrade naturally. In many circumstances, the site should be monitored over a period of time to ensure that the assessment is correct or that the rate of weathering and natural oil removal is proceeding as anticipated.

Applications

If conditions are suitable, natural recovery can be used on all types of shoreline and coastal environments and with all types of oil, as shown in Table 5.4. It is generally most appropriate for:

- small amounts of oil;
- lower viscosity, non-persistent types of oil;
- exposed shorelines, rather than sheltered shorelines with low wave-energy environments; and
- remote or inaccessible areas.

The natural recovery tactic is an option when an evaluation concludes that:

- treating or cleaning up the stranded oil may cause more damage than leaving the environment to recover naturally;
- natural recovery would not be accelerated by response techniques; or
- treating the shoreline could be unsafe for response personnel either due to the oil itself or environmental conditions such as weather, access, or other hazards.

The tradeoff or net environmental benefit analysis for each segment typically considers:

- the predicted fate and persistence of the residual oil;
- the estimated rate of natural recovery (time element);
- the possible benefits of a treatment or cleanup response in terms of accelerating recovery;
- the risks associated with the presence of the oil as it weathers; and
- the possible delays to recovery that may be caused by response activities.

Table 5.4 Applications for Natural Recovery

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline	■	■	■	□	□
Glacial and solid ice shoreline	■	■	□		
Solid manmade shoreline	■	■	■	□	□
Permeable manmade shoreline	■	■	■		
Sand beach	■	■	■		
Mixed sediment beach	■	■	■		
Pebble/Cobble beach	■	■	■		
Boulder beach	■	■	■		
Mud flat	■	■	■	■	
Sand flat	■	■	■		
Mixed and coarse sediment flat	■	■	■		
Peat shoreline	■	■	■		
Salt marsh	■	■	■	□	
Tundra cliff shoreline	■	■	■		
Inundated low-lying tundra shoreline	■	■	■		
Snow-covered shoreline	■	■	□		

■ Preferred option □ Possibly applicable for small amounts of oil

Constraints and Limitations

Natural recovery may not be appropriate if the oil spill is threatening important ecological resources or human activities or resources.

The potential for stranded oil to be remobilized and oil or re-oil adjacent resources or clean sections of shore must be considered. This threat to adjacent resources or areas may rule out the option to rely on natural recovery.

5.3 PHYSICAL METHODS OF RECOVERY – WASHING (TACTIC GROUPS 2 TO 8)

This group of tactics includes the following techniques for washing or flushing the oil from the substrate of the shoreline, including:

- flooding (tactic group 2);
- low-pressure, ambient-water washing and low-pressure, warm/hot water washing (tactics 3 and 4);
- high-pressure, ambient-water washing and high-pressure, warm/hot water washing (tactics 5 and 6);
- steam cleaning (tactic 7); and
- sandblasting (tactic 8).

When using washing techniques, the water stream usually moves the oil to a location downslope for containment, recovery, and collection for disposal. The oil is washed either:

1. onto the adjacent water where it is contained by booms and collected by skimmers or sorbents; or
2. towards a collection area, such as a lined sump or trench, where it is removed by a vacuum system, skimmer, or sorbents.

Washing techniques are distinguished from each other by the amount of pressure used and the temperature of the water. The ranges of temperature and pressure for the various types of washing and flushing tactics are shown in Table 5.5. In the table, the washing and flushing techniques are listed in order of their increasing pressure and temperature which generally improve the effectiveness of oil removal and increase the complexity of the operations and the biological effects. The tradeoff between the effectiveness of oil removal and biological effects often has to be assessed. If attached biota could be acutely affected, then temperatures should be kept below 40°C (warm).

Temperature is set by the washing unit or input water temperature and is easier to control than pressure. The pressure is a function of the unit nozzle pressure and the distance between the nozzle and point of impingement on the substrate. A dramatic difference in pressure can result from small changes in this distance. A rule of thumb would be to maintain at least 10 to 15 cm between the nozzle and the surface being cleaned. Another indicator of excessive pressure is if the blades of the common rockweed *Fucus sp.* are torn.

The equipment used to carry out the different types of washing techniques is usually available commercially.

Table 5.5 Summary of Temperature and Pressure Ranges for Washing and Flushing Tactics

Tactic	Pressure Range psi	Pressure Range bars	Temperature Range (°C)
(2) Flooding (deluge)	< 20	< 1.5	Ambient
(3) Low-pressure, ambient wash	< 50	< 3	Ambient
(4) Low-pressure, warm/hot wash	< 50	< 3	30 to 100
(5) High-pressure, ambient wash	60 to 1000	4 to 70	Ambient
(5) Pressure washing	> 1000	> 70	Ambient
(6) High-pressure, warm/hot wash	60 to 1000	4 to 70	30 to 100
(7) Steam cleaning	60 to 1000	4 to 70	100 to 200
(8) Sandblasting	~ 60	~ 4	n/a

5.3.1 FLOODING OR "DELUGE" (TACTIC GROUP 2)

Objective

The objective of this tactic is to flood a site with a large amount of ambient-temperature sea water so that mobile or remobilized oil is lifted and carried downslope to a collection area.

Description

A large amount of sea water is used to flood the surface area of impermeable bedrock or solid manmade shoreline or to raise the water table to the surface of the beach in the case of sediment shorelines. Mobile or non-sticky oil is transported with the water as it flows downslope due to gravity as shown in the inset of Figure 5.1. The oil is then collected with booms or other tactics for removal.

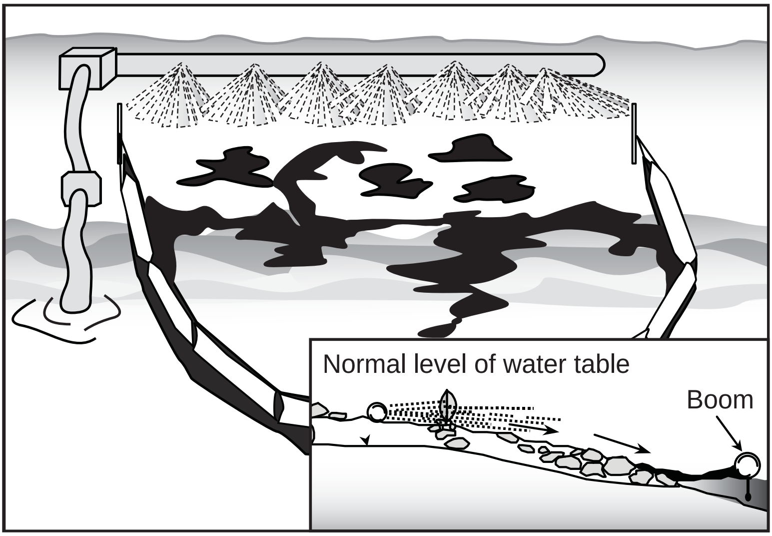

Figure 5.1 Flooding or 'deluge' with ambient sea water is used to move oil downslope to a collection area.

The high-volume (200 to 1000 L/minute), low-pressure supply of sea water at normal temperatures is pumped using large diameter pipes (10 to 20 cm) and/or hoses onto the upper section of the oiled shoreline as shown in Figure 5.1. Output pressures are low (less than 1.5 bars or approximately 20 psi).

Water is pumped onto the shoreline either directly from a hose without a nozzle as shown in Figure 5.2 or through a pipe or hose ("header") that is perforated at intervals with 0.25 to 0.5 cm holes and placed along the upper shoreline parallel to the water line as shown in Figures 5.1 and 5.3. A flexible hose is better for the latter application, as it conforms to the actual surface of the shoreline being flooded.

Applications

Flooding is practical and effective for cleaning up volatile, light, and medium oils on most types of shoreline as shown in Table 5.6. Effectiveness decreases as the viscosity of the oil increases and as the oil penetrates deeper on cobble or boulder beaches. This technique may have limited application on sand or mud flats and on steep impermeable surfaces, except when used as a low-pressure washing tactic as described in Subsections 5.3.2 and 5.3.3.

Figure 5.2 Flooding using hoses without nozzles.

Figure 5.3 Flooding with perforated header hose on the upper beach.

Table 5.6 Applications for Flooding

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline	■	■	■		
Glacial and solid ice shoreline	■	■	▪		
Permeable manmade shoreline	■	■	■		
Sand beach	■	■	■		
Mixed sediment beach	■	■	■		
Pebble/Cobble beach	■	■	■		
Boulder beach	■	■	■		
Mud flat	■	■	■		
Sand flat	■	■	■		
Mixed and coarse sediment flat	■	■	■		
Peat shoreline	■	■	■		
Tundra cliff		■	■	■	
Salt marsh	■	■	■		
Inundated low-lying tundra shoreline		■	■		

■ Preferred option ▪ Possibly applicable for small amounts of oil

This technique can be combined with trenches or sumps and vacuum systems to float and collect oil for recovery. Flooding is often used in combination with other washing techniques to transport dislodged oil and to prevent the oil from being redeposited elsewhere.

This technique generally has a low potential impact and is not intrusive in terms of ecological effects as shown in Table 5.3.

Flooding can be used to prevent oil from stranding on a shore, a shoreline protection tactic described in Section 3.8.

Constraints and Limitations

Avoid washing oil and/or sediments downslope into the lower intertidal zones that have attached plant or animal communities, particularly if these areas were not initially oiled. Work at mid-tide or higher tide levels so that oil is collected on the surface of the water when these communities are below the water line.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline.

5.3.2 LOW-PRESSURE, AMBIENT WATER WASHING (TACTIC GROUP 3)

Objective

This tactic is used to wash and flush oils at low pressure, using sea water at ambient temperatures, towards a collection area.

Description

Hand-operated or remote-controlled hoses with normal temperature sea water wash, flush, and herd oil to a collection point for recovery and removal.

Output pressures from the hose are low, less than 3 bars or 50 psi, and are usually controlled by a nozzle.

Oil that is flushed or dislodged by the low-pressure hose(s) is readily carried downslope by the flow of water. Mobile or non-sticky oil is transported with the water as it flows downslope, which prevents the oil from being redeposited elsewhere. The oil is contained and collected for removal by booms or other tactics as shown in Figure 5.4.

Applications

Washing with low-pressure, ambient temperature water is practical and effective on most types of impermeable and permeable shorelines. Specific applications are shown in Table 5.7. Effectiveness decreases as the viscosity of the oil increases and where the oil penetrates deeper into the sediments such as on cobble or boulder beaches. This technique may have limited application on sand beaches.

This tactic can be combined with **flooding** to prevent oil from being redeposited downslope.

Table 5.7 Applications for Low-pressure, Ambient Water Washing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline	■	■	■	▪	
Glacial and solid ice shoreline	■	■	■	▪	
Solid manmade shoreline	■	■	■	▪	▪
Permeable manmade shoreline	■	■	■		
Sand beach	▪				
Mixed sediment beach	▪	■	■		
Pebble/Cobble beach	▪	■	■		
Boulder beach	▪	■	■		
Mud flat	■	■	■		
Sand flat	■	■	■		
Mixed and coarse sediment flat	▪	■	■		
Peat shoreline	■	■	■		
Salt marsh	■	■	■		
Tundra cliff shoreline	■	■	■		
Inundated low-lying tundra shoreline	■	■	■		
Snow-covered shoreline	■	■	■		

■ Preferred option ▪ Possibly applicable for small amounts of oil

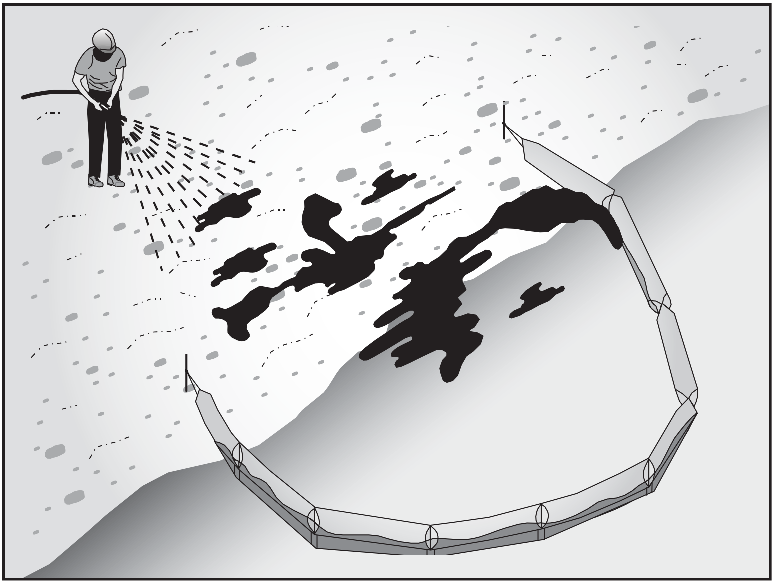

Figure 5.4 **Low-pressure ambient water washing flushes oil downslope to a collection area.**

As shown in Table 5.3, low-pressure, ambient temperature washing is generally not intrusive in terms of ecological effects as it leaves most organisms in place. It is often appropriate for use on oiled marshes or shorelines with vegetation.

Washing Constraints and Limitations

Avoid washing and flushing oil and/or sediments downslope into lower intertidal zones that have attached plant or animal communities, particularly if these areas were not initially oiled.
Work at mid-tide or higher tide levels so that oil is collected on the surface of the water when these communities are below the water line.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline. This oil may affect adjacent resources or may oil or re-oil clean shorelines.

5.3.3 LOW-PRESSURE, WARM/HOT WATER WASHING (TACTIC GROUP 4)

Objective

The objective of this tactic is to wash and flush oils towards a collection area using heated sea water at low pressure.

Description

With hand-operated or remote-controlled hoses, heated sea water is used to wash, flush, and herd oil to a collection point for recovery and removal as shown in Figure 5.5. Warm sea water dislodges and flushes oil that cannot be removed using low-pressure, ambient temperature water.

Output pressures from the hose are usually controlled by a nozzle and are low (less than 3 bars or 50 psi). Water is heated to between 30°C (warm) and 100°C (hot).

Oil that is flushed or dislodged by the low-pressure hoses is readily carried downslope by the high-volume flow of water. Mobile or dislodged oil is transported with the water as it flows downslope, which prevents the oil from being redeposited elsewhere. Booms or other tactics of trapping and containment collect the oil for removal.

This tactic is sometimes confused with steam cleaning (see Section 5.3.6) as steam is generated when the water is warmer than the ambient air temperature.

Figure 5.5 Low-pressure Warm Water Washing

Table 5.8 Applications for Low-pressure, Warm/Hot Water Washing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline			■	■	■
Glacial and solid ice shoreline			■	■	
Solid manmade shoreline	■	■	■	■	■

■ Preferred option ▪ Possibly applicable for small amounts of oil

Applications

This technique is practical and effective for cleaning up medium, heavy, and solid oils from most types of impermeable shorelines as shown in Table 5.8. It may have limited application on sand beaches, sand flats, or mixed-sediment beaches and is probably not appropriate on mud flats. Effectiveness decreases as the viscosity of the oil increases and as the oil penetrates deeper on cobble or boulder beaches.

This technique can be combined with **flooding** to prevent oil from being redeposited farther downslope.

This tactic is generally not highly intrusive in terms of ecological effects, if used carefully in conjunction with high-volume flooding.

Avoid washing if it moves warm sea water, oil, and/or sediments downslope into the lower intertidal zones that have attached plant or animal communities, particularly if these areas were not initially oiled. Work at mid-tide or higher tide levels so that oil is collected on the surface of the water when these communities are below the water line.

If used in conjunction with flooding, the potential adverse effects of using heated water on shoreline organisms are minimized as the temperature is rapidly lowered by mixing with the cooler water used in flooding.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline. If not contained, this oil could affect adjacent resources, strand on clean sediments or cleaned shorelines.

5.3.4 HIGH-PRESSURE, AMBIENT WATER WASHING (TACTIC GROUP 5)

Objectives

The objective of this tactic is to wash and flush oils towards a collection area using sea water at ambient temperatures and high pressure.

Description

With hand-operated or remote-controlled hoses with jets, sea water at ambient temperature is used to wash, flush, and herd oil to a collection point for recovery and removal. The higher water pressure provides the increased physical force required to dislodge and flush oil that cannot be removed using lower pressure, ambient temperature water. This tactic is shown in Figure 5.6.

Output pressures from the hose are usually controlled by a nozzle and exceed 4 bars or 60 psi. If pressures higher than 70 bars (1000 psi) are used, this technique is commonly referred to as pressure washing. Commercial units are available that produce up to 275 bars (approximately 4000 psi) of pressure.

Figure 5.6 High Pressure Washing

Oil that is flushed or dislodged by the high-pressure hoses is readily carried downslope by the high-volume flow of sea water. Mobilized oil is transported with the water as it flows downslope, which prevents the oil from being redeposited elsewhere. The oil can then be collected using booms or other tactics of trapping and containment and removed.

Applications

This technique is usually only used for high viscosity oil on solid surfaces such as bedrock, ice, or solid manmade shorelines as shown in Table 5.9.

On sloping outcrops or structures, this technique can be combined with **flooding** to prevent oil from being redeposited downslope.

Constraints and Limitations

High-pressure water can dislodge or damage attached healthy organisms.

Avoid washing that moves oil and/or sediments downslope to lower intertidal zones that have attached plant or animal communities, particularly if these areas were not initially oiled. Work should be conducted at mid-tide or higher tide levels so that oil is collected on the surface of the water when these communities are below the water line.

High-pressure action could emulsify the oil, if this has not occurred already.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline. This oil may affect adjacent resources or oil or re-oil clean sediments.

Table 5.9 Applications for High-pressure, Ambient Water Washing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline			■	■	■
Glacial and solid ice				▪	▪
Solid manmade shoreline			■	■	■

■ Preferred option ▪ Possibly applicable for small amounts of oil

5.3.5 HIGH-PRESSURE, WARM/HOT WATER WASHING (TACTIC GROUP 6)

Objective

This tactic uses heated sea water at high pressure to wash and flush oils towards a collection area.

Description

Hand-operated or remote-controlled hoses with heated sea water are used to wash, flush, and herd oil to a collection point for recovery and removal. The higher pressure and warm water dislodge and wash tenacious oil that cannot be dislodged by ambient-water washing tactics (Figure 5.6).

Output pressures from the unit may be fixed or controlled by a nozzle and exceed 4 bars (60 psi). Water is heated to between 30° (warm) and 100°C (hot).

Applications

This tactic is generally used only to clean heavy and solid oils from solid manmade structures, as shown in Table 5.10. It may be the only choice for very heavy residues that adhere strongly to a manmade substrate and that have resisted other washing options.

This tactic can be combined with **flooding** or **low-pressure washing** on sloping structures. Oil that is flushed or dislodged is readily carried downslope by the high volume flow of water or can be directed to a collection area by the low-pressure hoses. Mobilized oil is transported with the water as it flows downslope which prevents the oil from being redeposited elsewhere. Booms or other tactics of trapping and containment collect the oil for removal.

Table 5.10 Applications for High-pressure, Warm/Hot Water Washing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Solid manmade shoreline			■	■	■

■ Preferred option   ▪ Possibly applicable for small amounts of oil

Constraints and Limitations

High-pressure water can dislodge or damage attached healthy organisms.

Avoid washing that moves oil and/or sediments downslope to lower intertidal zones with attached plant or animal communities, particularly if these areas were not initially oiled. Work at mid-tide or higher tide levels so that oil is collected on the surface of the water when these communities are below the water line.

High-pressure action could emulsify the oil if this has not occurred already.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline. This oil may affect adjacent resources or may oil or re-oil clean sediments.

5.3.6 STEAM CLEANING (TACTIC GROUP 7)

Objective

Steam cleaning is used to remove stains or dislodge thin layers of highly viscous oils from hard, impermeable surfaces.

Description

Hand-operated or remote-controlled steam units dislodge, wash, and herd oil to a collection point for recovery and removal. The steam generates water and oil that has been flushed or dislodged is carried downslope by the flow of the water. This prevents the oil from being redeposited elsewhere. Booms or other tactics of trapping and containment collect the oil for removal.

Output pressures from the unit are generally over 4 bars (60 psi) and may be as high as 70 bars (1000 psi) with steam temperatures of over 100°C and up to 200°C.

This tactic is often confused with hot water washing, which also produces considerable amounts of steam.

Applications

As shown in Table 5.11, steam cleaning is primarily used for cleaning small amounts of persistent heavy or solid oils from solid manmade surfaces. This technique can be combined with **flooding**.

Table 5.11 Applications for Steam Cleaning

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Solid manmade shoreline			■ (possibly applicable)	■ (possibly applicable)	■ (possibly applicable)

■ Preferred option ■ Possibly applicable for small amounts of oil

Constraints and Limitations

The operator of a hand-held steam unit must follow strict safety guidelines and an assistant must be available to handle the hose system and watch the operation from close proximity.

Steam cleaning is generally very intrusive in terms of ecological effects and will kill most living organisms. It should therefore not be used in areas with extensive populations of plants or animals.

Avoid steam cleaning if it will move oil and/or sediments downslope to lower intertidal zones with attached plant or animal communities, particularly if these areas were not initially oiled. This can be avoided by working at mid-tide or higher tide levels so that oil is collected on the surface of the water at times when these communities are below the water line.

In most cases, steam cleaning will emulsify the oil, if this has not occurred already.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal. Otherwise, the technique only disperses the oil and does not clean the shoreline. This oil may affect adjacent resources or oil or re-oil clean sediments.

5.3.7 SANDBLASTING (TACTIC GROUP 8)

Objective

Sandblasting is used to remove stains or thin layers of weathered oil from hard, impermeable surfaces.

Description

Hand-operated or remote-operated sandblast units dislodge oil or abrade stains and thin weathered films of oil from a hard surface. Output pressures from the hose are usually less than 4 bars (60 psi). Spent sand and dislodged oil are collected by a drop cloth or similar arrangement below the working area.

Applications

Sandblasting is used only to remove resistant heavy or solid oils from impermeable surfaces, particularly manmade stone or concrete structures (Table 5.12).

Constraints and Limitations

The operator of a hand-held unit must follow strict safety guidelines and an assistant must be available to handle the hose system and watch the operation from close proximity.

This technique is generally very intrusive in terms of ecological effects. Sandblasting will remove all organisms and leave a clean and pristine, but barren surface.

Sandblasting systems use up to 500 kg of sand per hour and generate a high volume of waste material. Avoid moving sand and oiled sand to lower intertidal zones that have attached plant or animal communities, particularly if these were not initially oiled.

Oil attached to sand particles can separate on contact with water. Remobilized oil can be contained with booms and recovered for removal.

Table 5.12 Applications for Sandblasting

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Solid manmade shoreline				Possibly applicable	Possibly applicable

Preferred option — Possibly applicable for small amounts of oil

5.4 PHYSICAL METHODS - REMOVAL (TACTIC GROUPS 9 TO 13)

This group of tactics involves physically removing oil or oiled materials, such as sediments, debris, and vegetation, from the shore zone for disposal. They include various removal techniques ranging from:

- manual and mechanical removal (tactics 9 and 11);
- vacuuming (tactic 10);
- vegetation cutting (tactic 12); and
- passive sorbents (tactic 13).

Most of the equipment required for physical removal is also used for non-spill related activities and is available commercially. Mechanical removal tactics primarily use equipment designed for earth-moving or construction projects, although a few commercial devices are designed specifically for use in oil spill cleanup operations. Most sorbents referred to in this section are manufactured specifically for oil spills.

The size of the area, the type and amount of oil, the type of shoreline, and accessibility to the site are important factors to consider when selecting one of these tactics. Efficiency and cost are also evaluated in terms of the number of times the material is handled and the volume of waste that is generated. A **single-step transfer system**, such as a front-end loader that removes material from a beach directly into a truck, uses fewer resources than a **multiple-step transfer system**, such as a grader that sidecasts material for collection by a front-end loader or an elevating scraper.

Efficiency factors for the various physical removal tactics include:

- the relative requirements for resources;
- relative cleanup rates;
- whether they involve a single step or multiple steps; and
- the amount of waste generated.

As none of these tactics has all of the four ideal attributes of minimal requirements for resources, a rapid cleanup rate, a single-step operation, and minimal waste generation, selecting the most appropriate removal option involves some level of compromise or tradeoff.

The efficiency factors of the various physical removal tactics are summarized in Table 5.13

Table 5.13 Summary of Efficiency Factors for Physical Removal Tactics

Technique	Labour Requirements	Relative Cleanup Rate	Single- or Multiple-Step	Waste Generation
(9) Manual removal	Intensive	Slow	Multiple	Minimal
(10) Vacuums	Intensive	Slow	Multiple	Moderate
(11) Mechanical removal techniques				
Grader/Scraper	Minimal	Very rapid	Single/ Multiple	Moderate
Front-end loader	Minimal	Rapid	Single	High
Bulldozer	Minimal	Rapid	Multiple	Very high
Backhoe	Minimal	Medium	Single	High
Dragline/Clamshell	Minimal	Medium	Single	High
Beach cleaners	Minimal	Slow-Medium	Varied	Low
(12) Vegetation cutting	Intensive	Slow	Multiple	Can be high
(13) Passive sorbents	Intensive with large amounts of oil	Slow	Multiple	Can be high

5.4.1 MANUAL REMOVAL (TACTIC GROUP 9)

Objective

Oil or oiled materials, including oiled sediments, are removed using manual labour and hand tools.

Description

Cleanup teams pick up oil, oiled sediments, or oily debris with rakes, forks, trowels, shovels, sorbent materials, or buckets as shown in Figures 5.7 and 5.8. This may include scraping or wiping with sorbent materials or sieving if the oil has come ashore as tar balls. Workers wear **personal protective equipment** (PPE) that includes splash suits or rain gear, boots, and gloves.

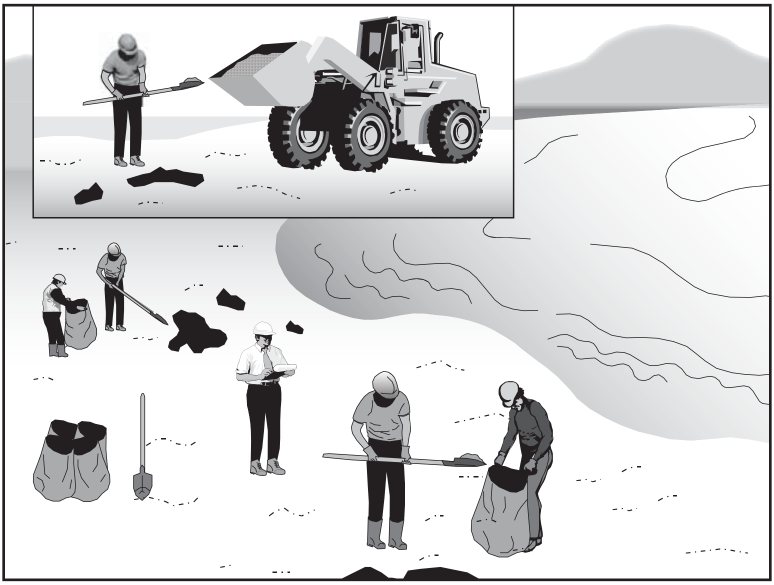

Figure 5.7 Oiled sediment is shovelled into bags or directly into front-end loader to reduce a transfer step.

Collected material is placed directly in plastic bags, drums, or other containers for transfer. If the containers are to be carried to a temporary storage area, they should not weigh more than one person can easily and safely carry. To avoid spilling, containers should not be overfilled or dragged along the ground. As an example of tactics used in combination, collected material can be placed directly into the bucket of a front-end loader, as shown in the inset in Figure 5.7.

Applications

This technique can be used practically and effectively in any location, for small amounts of oil on most types of shoreline as shown in Table 5.14. Access to the shore zone is a primary consideration. Safety must be considered in areas with rapidly changing tidal water levels, slippery bedrock outcrops, and when volatile oils are present.

Manual removal is most applicable for:

- small amounts of viscous oil, e.g., asphalt pavement;
- surface or near-surface oil; and
- areas inaccessible to vehicles or where vehicles cannot operate.

A straight-edge shovel is effective on sand beaches and a pointed shovel is usually more effective on pebble/cobble or mixed-sediment beaches.

Figure 5.8 Manual Removal of Oil with Shovels, Bags, and Buckets

Response crews should work from a clean area towards the oiled area to avoid walking on oiled patches and tracking oil into clean areas.

Although this technique is labour-intensive and progresses slowly on large oiled areas, it generates less waste than mechanical removal as shown in Table 5.13. The waste materials, such as tar balls, oiled sediment, and oiled debris, are easy to segregate during cleanup.

Vehicles or vessels are required to transfer collected materials to temporary storage or permanent disposal sites.

Table 5.14 Applications for Manual Removal

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		▪	▪	▪	▪
Glacial and solid ice shoreline		▪	▪	▪	▪
Solid manmade shoreline		▪	▪	▪	▪
Permeable manmade shoreline		▪	▪	▪	▪
Sand beach		▪	▪	▪	▪
Mixed sediment beach		▪	▪	▪	▪
Pebble/Cobble beach		▪	▪	▪	▪
Boulder beach		▪	▪	▪	▪
Mud flat			▪	▪	▪
Sand flat		▪	▪	▪	▪
Mixed and coarse sediment flat		▪	▪	▪	▪
Peat shoreline		▪	▪	▪	▪
Salt marsh		▪	▪	▪	▪
Tundra cliff shoreline			▪	▪	▪
Inundated low-lying tundra shoreline		▪	▪	▪	▪
Snow-covered shoreline		▪	▪	▪	▪

■ Preferred option ▪ Possibly applicable for small amounts of oil

Constraints and Limitations

Avoid walking in the oiled zone to prevent carrying oil into areas that have already been cleaned. In marshes and tidal flats, foot traffic can break or crush vegetation or trample oil into subsurface sediments. When large numbers of personnel are required to meet the cleanup objectives, excessive foot traffic can damage vegetated areas such as backshore dunes or disturb adjacent resources such as nesting birds.

Care should be exercised as oiled or wet bedrock and pebbles/cobbles can be very slippery leading to trips, slips, and falls.

5.4.2 VACUUMS – ONSHORE POOLED OIL (TACTIC GROUP 10A)

Objective

Vacuums are used to remove oil by suction from areas where it has pooled or collected in sumps or depressions.

Description

Commercially available vacuum equipment is used which includes small hand-carried or larger truck-mounted vacuum systems. The suction end of these units is usually deployed manually to collect oil and/or oily water as shown in Figure 5.9.

These units are not the same as mobile vacuum systems that have a fixed slot or similar suction system mounted below a mobile platform (usually a tank truck) and are not labour-intensive.

Several types of commercially available vacuum units have been designed specifically for shoreline cleanup. These involve a pump and small, detachable storage drums (0.2 m³/45 gallons). Some feature a dual-head system with water jets to mobilize oil mounted next to a suction head that lifts and recovers the oil/water mixture.

Figure 5.9 Oil Removal by Vacuum Systems

Applications

Vacuums are primarily used when oil is pooled in natural depressions and hollows or has been herded into collection areas, such as lined pits or trenches (sumps). This technique can be combined with flooding or deluge techniques to float and collect oil. The dual-head wash vacuum system is used in places that are hard to access, such as between boulders.

The types of shoreline and oil for which vacuums can be used to clean up onshore pooled oil are shown in Table 5.15

Constraints and Limitations

This tactic is used primarily to clean up large amounts of oil and is labour-intensive as the operator can only cover a small area at a time. Equipment must be moved frequently and the suction arm must be handled or operated manually. A storage unit can fill in minutes if there are large amounts of oil.

It is not safe to use vacuums with volatile oils or oils that cannot be pumped.

Table 5.15 Applications for Vacuums for Removing Onshore Pooled Oil

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		Preferred option	Preferred option	Possibly applicable for small amounts of oil	
Glacial and solid ice shoreline		Preferred option	Preferred option	Possibly applicable for small amounts of oil	
Permeable manmade shoreline		Preferred option	Preferred option	Possibly applicable for small amounts of oil	
Sand beach		Preferred option	Preferred option		
Mixed sediment beach		Preferred option	Preferred option		
Mud flat		Preferred option	Preferred option		
Sand flat		Preferred option	Preferred option		
Mixed and coarse sediment flat		Preferred option	Preferred option	Possibly applicable for small amounts of oil	
Peat shoreline		Preferred option	Preferred option		
Salt marsh		Possibly applicable for small amounts of oil	Possibly applicable for small amounts of oil		
Inundated low-lying tundra shoreline		Preferred option	Preferred option	Preferred option	
Snow-covered shoreline		Preferred option	Preferred option		

Preferred option | Possibly applicable for small amounts of oil

5.4.3 VACUUMS—NEARSHORE SUNKEN OIL (TACTIC GROUP 10B)

Objective

Vacuums are used to remove oil by suction on the sea bed in shallow water (less than 2 m deep) immediately adjacent to the shoreline.

Description

Commercially available vacuum equipment is manually deployed from the shore or mounted on a floating platform. For large amounts of mobile oil, a decanting process is required to separate oil and water. For sunken solid particles, such as tar balls, the oil can be collected in a filter or mesh.

Applications

Vacuums are one of the few practical options, along with manual recovery, for removing nearshore sunken oil in shallow waters less than 2 m deep.

Constraints and Limitations

Poor visibility due primarily to suspended sediments may limit efficiency and effectiveness in locating and removing sunken oil. An oil-water separation system or filter-mesh device is required as vacuums recover large volumes of water with the oil.

photo credit: Gavin Berg

Figure 5.10 Shallow-water Vacuuming of Sunken Oil

5.4.4 MECHANICAL REMOVAL (TACTIC GROUP 11)

Objective

Oil and oiled materials are removed using mechanical equipment.

Description

Oil and oiled surface and subsurface materials are removed from shorelines using a range of mechanical devices. Mechanical removal is faster than manual removal but generates more waste.

The method of operation varies considerably depending on the type of equipment available and its ability to operate on a particular section of shoreline. The efficiency of each type of equipment, in terms of the rate of cleaning that can be achieved and the amounts of waste generated, is shown in Table 5.13.

Elevating scrapers, front-end loaders, backhoes, or vacuum trucks can remove and transfer material directly to a truck or temporary storage area in a single step. This is shown in Figure 5.11, 5.12, and 5.13. Other equipment, such as graders, sidecast material that must then be picked up by scrapers, loaders, or backhoes for transfer. Two-staged mechanical removal is shown in Figures 5.14 and 5.15.

The various types of earth-moving equipment are summarized in Table 5.16.

Several mobile beach cleaners have been developed specifically for oil spill cleanup (Table 5.17). This equipment carries out a wide range of single-step techniques to lift or separate oil and/or oiled sediments. A common example is a mobile sieving unit drawn by a tractor that is designed for removing unoiled debris, but can be adapted to pick up tar balls and oiled debris. This is shown in Figure 5.16.

Off-site beach-cleaning machines that treat or wash oiled materials are included with this technique. These involve a waste management program of transfer and temporary storage and treatment, even if sediments are replaced on the shore. This is a multi-step process as oiled material is removed from the beach, transferred to and from the treatment site, and subsequently replaced by one or more types of earth-moving equipment.

As each of these mechanical beach-cleaning techniques generates waste, the level of effort required is comparable to other oil removal techniques. Mechanical removal options are different from mechanical in-situ treatment options that do not generate waste materials. Mechanical in-situ tactics are described in Section 5.5.

Table 5.16 Summary of Earth-moving Equipment

Machine	Technique	Applicability
Elevating Scraper	– Moves parallel to the water line, scraping off a thin layer of surface oiled sediment that is collected in a hopper – Also removes windrows	– Limited to relatively hard and flat sand beaches with surface oiling – Reduced tire pressure can extend operations
Motor Grader	– Moves parallel to the water line, side-casting off a thin layer of surface oiled sediment that forms a linear windrow – Excessive spillage may result when more than two passes are made – Usually better to create multiple windrows than to move one successively up a beach	– Limited to relatively hard sand beaches with surface oiling – Can operate on low-angle slopes – Reduced tire pressure can extend operations
Front-end Loader	– Bucket lifts oiled sediments for transfer to truck or temporary storage site – For surface oiling, bucket should lift only a thin cut to avoid removing clean sediments – Also removes windrows	– Can operate on most sediments to remove surface and subsurface oil – Traction is reduced as sediment size increases
Bulldozer	– Blade moves oiled sediments for pickup and transfer by other equipment – Least preferred earth-moving equipment, has least control of depth of cut and can mix oil into sediments	– Can operate on most sediments to move surface and subsurface oil – Traction is reduced as sediment size increases
Backhoe	– Bucket lifts oiled sediments for transfer to truck or temporary storage site – For surface oiling, bucket should lift only a thin cut to avoid removing clean sediments – Extended arm can reach from a platform or clean area	– Can operate on most sediments or on steep slopes to remove surface and subsurface oil – Traction is reduced as sediment size increases
Dragline/ Clamshell	– Bucket lifts oiled sediments for transfer to truck or temporary storage site – Extended arm can reach from a platform or clean area – Poor control of depth of cut	– Can operate on most sediments or on steep slopes to remove surface and subsurface oil

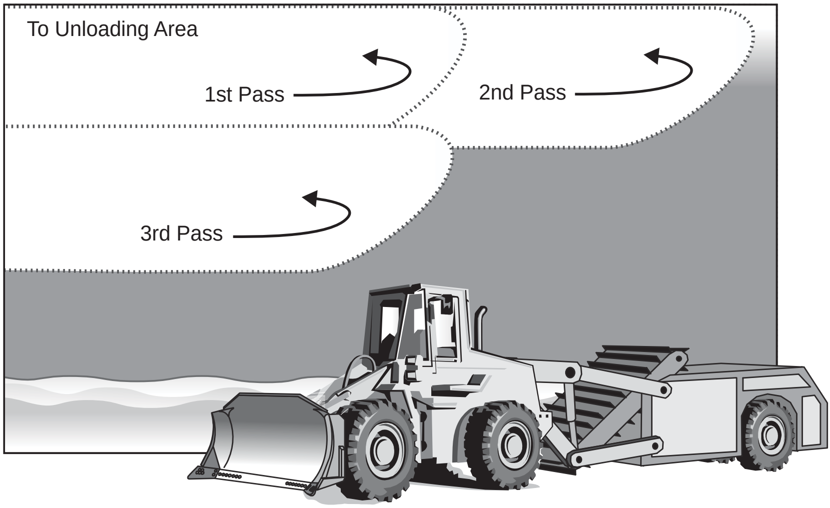

Figure 5.11 Direct Mechanical Removal Using an Elevating Scraper

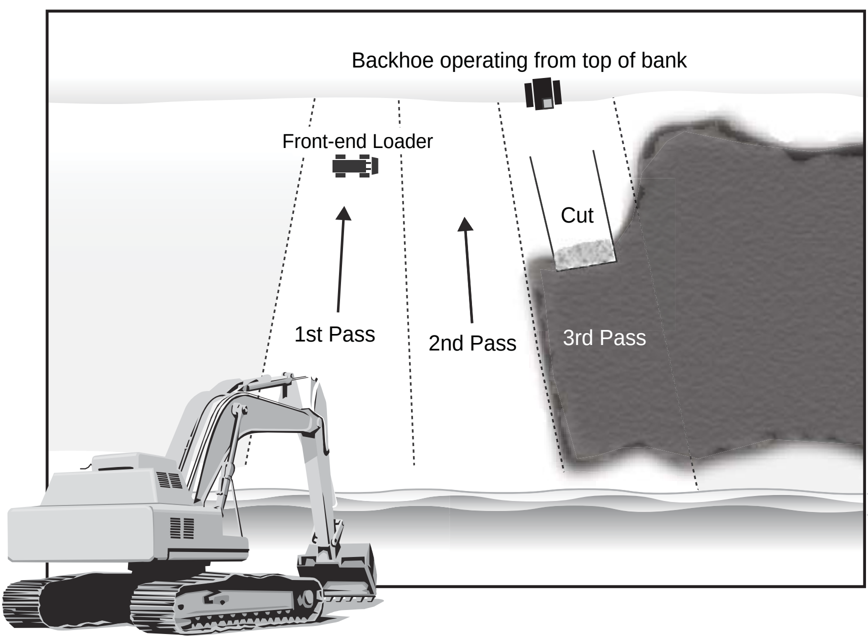

Figure 5.12 Direct Mechanical Removal Using a Backhoe

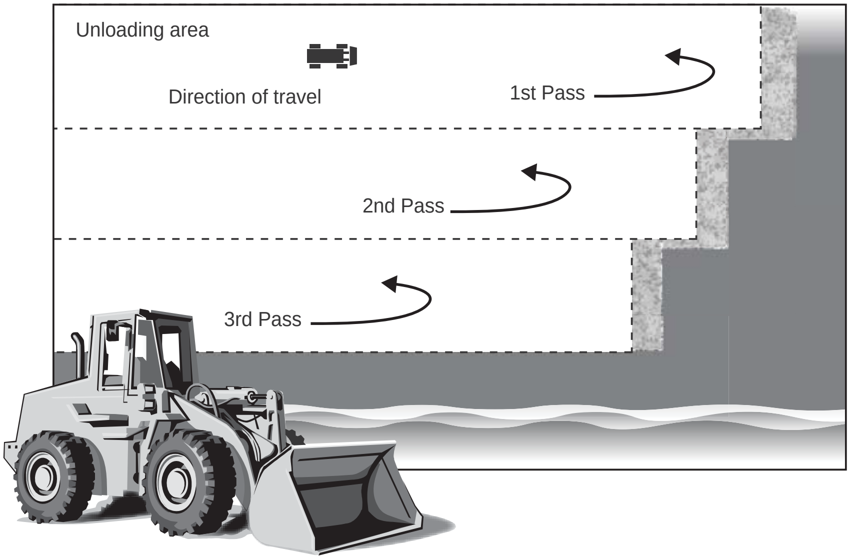

Figure 5.13 Direct Mechanical Removal Using a Front-end Loader

The illustrations in Figures 5.11 to 5.16 are intended as a guide. Operators can usually provide suggestions or improvisations to meet the cleanup objectives for a particular section of beach.

Applications

As shown in Table 5.18, mechanical removal can be used on all types of shoreline except bedrock and solid manmade shorelines. The suitability of different types of machines for cleaning up oil on shorelines is determined by the weight-bearing capacity of the sediments and the slope of the shore zone, as well as the performance characteristics of the individual equipment.

The various types of commercially available earth-moving equipment have different operational requirements and different applications, as summarized in Table 5.16. The most important variable is the weight-bearing capacity of the sediment on the shoreline, which determines whether a piece of equipment can travel on the shore without becoming immobilized. Mechanical equipment therefore has limited use on sand or mud flats due to the poor weight-bearing capacity of these sediments.

Traction for wheeled equipment on soft sediments with low weight-bearing capacity can be improved by reducing tire pressure. Although tracked equipment may be able to operate where wheeled vehicles cannot, this is not a preferred option as tracks disturb sediments much more than tires.

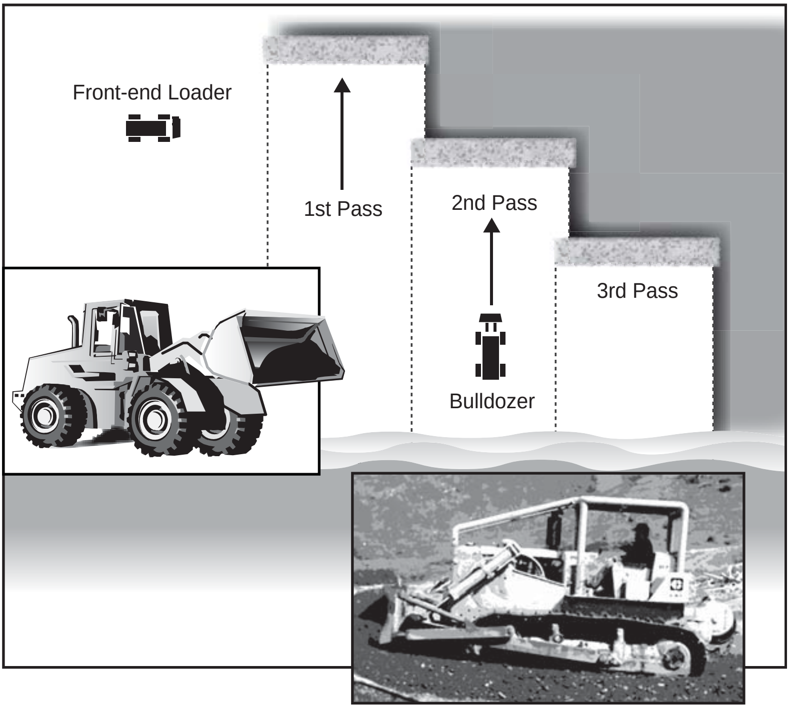

Figure 5.14 Two-stage Mechanical Removal with Bulldozer Supported by Front-end Loader

Each type of equipment has a particular application.

- Scrapers and graders operate only on hard and relatively flat surfaces and can move only a thin cut (approximately 10 cm) of surface material.
- Loaders, bulldozers, and backhoes operate in a wider range of conditions and are designed to dig and move large volumes of material.
- Backhoes, draglines, and clamshells have an extending arm or crane so that they can be operated from a barge or a backshore area and reach to pick up material.
- Beach-cleaning machines operate in a number of different ways as described in Table 5.17. Mobile equipment operates on the oiled beach, whereas other equipment operates off-site (adjacent to the oiled beach) to clean oiled sediment that has been removed and subsequently return it to the beach.
- Vacuum trucks remove pooled oil or oil collected in lined sumps.

Only elevating scrapers, front-end loaders, backhoes, draglines, clamshells, or vacuum trucks can remove material directly from the shoreline. Graders and bulldozers move material that is then removed by other types of machines.

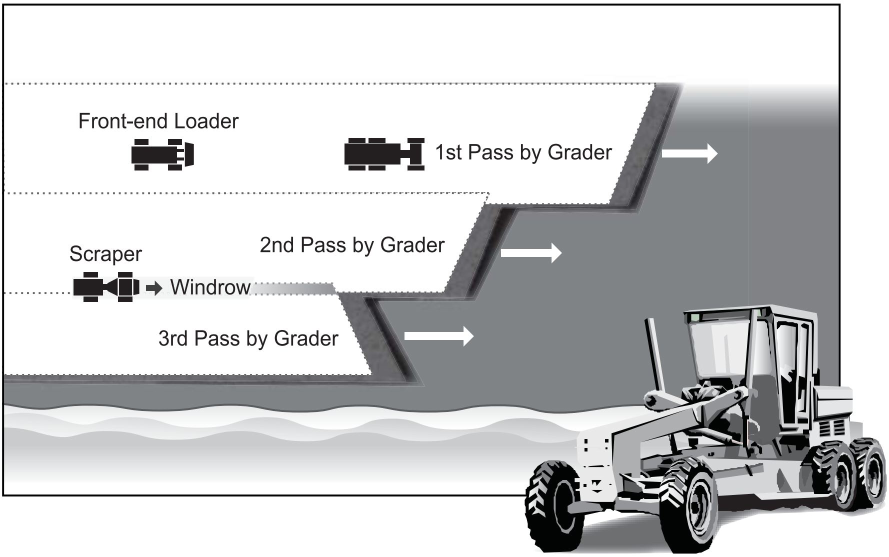

Figure 5.15 Two-stage Removal with Grader Supported by Front-end Loader or Elevating Scraper

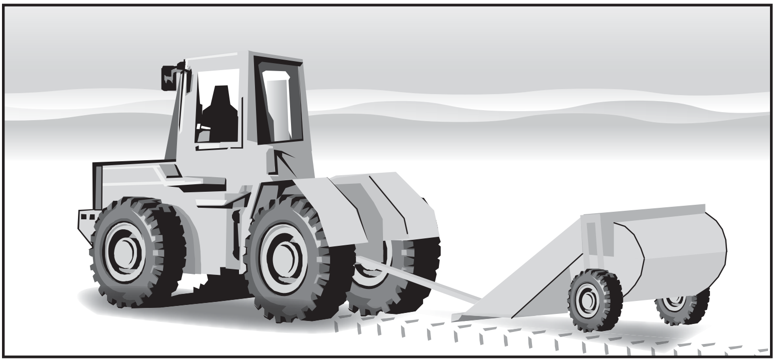

Figure 5.16 Direct Mechanical Removal Using a Mobile Beach-cleaning Machine

Table 5.17 Beach-cleaning Equipment (from Taylor et al., 1994)

Machine	Technique	Applicability
Mobile Lifters/ Sorters and Rakes	– Moving vehicle picks up oil and/or sediment by belts, brushes, rakes, scrapers, sieves, tines or water jets to separate oil from the sediments	– Usually limited to semi-solid, solid, or weathered oils that can be easily separated from clean sediments
Mobile Vacuums	– Vacuum systems with a fixed slot or similar suction system that is mounted below a mobile platform (usually a tank truck)	– Restricted to flat, hard beaches with a thin layer of surface oil
Mobile Washers	– Oiled sediments are picked up, treated, and replaced as the vehicle travels forward	– Can handle thin layers of oiled sands and most oil types – Usually slow throughput volumes
Off-site Sorters	– Oiled materials are removed from the beach, sorted or sieved, and the clean material is replaced – Oily wastes are disposed of	– Can handle most sizes of sediments, but only weathered oil types – Usually slow throughput volumes
Off-site Washers or Treaters	– Oiled materials are removed from the beach, treated, and the treated materials are replaced or disposed of	– Can handle most sizes of sediments and oil types – Usually slow throughput volumes

In almost all cases, experienced machine operators should perform test runs or trials to determine exactly how particular types of machines will be used. The applicability of one type of machine may vary locally due to changes in types of sediment and beach slope, both across shore, that is between the upper intertidal zone and the supra-tidal zone, and alongshore.

The equipment is often used to remove only a thin cut of oiled sediment. This is the opposite of conventional procedures for earth-moving which move as much material as efficiently as possible. This usually involves digging into the sediment and filling the front-end bucket. For removing surface oil, however, a thin cut and a partially filled bucket are more appropriate.

The objectives of the beach cleanup should be discussed with the contractor and/or operator so that they are aware of the desired endpoint(s). They can usually recommend the most appropriate or practical piece of equipment or removal technique to achieve a particular objective.

Table 5.18 Mechanical Removal

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Glacial and solid ice shoreline		■	■	■	■
Permeable manmade shoreline		■	■	■	■
Sand beach		■	■	■	■
Mixed sediment beach		■	■	■	■
Pebble/Cobble beach		■	■	■	■
Boulder beach		□	□	□	
Sand flat			■	■	■
Mixed and coarse sediment flat		■	■	■	■
Peat shoreline		■	■	■	■
Tundra cliff shoreline		■	■	■	■
Snow-covered shoreline		□	■	■	■

■ Preferred option □ Possibly applicable for small amounts of oil

Constraints and Limitations

If used on mud tidal flats, salt marshes, or tundra surfaces, mechanical techniques can cause significant adverse effects, either by mixing oil with the clean surface or subsurface sediments or by damaging plant stems and root systems. It is unlikely that machinery could be deployed on most boulder beaches.

Earth-moving equipment is designed to rapidly and efficiently move large amounts of material, which is not always an appropriate approach for shoreline cleanup.

Avoid repeated handling or transfer of oiled sediments as much as possible as this increases the potential for spillage and decreases efficiency.

5.4.5 VEGETATION CUTTING (TACTIC GROUP 12)

Objective

Vegetation cutting involves removing parts of oiled plants in order to prevent the oil from remobilizing or to protect animals and birds from contact with the oil.

Description

Vegetation cutting is usually a manual operation whereby scythes, knives, powered weed cutters, and/or rakes are used to cut and collect the oiled vegetation as shown in Figure 5.17. Mechanical cutters can also be used, depending on the conditions at the site, i.e., weight-bearing capacity, access to the site, and the types of plants. Floating weed cutters can be used to work close to the shoreline if the water is not too deep. This is shown in Figure 5.18.

Applications

As shown in Table 5.19, vegetation cutting is primarily used to remove small amounts of oiled vegetation from bedrock shorelines, salt marshes, and inundated low-lying tundra. It is suitable for use on a variety of different plants. It is most commonly used for oiled vegetation in wetlands or marshes and for oiled seaweeds.

Oil readily adheres to and is retained on the stems and leaves of dry vegetation. If there is extensive oiled vegetation, significant amounts of oil can be recovered by cutting and removing this vegetation.

This tactic is most applicable when:

- the continued presence of oil on vegetation could threaten animals and birds that use the area;
- oil on vegetation could be remobilized and released to oil other adjacent areas; or
- the oiled vegetation, either intact or detached, could adversely affect adjacent healthy organisms.

Figure 5.17 Manual Cutting of Vegetation

Constraints and Limitations

The effects of cutting marine vegetation at different times of the year are not well documented. It is assumed that cutting oiled vegetation during the active growing season could adversely affect the plant and should only be considered if the risk of leaving the oil threatens other resources, e.g., migratory or nesting birds, as the loss of plants or stems removes habitat for some species.

Where the option exists, cut vegetation late in the growing season or during the winter die-back season to minimize risk to the plants.

When cutting, remove only the oiled parts of the plant. For example, it is less intrusive to cut only the stem at the oiled level and leave the lower unoiled parts of the stem and roots systems intact.

In marshes, cut plants from a boat or using boardwalks or mats as foot traffic can damage the plants and trample oil into the sediments.

Figure 5.18 On-water Vegetation Cutting and Removal Using a Reed Harvester

Table 5.19 Applications for Vegetation Cutting

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		■	■	■	■
Salt marsh		■	■	■	■
Inundated low-lying tundra shoreline		■	■	■	■

■ Preferred option ■ Possibly applicable for small amounts of oil

5.4.6 PASSIVE SORBENTS (TACTIC GROUP 13)

Objective

Sorbent materials are placed and left in fixed locations to collect oil that comes in contact with the sorbent.

Description

Sorbent materials can be used in both protection and cleanup mode. They are placed in the shore zone to collect floating oil as it comes ashore or to collect remobilized stranded oil as it leaches off the shoreline and out of the shoreline sediments. This is shown in Figure 5.19. Commercially available sorbents are supplied as pads, rugs, blankets, rolls, sweeps, pillows, or booms. Locally available materials, such as straw or peat, are sometimes used but are usually less effective and efficient than commercial sorbents.

Sorbent booms or sweeps are usually fixed in place with stakes and/or anchors in a line or parallel lines to form a floating barrier that moves with the tide at the water's edge. Individual sorbents can also be staked to swing over a fixed area in the intertidal zone.

In both the protection and cleanup modes, the sorbent material is left to collect oil on contact for subsequent removal and disposal. Certain types of sorbents can be cleaned and reused.

This technique is not the same as using sorbent materials to manually remove oil, which is described in Section 5.4.1 (Tactic 9).

Applications

As shown in Table 5.20, sorbents can be used on any type of shoreline and for most types of oil, although they are less effective for very viscous semi-solid or solid oils and volatile types of oil.

Sorbents are often used as a followup technique after bulk oil has been removed or in areas where access is difficult.

In a peat-rich environment, natural peat can be used as a sorbent on fresh crude oil and products.

Figure 5.19 Passive Use of Sorbents Anchored in the Intertidal Zone to Collect Oil on Contact

Constraints and Limitations

Sorbents quickly reach their capacity when in contact with large amounts of oil. They must be replaced frequently, even when dealing with relatively small amounts of oil. This is labour-intensive and can generate large amounts of waste on a daily basis.

If poorly secured, lines of sorbents on ropes become tangled quickly. Cutting the entangled sorbents for bagging and removal is time-consuming and difficult.

Loose sorbents, such as cork, peat moss, wood chips, and sawdust, are generally not used as they are difficult to contain and may sink or migrate into non-oiled areas.

Table 5.20 Applications for Sorbents

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		□	□	□	
Glacial and solid ice shoreline	□	□	□		
Solid manmade shoreline	□	□	□	□	
Permeable manmade shoreline		□	□	□	
Sand beach		□	□		
Mixed sediment beach		□	□		
Pebble/Cobble beach		□	□	□	
Boulder beach		□	□	□	
Mud flat		□	□	□	
Sand flat		□	□	□	
Mixed and coarse sediment flat		□	□	□	
Peat shoreline		□	□	□	
Salt marsh		□	□	□	
Tundra cliff shoreline		□	□	□	
Inundated low-lying tundra shoreline		□	□	□	
Snow-covered shoreline	□	□	□		

■ Preferred option □ Possibly applicable for small amounts of oil

5.5 PHYSICAL METHODS – IN-SITU TREATMENT (TACTIC GROUPS 14 TO 16)

These treatment tactics are conducted on site and in situ, which minimizes the generation or recovery of oiled materials requiring transfer and disposal. In-situ treatment tactics presented in this section include:

- **mechanical mixing** (also known as tilling, land farming, or aeration) (tactic group 14);
- **sediment relocation** (also known as berm relocation or surf washing) (tactic group 15); and
- **burning** (tactic group 16).

Dispersants, **nutrient enhancement**, or **bioremediation** are other forms of in-situ treatment that are discussed in Section 5.6, Chemical/Biological Response.

Mechanical mixing of oiled sediments involves agitation either in the absence of water above the water line, which is called **dry mixing**, or underwater, which is referred to as **wet mixing**. In both cases, the intent is to mix or turn over the sediment in situ. This differentiates **mixing** from **sediment relocation** which involves intentionally moving sediments from one location to another.

Neither **mechanical mixing** nor **sediment relocation** entails any transfer or disposal of oiled sediments. These tactics either physically expose oiled sediments and/or move the oiled sediments to a different location in terms of wave exposure in order to promote or increase natural weathering and natural waterborne removal processes.

In some cases, oil released in the water resurfaces and is then recovered by passive **sorbents** or from within a boomed containment area. Some oil is put into fine particle suspension in the water column and is left to natural dispersion and biodegradation processes.

When evaluating the appropriateness of in-situ treatment, the consequences of not removing the oil must be considered. In particular, the anticipated change in oil weathering or natural removal rates that would be caused by the treatment should be evaluated. More detailed technical discussions on the applicability and limitations of mixing and sediment relocation are provided in Owens and Sergy, 2003 and 2004b.

5.5.1 DRY MIXING (TACTIC GROUP 14A)

Objective

Dry mixing is used to break up or increase the exposure of the surface and/or subsurface oil to both air and subsequent tides, in order to accelerate natural weathering and removal processes without removing sediment.

Description

Oiled sediments are agitated by tilling, raking, digging, or ploughing actions that physically turn over or displace sediments on the surface and subsurface. Rotary garden tillers or rakes are used to manually mix the sediments. For larger applications, heavier machinery is used including agricultural equipment, such as disc systems, harrows, ploughs, rakes or tines, or earth-moving equipment, such as rippers (tines), front-end loaders, backhoes, graders, or bulldozers. Agricultural “rippers” or “scarifiers” usually break up sediments to a depth of 50 cm whereas backhoes dig to significantly greater depths, i.e., on the order of a metre or more.

There is no removal of oiled sediments associated with dry mixing. Oil that is released during a rising tide can be contained and recovered with passive sorbents as an example.

Examples of dry mixing are shown in Figure 5.20.

Figure 5.20 Dry Mixing of Oiled Intertidal Sediments on Sand and Mixed Sediment Beaches

Table 5.21 Applications for Dry Mixing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Permeable manmade		■	■	■	
Sand beach		■	■	■	
Mixed sediment beach		■	■	■	
Pebble/Cobble beach		■	■	■	
Sand flat		▪	▪		
Mixed and coarse sediment flat		■	■	■	
Peat shoreline			▪		
Tundra cliff shoreline		■	■	■	
Snow-covered shoreline		■	■	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Applications

Dry mixing increases the exposure of oiled sediments on the surface and in the subsurface to air and water and/or breaks up a layer of oil on the surface to prevent the formation of asphalt pavement. Dry mixing reduces the compaction of the sediment and enhances penetration of air and water.

This technique can be used to remove oil from sand, pebble, cobble and mixed sediment shorelines, and from peat and tundra cliff shorelines as shown in Table 5.21. The weight-bearing capacity of the sediments on the beach or tidal flat will determine which types of equipment to use.

Dry mixing is particularly useful in promoting evaporation. Safety evaluations are crucial to ensure that volatile fractions are not present in the oil.

If oil or oiled sediments have been buried by a clean layer of material, it may be appropriate to remove or sidecast that clean layer to a temporary storage location. This material is then replaced after the exposed oiled materials have been reworked and redistributed by wave action and allowed to weather.

This technique can be combined with **manual removal** to pick up exposed patches of oil or with **bioremediation**. The technique may be appropriate for use after the bulk of the oil has been removed by mechanical tactics.

On exposed coasts where sediment reworking takes advantage of wave action, effectiveness is a function of seasonal wave-energy levels. The usefulness of the technique may decrease in summer months. In sheltered or low wave-energy environments where this technique provides contact between oil and fine particles, the availability of fines should be established before this approach is selected.

Constraints and Limitations

The objective is to expose the oil and accelerate natural weathering processes, not to bury the oil as this would delay its physical breakdown or weathering.

This technique is not appropriate if it causes the release of large amounts of oil that could threaten to re-oil the beach or adjacent locations.

Be careful not to alter the shoreline in a way that would cause erosion or accretion where these processes are an issue.

This tactic may affect biological populations, i.e., infauna and epifauna/flora.

5.5.2 WET MIXING (TACTIC GROUP 14B)

Objective

Wet mixing is used to release and recover surface or subsurface oil by physically agitating intertidal sediments in shallow water (less than 1 m deep) on site.

Description

Wet mixing is used in shallow water (less than 1 m deep) either in the intertidal zone during rising or falling tides or at the water line during the tidal low-water slack. The sediments are agitated in situ to release the oil by physical abrasion. The released oil is recovered within the containment area by skimmers or sorbents.

Oiled sediments can be mixed using agricultural equipment, such as disc systems, harrows, ploughs, rakes or tines, or earth-moving equipment, such as rippers (tines), front-end loaders, or backhoes as shown in Figure 5.21 (top).

Water jets, either high-volume, low-pressure or low-volume, high-pressure, can also be used to agitate the underwater sediments within a boomed containment area, which is shown in 5.21 (middle).

Custom-designed machines that combine mechanical mixing with water jets have proven very effective. Such a machine, known as a 'Muck Monster', is shown in Figure 5.21 (bottom).

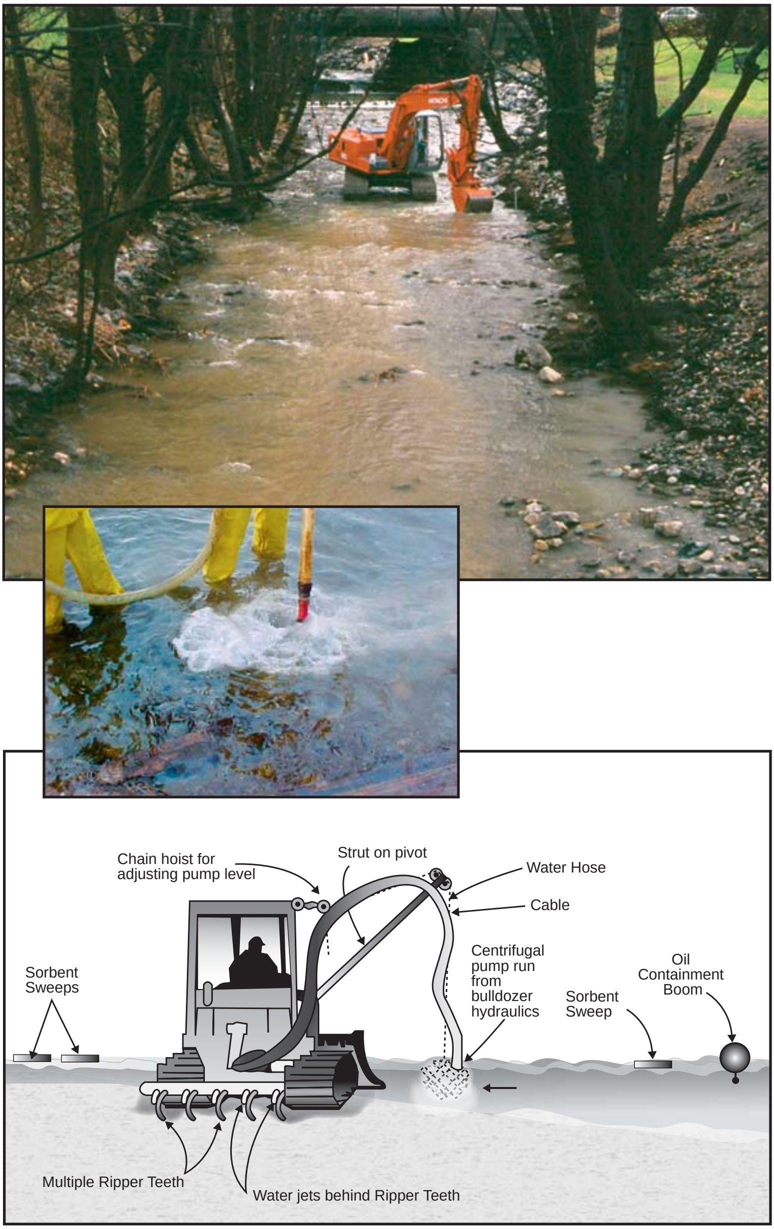

Figure 5.21 Wet Mixing Using a Backhoe (top), a Stinger to Agitate Oiled Sediments (middle), and a Custom Designed Machine (bottom), the "Muck Monster" (adapted from Miller, 1987)

Table 5.22 Applications for Wet Mixing

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Sand beach		■	■	▪	
Mixed sediment beach		■	■	▪	
Pebble/Cobble beach		■	■	▪	
Mud flat		■	■	▪	
Sand flat		■	■	▪	
Mixed and coarse sediment flat		■	■	■	
Peat shoreline		■	■	▪	
Snow-covered shoreline		■	■	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Applications

Wet mixing can be used on mud, sand, mixed sediment, pebble/cobble beaches, sand, mixed and coarse sediment flats, and peat and snow-covered shorelines for light and medium oils that will float to the water surface when agitated. It can sometimes be used to remove small amounts of heavy oil on these same types of shorelines (Table 5.22).

If the oiled sediments are in the intertidal zone, this technique is typically applied when the tide is rising.

Constraints and Limitations

The type of equipment that can be used is determined by the weight-bearing capacity of the sediments on the beach or tidal flat. Most types of equipment will not operate in water deeper than 1 m.

This tactic may adversely affect the biota living in or on the surface of the sediments.

5.5.3 SEDIMENT RELOCATION (TACTIC GROUP 15)

Objective

The objective of sediment relocation is to move oiled materials from one location to another location where there is a higher level of water movement, typically wave energy, that is available to accelerate natural oil removal processes.

Description

Earth-moving equipment, such as front-end loaders, graders, or bulldozers, is used to move the oil or oiled sediments from the surface or subsurface areas where they are protected from natural physical abrasion and weathering processes to locations where these processes are more active, such as the intertidal zone. Examples of sediment relocation are shown in Figure 5.22.

Sediment relocation differs from mixing techniques as the oiled sediments are physically moved from one location to another as opposed to being agitated in place. Although the physical movement causes mixing of the oiled sediment, the intent is to move the material to areas with higher levels of wave energy and greater potential for being washed by water, e.g., sediments are moved from above the normal high water level to the mid- or lower-intertidal zone.

Oil released from the substrate enters the water column as particulate oil, dispersed oil, or oil-mineral aggregates. The bulk of the oil dissipates in the water column and is not collected. **Passive sorbents** can be used to collect oil that resurfaces in the immediate area of the relocated sediments.

Sediment relocation can be combined with **manual removal** techniques to recover small patches of high-concentration oil uncovered during excavation.

Wet mixing techniques can be used for oiled sediments that are first relocated to shallow waters in order to accelerate the natural removal of oil by wave energy.

Figure 5.22 **Oiled sediment is relocated from the upper to the lower intertidal zone where there is a greater potential for sediment reworking.**

Table 5.23 Applications for Sediment Relocation

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Sand beach		■	■	■	
Mixed sediment beach		■	■	■	
Pebble/Cobble beach		■	■	■	
Peat shoreline			■		
Tundra cliff shoreline		■	■	■	
Snow-covered shoreline		■	■	▪	

■ Preferred option ▪ Possibly applicable for small amounts of oil

Applications

As shown in Table 5.23, this technique can be applicable for removing light, medium, and heavy oils from sand, mixed-sediment, and pebble/cobble (coarse-sediment) beaches, tundra cliff shorelines, and snow-covered shorelines, as well as medium oil from peat shorelines. It is particularly useful:

- when oiled sediments are located above the limit of normal wave action, for example, if a beach is oiled during a storm surge or a period of higher tide levels;
- when oil or oiled sediments have been buried or oil has penetrated to a depth below the zone where sediments are reworked by normal or seasonal wave action;
- for "polishing" sand or fine mixed sediments after most of the oil or oiled sediment has been removed and only light oiling, such as stains, remain;
- in promoting evaporation and physical abrasion, although safety aspects must be evaluated to ensure that volatile fractions are not present;
- when sediment removal is ruled out due to a lack of natural sediment replenishment, waste transfer and/or disposal issues, logistical constraints in remote areas, or inaccessibility to a segment location;
- immediately before expected storm events or periods of high wave-energy levels; and
- to remove stranded oil rapidly or immediately.

If oil or oiled sediments have been buried by a clean layer of material, it may be appropriate to remove or sidecast that clean layer to a temporary storage location. This material is then replaced and allowed to weather after wave action has reworked and redistributed the exposed oiled materials.

On exposed coasts where sediment reworking takes advantage of the high wave action, effectiveness depends on seasonal levels of wave energy. This technique may be less useful in summer months. In sheltered or low wave-energy environments where this technique provides contact between oil and fine particles, it should be determined whether fines are available before this approach is selected.

Constraints and Limitations

The objective is to expose the oil to physical degradation processes caused by waves, not to bury the oil as this would delay its physical breakdown or weathering.

This technique is not appropriate if it causes the release of large amounts of oil that could threaten to re-oil the beach or adjacent locations.

Oiled materials should not be moved into shoreline areas where the oil and/or the sediments could damage other resources, such as healthy, unoiled biological communities in the lower intertidal zone.

5.5.4 BURNING (TACTIC GROUP 16)

Objective

Oil, oiled debris, or oiled vegetation is burned at the site to remove or reduce the amount of oil on the shoreline.

Description

Burning is primarily used for oiled combustible materials, such as logs or debris, that can be collected and piled to facilitate burning as shown in Figure 5.23. It can also be used when vegetation has been oiled, such as in a salt marsh or wetland.

In limited circumstances, direct burning of oil on a beach can be carried out if the oil is pooled or concentrated in sumps, trenches, or other types of containers.

Burning efficiency can be improved by using fans to provide wind on piles to be burned. Torches can be used to burn oil from hard substrates, but it is labour-intensive and uses large amounts of energy to remove small amounts of oil.

In most cases, heavy or solid burned oil residues remain which must be recovered manually.

Figure 5.23 Removal of Oiled Logs by Burning

Table 5.24 Applications for Burning

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Glacial and solid ice shoreline	Preferred option	Preferred option	Preferred option	Possibly applicable for small amounts of oil	
Salt marsh	Preferred option	Preferred option	Preferred option	Preferred option	
Snow-covered shoreline	Preferred option	Preferred option	Preferred option	Possibly applicable for small amounts of oil	

Preferred option   Possibly applicable for small amounts of oil

Applications

Burning can be used for oiled logs and debris collected on any type of shoreline or when oil has been collected in sumps or drums and can be ignited with sustained combustion.

Burning is effective for directly removing light, medium, and heavy oil from glacial and solid ice (on ice or in ice leads), salt marshes, and snow-covered shorelines (Table 5.24).

Constraints and Limitations

Even when collected in sumps, heavy or emulsified oils are often difficult to ignite and/or it is difficult to sustain combustion.

Burning heavily oiled marsh vegetation when soils are dry can destroy the root systems and have a major impact on the ecosystem. Wet soils protect the root systems from heat damage so that recovery from burning is more rapid (Lin et al., 2005).

Generation of smoke may be an undesirable side effect, although this is not a health or safety issue if standard safety precautions are observed. Burning generally requires a permit from local authorities, especially if it is planned on a large scale.

5.6 CHEMICAL AND BIOLOGICAL TREATMENT (TACTIC GROUPS 17 TO 20)

This group of treatment tactics includes:

- **dispersants** (tactic group 17);
- **shoreline cleaners** (tactic group 18);
- **solidifiers** and visco-elastic agents (tactic group 19); and
- **bioremediation** (tactic group 20).

When these tactics are used, chemical or chemical/biological agents are added to the stranded oil or oiled sediments to:

- facilitate removal of the oil from the shore zone; or
- accelerate **natural recovery**, degradation, and weathering processes on site.
- the effects of adding another substance that could adversely affect the ecosystem; and
- the effects of moving oil from the shore into the water column.

Chemical and biological agents are regulated by the federal government and the appropriate approvals and compliance are required for their use.

Bioremediation by nutrient enrichment can require the use of products that have been developed for applications other than oil spills. All the other techniques use agents or materials specifically designed for oil spill response that are available commercially from manufacturers and/or suppliers. Only dispersant application and bioremediation are stand-alone techniques as the other tactics require an additional removal step.

5.6.1 DISPERSANTS (TACTIC GROUP 17)

Objective

Dispersants are used to remove oil from the shore zone by adding a chemical agent that enhances the formation of fine oil droplets, which are subsequently dispersed into the adjacent waters to biodegrade.

Description

The dispersant (or surfactant) alters the surface tension of the oil so that small oil particles form that will not stick to each other or to substrate materials. The fine oil droplets are lifted by the tides and transported away from the shore. The increased surface area accelerates weathering and degradation of the oil in the water column.

The dispersed oil is not recovered.

Dispersants are usually applied manually using either a backpack spray or a hose system. More ground can be covered faster by using mechanical spray systems from all-terrain vehicles (ATVs) or similar vehicles.

Applications

Dispersants are used to remove oil from bedrock and from solid manmade shorelines as shown in Table 5.25. They are most effective with low-viscosity and fresh oils and work to a lesser degree on higher viscosity oils.

The agent can be applied directly to an oiled area and left to work or used as a pre-soak before flooding or washing. In some cases, effectiveness is a function of mixing and the dispersant and oil may have to be mixed if this is not accomplished by wave agitation.

Different types of dispersants have been developed for different environmental conditions and varieties are available for use in fresh water, at colder temperatures, or for high-viscosity, emulsified, or weathered oils.

Table 5.25 Applications for Dispersants

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		■	■		
Solid manmade shoreline		■	■		

■ Preferred option ▪ Possibly applicable for small amounts of oil

As dispersants and **shoreline cleaners** (see Subsection 5.6.2) have opposite mechanisms, a good dispersant is a poor surface washing agent and a good shoreline cleaner is a poor dispersing agent. Once a dispersant has been applied, oil will not stick to the substrate, **sorbents**, or surface of certain types of skimmers such as discs.

Constraints and Limitations

Dispersants change the form of the oil into fine droplets and move the oil from the shore to the water column. This action changes the environmental exposure to oil, which may be either more or less acceptable.

The use of dispersants adds a chemical to the environment, which may have other side effects. Regardless of impact, such an action requires compliance with federal regulations.

5.6.2 SHORELINE CLEANERS (TACTIC GROUP 18)

Objectives

Shoreline cleaners are used to remove or lift oil from shoreline substrates by adding a chemical agent so that the oil can be contained and recovered on the adjacent waters.

Description

Shoreline cleaners, also known as surface washing agents or beach cleaners, contain a surfactant or solvent to facilitate or increase the efficiency of removal of stranded oil by washing. Whereas hydrocarbon solvents alter the viscosity of the oil, surfactants alter the surface tension of the oil by a mechanism often referred to as **detergency** so that the oil does not stick to substrate materials. The oil is lifted by the tides and may drift away from the shore unless it is recovered.

Applications

As shown in Table 5.26, shoreline cleaners can be used to remove medium and light oil from bedrock, solid manmade and permeable manmade shorelines, and pebble/cobble and boulder beaches. This technique can also be used on coarse-sediment beaches to minimize oil penetration into the subsurface.

The agent can be applied directly to an oiled area with a hand spray or hose system. It can be used directly or as a pre-soak that is left for some time before **flooding** or **washing** is carried out. The soak time varies depending on the temperature and the character of the oil. Shoreline cleaning agents can also be used in a protection mode to pre-treat shorelines and prevent oil from becoming stranded on the substrate.

Table 5.26 Applications for Shoreline Cleaners

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		Preferred option	Preferred option		
Solid manmade shoreline		Preferred option	Preferred option		
Permeable manmade shoreline		Possibly applicable	Possibly applicable		
Pebble/Cobble beach		Possibly applicable	Possibly applicable		
Boulder beach		Possibly applicable	Possibly applicable		

Preferred option | Possibly applicable for small amounts of oil

Shoreline cleaners are used in conjunction with oil collection techniques, such as **sorbents** and skimmers, to contain and recover the oil as is it released. Unlike dispersed oil, these mixtures can be recovered.

The effectiveness of this technique depends on the type of oil and decreases as the specific gravity of the oil increases. Its success also depends somewhat on the mixing of the agents with the oil and the ability to contain and recover the released oil.

As shoreline cleaning agents and **dispersants** have opposite mechanisms, a good shoreline cleaner is a poor dispersant and visa versa.

Constraints and Limitations

Shoreline cleaners expose intertidal and nearshore biota to a chemical that may have toxic side effects. Regardless of its impact, the action of adding a chemical to the environment requires compliance with federal regulations.

The effectiveness of shoreline cleaners must be verified not only to ensure that they are removing oil, but also that the oil being re-floated is contained.

5.6.3 SOLIDIFIERS (TACTIC GROUP 19)

Objective

Solidifiers are a chemical agent added to the stranded oil to alter the viscosity of the oil and thereby facilitate its collection and recovery.

Description

Solidifying agents are also known as elastomizers, gelling agents, or spill recovery enhancers. Solidifiers change the oil from a liquid to a solid in order to make recovery easier or to prevent the oil from remobilizing or spreading. The visco-elastic agents or elasticity modifiers change the elasticity of the oil.

Applications

These agents may be available in a liquid or powder form. The latter can either be applied directly or mixed with water before application. The agent is spread manually or sprayed over and mixed with the stranded oil or oiled sediments. These agents are used in conjunction with removal techniques, such as manual pickup.

Solidifiers and visco-elastic agents are most appropriate on light and medium oils. They should not be used on beach sediments with large pore spaces, such as cobble or boulders, as oil may penetrate into the subsurface sediments and become difficult to remove.

In practice, the potential applicaton of solidifiers is limited to very small areas or small volumes of oil. This tactic has rarely been used on spills.

Constraints and Limitations

The amount of agent to apply increases as the viscosity of the oil decreases. For example, it would take 10 to 20 times more agent to change the viscosity of some light fuel oils than it would for a heavy fuel oil. From 10 to 40% by weight of product to oil may be required to solidify the oil.

The effectiveness of the solidifying or visco-elastic agent depends on the cure time and the contact area. Unless mixed correctly, the application can produce a conglomeration of solid, liquid, and semi-solid oil. Effectiveness also decreases for emulsified, weathered, thick, or heavy oil due to the difficulty of mixing the agent and the oil.

Typically the end product includes a very light proportion of sediment that is encapsulated with the oil.

Precaution must be taken not to use solidifiers where they may incorporate or smother healthy plants and animals.

Adding a chemical to the environment requires compliance with federal regulations.

5.6.4 BIOREMEDIATION (TACTIC GROUP 20)

Objective

Bioremediation is a tactic used to enhance or increase the rate of biodegradation of oil in the intertidal zone by adding oil spill bioremediation agents.

Three classes of oil spill bioremediation techniques have been recognized.

- **Bioenhancement agents** contain only non-living materials such as nutrients (fertilizers containing nitrogen and phosphorus) intended to accelerate the natural oil-degrading activity of the indigenous microbial population at a spill site.
- **Bioaugmentation agents** contain living microbes and possibly also chemical agents to enhance oil biodegradation. They are intended to increase or supplement the natural rate of biodegradation of hydrocarbons at a spill site.
- **Phytoremediation** involves the use of fungi and plants to accelerate oil degradation.

Historically, bioaugmentation and phytoremediation techniques have had limited use and application for the remediation of oil on shorelines. Most bioremediation involves bioenhancement, which is adding nutrients to oiled substrates on site. This section therefore focuses on the bioenhancement approach.

Description

Naturally occurring micro-organisms (bacteria) use oxygen to convert hydrocarbons into water and carbon dioxide. This process usually occurs at the oil/water interface and is limited primarily by the availability of oxygen and nutrients and the exposed surface area of the oil. The rate of biodegradation can be accelerated if one or all of these three limiting factors can be changed.

Nutrients can be added in solid or liquid forms. Solid fertilizers, such as pellets, can be broadcast on an oiled substrate with seed spreaders used on lawns or fields. The fertilizer slowly dissolves on contact with water and releases water-soluble nutrients over time. Liquid fertilizers can be sprayed onto a shoreline using a number of commercially available types of equipment, such as paint sprayers or sprayers in back packs.

Off-site treatment of oiled sediments is similar to land farming technology and could involve bioaugmentation and/or phytoremediation as well as adding nutrients.

Applications

Bioremediation can be used to treat light and medium oils on bedrock and all other shorelines with sand, granule, pebble, cobble, or boulder sediments (Table 5.27). Bioremediation can be used where there is light oiling or on residual oil ("polishing") after mobile or bulk oil has been removed from the shoreline. This is not a short-term solution, i.e., it may take days to weeks, and it is not suitable for short-term oil removal. The agents can be reapplied periodically, i.e., in weeks or months as appropriate to continue the supply of nutrients.

Although fertilizers can be used alone on a shore to degrade residual surface and/or subsurface oil, the process is more effective if combined with **mixing** or other tactics for breaking the oil down into smaller particles. This significantly increases the surface area available to the micro-organisms. Both **mixing** and **sediment relocation** tactics increase both the availability of oxygen and the exposed surface area of the oil available for biodegradation.

Table 5.27 Applications for Bioremediation

Marine Shoreline Category	Volatile	Light	Medium	Heavy	Solid
Bedrock shoreline		▪	▪		
Permeable manmade shoreline		▪	▪		
Sand beach		▪	▪		
Mixed sediment beach		▪	▪		
Pebble/Cobble beach		▪	▪		
Boulder beach		▪	▪		
Mixed and coarse sediment flat		▪	▪		

■ Preferred option ▪ Possibly applicable for small amounts of oil

Constraints and Limitations

This is an effective but relatively slow process compared to other options.

Nutrient enrichment is more effective during warmer seasons, as the rate of biodegradation decreases with lower temperatures.

The biodegradation of the heavier components of oil and residues, such as weathered asphaltenes and resins, is very limited. It therefore has little benefit for oil from which the degradable fractions have already been removed.

Bioremediation can be used without affecting plants or animals. Nutrients should not be over-used, however, as this action can alter the normal balance of processes.

Bioremediation agents may be subject to federal and/or provincial approvals and regulations, particularly those that include viable organisms.

5.7 WASTE GENERATION

Waste generation, handling, and disposal must be considered in shoreline cleanup planning. When selecting treatment techniques, it is important to understand the types and relative amounts of waste generated by the different treatment options. This element of the decision-making process is particularly important for operations in remote areas where transferring and storing waste may be a constraint (Section 4.18.2).

The types and relative amounts of waste that are typically generated as well as the relative level of manpower required for the various shoreline treatment or cleanup options are shown in Table 5.28.

The use of oleophilic skimmers and oil-water separators can significantly reduce the high amount of liquids produced by some of these treatment options.

In Table 5.28, the terms "High" and "Moderate" refer to waste generation and indicate the relative amounts of oil and oiled wastes that can be directly generated by these activities. The term "None" refers to oily wastes. All treatment activities generate some form of operational waste.

From a waste minimization and management perspective, the preferred options are the following in-situ techniques that generate only waste materials directly related to operations or logistics and not oil or oily wastes.

- Natural recovery
- Mixing
- Sediment relocation
- Burning
- Dispersants
- Bioremediation

These treatment options are particularly attractive for operations in remote areas where it may be necessary to transport waste long distances for disposal.

Waste Generation as a Function of Spill Size

The amount of waste generated by oil spill response activities is not determined by the size or location of the spill, but rather is a direct result of the response objectives and the response activities selected by the spill management team. Managers and planners must therefore be provided with relevant information about potential types and amounts of waste that would be generated as a result of decisions made in selecting cleanup options and treatment endpoints.

Table 5.28 Waste Generation and Labour Requirements for Various Shoreline Treatment Options

Treatment Option	Waste Generation Amount	Waste Generation Type	Labour Requirements
Natural recovery	None		
Physical cleaning – Washing and recovery			
Flooding – Deluge	High	Liquids	Intensive
Low-pressure washing	High	Liquids	Intensive
High-pressure washing	High	Liquids	Intensive
Steam (“spot”) cleaning	Moderate	Liquids	Moderate
Sand blasting	High	Solids	Moderate
Physical cleaning – Removal			
Manual removal	Moderate/High	Solids	Intensive
Mechanical removal	High	Solids	Minimal
Vacuums	High	Liquids	Intensive
Vegetation cropping	Moderate/High	Solids	Intensive
Passive sorbent collection	Moderate/High	Solids	Intensive
Physical cleaning – In-situ treatment			
Mixing	None		Minimal
Sediment relocation	None		Minimal
Burning	None		Minimal
Chemical – Biological treatment			
Dispersants	None		Minimal
Shoreline cleaners	Moderate	Liquids	Minimal
Solidifiers	Moderate	Solids	Minimal
Bioremediation	None		Minimal

Waste Transfer and Waste Management in Remote Areas

In remote areas, waste management does not follow the typical model that begins with the collection and temporary or short-term storage, i.e., for days, of recovered waste at or close to the work location (primary storage), followed by transfer to an intermediate or long-term storage location, i.e., for weeks to months, where materials are consolidated before treatment, recycling, and final disposal.

Transportation is primarily by sea in remote areas. Roads or overland access from villages or communities to a spill operations area are rare. Barges are usually the primary transfer vehicle from the spill operations area to a temporary or long-term storage location or directly to the final disposal site. Intermediate transfers of waste by helicopter or all-terrain vehicles may help to consolidate the waste materials but are not suitable for managing large amounts of waste.

Waste Generation Data

Very little data is available on the actual amounts of waste generated by most treatment options. The following two maximum amounts have been estimated based on waste generated by sediment removal obtained from spill response data for specific individual shoreline segments of mixed sand, pebble, and cobble sediments.

- **Mechanical removal**
  - based on linear oiled shoreline data: 4.0 m^3/m
  - based on oiled area data: 1.3 m^3/m^2
- **Manual removal**
  - based on linear oiled shoreline data: 2.5 m^3/m
  - based on oiled area data: 1.4 m^3/m^2

In each of these cases, treatment endpoints required that most of the oiled sediments be removed. As these endpoint standards are relaxed, the amount of waste generated would be reduced.

Based on actual spill response data, Owens et al. (2009) define four categories of waste volumes.

Very High	≥ 1.0 m^3 per metre length of oiled shoreline
High	0.1 to 0.99
Low	0.01 to 0.099
Very Low	< 0.01

Figure 5.24 **Proper waste management planning and practice (top) are essential to avoid situations that are costly and difficult to remedy (bottom).**

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Appendices

1 Segment Treatment Recommendation Transmittal Form

2 Segment Inspection Report

3 Conversions

Appendix 1
Segment Treatment Recommendation Transmittal (STRT)

Site Location: | **Ops Division:**

Segment ID: | **Length:** | **Survey Date:**

Shoreline Type: | **Coastal Character:**

Oiled Area for Treatment

Treatment Endpoint Criteria

Treatment Recommendations

Operational - Staging - Logistical Information

Ecological/Cultural Comments/Constraints

Waste Issues

Safety Issues

Approved: (signature blocks for all necessary parties from environmental leader up to OSC)

Attached: □SOS Form □Segment Map □Fact Sheet □Endpoints □Other ____

Prepared by:___________ Date:___________

Appendix 2
Segment Inspection Report (SIR)

Operations Division:	Inspection Team		
Segment ID:	Name	Agency	Signature
Segment Length:			
Inspection Date:			
Tide Stage:			
Weather: Sun/Cloud/Rain/Snow/			

Pre-Treatment Oiling Conditions ☐ attached
(also can be provided as attachment e.g. SOS form, sketch, STRT)

Treatment Method or Plan ☐ attached
(also can be provided as attachment)

Treatment Endpoint Criteria ☐ attached

Observations and Recommendations Inspected Entire Segment: Y / N

☐ Segment meets endpoint criteria and conditions.
NO further treatment required.

☐ Segment DOES NOT MEET endpoint criteria and conditions.
The following specific treatment actions are required.

☐ attached

Approved by:

FOSC	POSC	RP
____________	____________	____________

☐ First Nation, Landowner or Other Stakeholder comments attached

Appendix 3
Conversions

LENGTH

1 centimetre	=	0.394 inches
1 inch	=	2.54 cm
1 foot	=	0.3048 metres
1 kilometre	=	0.6214 statute miles
1 kilometre	=	0.5399 nautical miles
1 metre	=	3.281 feet
1 nautical mile	=	6076 feet
1 nautical mile	=	1.852 kilometres
1 nautical mile	=	1.1508 statute miles
1 statute mile	=	1.609 kilometres

AREA

1 acre	=	43,560 feet^2
1 acre	=	0.4047 hectares
1 hectare	=	2.471 acres
1 hectare	=	10,000 metres^2
1 square kilometre	=	0.3861 miles^2
1 square mile	=	640 acres
1 square mile	=	2.60 kilometres^2
1 square nautical mile	=	848.8 acres
1 square nautical mile	=	1.326 statute miles^2

SPEED

1 knot	=	0.514 cm/second
1 knot	=	1.688 feet/second
1 knot	=	1.15 statute (st.) miles/hour
1 st. mile/hour	=	0.869 knots
1 st. mile/hour	=	0.45 metres/second
1 metre/second	=	1.95 knots
1 metre/second	=	3.28 feet/second
1 metre/second	=	2.24 st. miles/hour

VOLUME

1 barrel (U.K.)	=	35 Imperial gallons (approximate)
1 barrel (U.S.)	=	42 US gallons (approximate)
1 barrel (U.S.)	=	5.6 feet^3 (approximate)
1 barrel (U.S.)	=	159 litres (approximate)
1 barrel (U.S.)	=	0.16 metres^3 (approximate)
1 cubic foot	=	6.2288 Imperial gallons
1 cubic foot	=	7.4805 US gallons
1 cubic foot	=	0.1781 US barrel
1 cubic foot	=	28.316 litres
1 cubic foot	=	0.02832 metres^3
1 cubic inch	=	16.39 centimetres^3
1 litre	=	0.22 Imperial gallons
1 litre	=	0.2642 US gallons
1 litre	=	0.00629 US barrels
1 litre	=	0.03532 feet^3
1 litre	=	1000 centimetres^3
1000 litres	=	1 metre^3
1 cubic metre	=	220.0 Imperial gallons
1 cubic metre	=	264.172 US gallons
1 cubic metre	=	6.289 US barrel
1 cubic metre	=	35.31 feet^3
1 cubic metre	=	1000 litres
1 Imperial gallon	=	1.2009 US gallons
1 Imperial gallon	=	0.02859 US barrels
1 Imperial gallon	=	0.1605 feet^3
1 Imperial gallon	=	4.546 litres
1 millilitre	=	1 centimetre^3
1 US gallon	=	0.83268 Imperial gallons
1 US gallon	=	0.02381 US barrel
1 US gallon	=	0.13368 feet^3
1 US gallon	=	3.7853 litres

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