FIELD GUIDE FOR OIL SPILL RESPONSE IN ARCTIC WATERS

EPPR Emergency Prevention, Preparedness and Response

A Program of the Arctic Council

Canada Denmark Greenland Finland Iceland Norway Russia Sweden USA

Legend

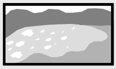
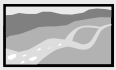
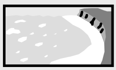
Bullets

✚	safety concerns with respect to human life and health
⚓	operational considerations that might limit or enhance a strategy or technique
✓	strategies or techniques recommended for a given scenario, usually appropriate
✗	strategies or techniques not recommended for a given scenario, rarely appropriate

Seasons

●	open water (water is free of any ice forms)
	freeze-up (new ice is forming)
	breakup (mature ice is melting)
○	frozen (ice is solid, usually continuous)

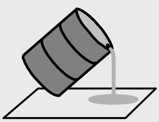
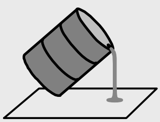
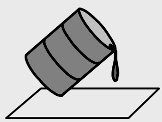
Environments

	seas
	lakes
	rivers
	shorelines

Oil Locations

oil on the surface in open water	oil beneath ice
oil submerged under open water	oil on ice
oil on water surface mixed in ice	oil submerged under solid ice
oil submerged under broken ice	

Oil Viscosity Ranges

	light (like water)		medium (like molassas)		heavy (like tar)

FIELD GUIDE
for
OIL SPILL RESPONSE
in
ARCTIC WATERS

prepared by

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prepared for

Emergency Prevention, Preparedness
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September 1998

Disclaimer

Nothing in the Guide shall be understood as prejudicing the legal position that any Arctic country may have regarding the determination of its maritime boundaries or the legal status of any waters.

Front cover painting titled “Arctic” by Christopher Walker. Acrylic polymer emulsion on masonite panel (36” x 48”). An internationally recognized painter, Walker has developed a distinctive reputation as a perceptual realist in Canadian art. He entered the Canadian Archives as ship’s artist on an historic research expedition to the north pole, called the “U.S./Canada 1994 Arctic Ocean Section”. It was on this voyage that the concept for “Arctic” was conceived. Walker continues his artistic development in Qualicum Beach, British Columbia.

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About EPPR

The Emergency Prevention Preparedness and Response (EPPR) Working Group was established to provide a framework for future cooperation in responding to the threat of environmental emergencies in the Arctic. EPPR works within the Arctic Environmental Protection Strategy (AEPS), which was adopted by Canada, Denmark/Greenland, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States through the Ministerial Declaration at Rovaniemi, Finland in 1991. The other working groups within AEPS are the Arctic Monitoring and Assessment Program (AMAP), Protection of the Arctic Marine Environment (PAME), Conservation of Arctic Flora and Fauna (CAFF), and Sustainable Development and Utilization (SDU).

The EPPR Working Group provides a forum in which member governments and indigenous peoples work to better prevent, prepare for and respond to environmental threats from accidental discharges of pollution from activities which take place in the Arctic.

EPPR operates through a system of National Contacts and meets at least annually to assess progress and to develop EPPR Work Plans. It has a chairperson, but neither vice-chair nor secretariat. EPPR does not receive funding or maintain accounts to support its operation or the development of projects, but works in accordance with the "lead country principle". Representation by indigenous peoples in all of EPPR's activities is an important aspect of its program. The Working Group has met in Lulea, Sweden (1992), Anchorage, Alaska (1994), Norilsk, Russia (1995), Yellowknife, Canada (1996), Ilulissat, Greenland (1997) and Rovaniemi, Finland (1998).

The majority of EPPR's work is directed at assessing threats to the Arctic environment which could result in the need for emergency response measures, and at facilitating the improved ability to prevent or mitigate these threats. Some examples of EPPR's efforts include: risk analyses; holding response exercises for emergencies such as radiological accidents and major oil spills; assessing environmental agreements; evaluating warning systems and communication networks; and sharing experience and technical information, including research and development data.

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1 Lexicon

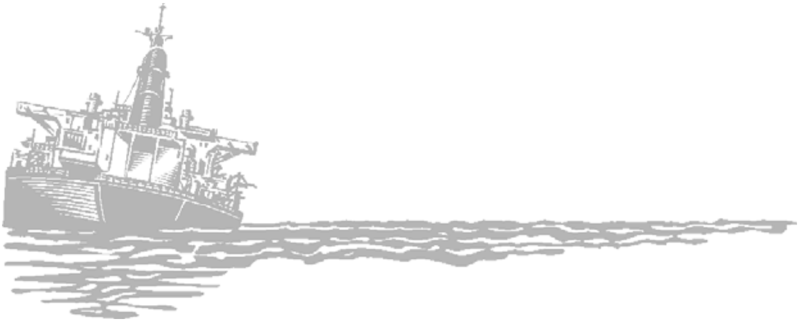

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Table of Contents

This section contains a list of terms and associated icons or bullets that are used throughout the Field Guide.

1.1 Bullets

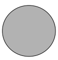
✚ safety concerns with respect to human life and health

⚓ operational considerations that might limit or enhance a strategy or technique

✔ strategies or techniques recommended for a given scenario that usually are appropriate and practical

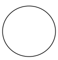
✗ strategies or techniques not recommended for a given scenario; rarely appropriate or practical

1.2 Seasons

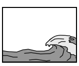
 open water (water is free of any ice forms)

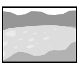
 freeze-up (new ice is forming)

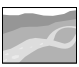
 breakup (mature ice is melting)

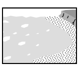
 frozen (solid, usually continuous ice is present)

1.3 Environments

 seas

 lakes

 rivers

 shorelines

1.4 Response Methods

A	mobile floating barriers
B	stationary barriers
C	subsurface barriers
D	berms
E	trenches or slots
F	diversion booming
A	advancing skimmers
B	stationary skimmers
C	vacuum systems
A	burning oil on water contained in booms
B	burning oil on ice
C	burning oil in broken ice
A	vessel dispersant application
B	aerial dispersant application

1.5 Response Feasibility

○	good/recommended
◒	fair/conditionally recommended
●	poor/not recommended

1.6 Oil Location

 oil on the surface in open water

 oil submerged under open water

 oil on water surface mixed in ice

 oil submerged under broken ice

 oil beneath ice

 oil on ice

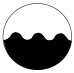
 oil submerged under solid ice

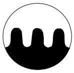
1

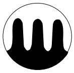
1.7 Shoreline Treatment Methods

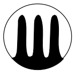
	natural recovery (general method)
	washing/recovery (general method)
	removal (general method)
	in-situ treatment (general method)
	chemical/biological (general method)
1	natural recovery
2	flooding
3	low-pressure, cold-water wash
4	low-pressure, warm- or hot-water wash
5	high-pressure, cold-water wash
6	high-pressure, warm- or hot-water wash
7	steam cleaning
8	sand blasting
9	manual removal
10	vacuum systems
11	mechanical removal
12	vegetation cutting
13	passive sorbents
14	mixing
15	sediment relocation
16	burning
17	dispersants
18	shoreline cleaners
19	solidifiers and visco-elastic agents
20	nutrient enrichment/bioremediation

1.8 Tidal Ranges

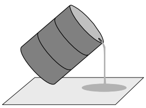

less than 1.0 m

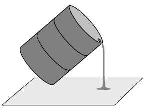

1 - 3 m

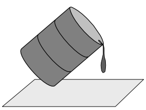

3 - 10 m


more than 10 m

1.9 Oil Viscosity Ranges


light (like water)


medium (like molasses)


heavy (like tar)

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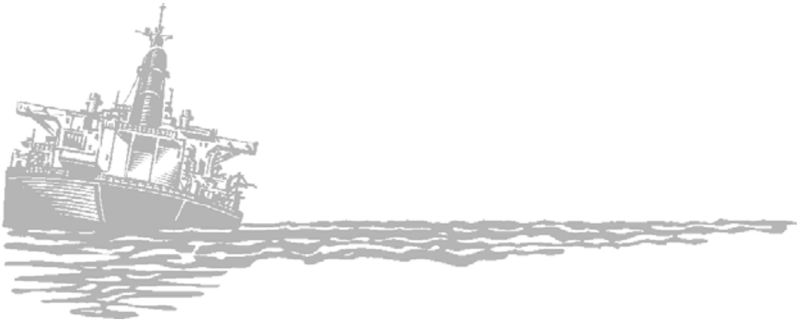
2 Introduction

2



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2.1 Introduction

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2.1.1 Purpose

This Field Guide was developed to provide circumpolar countries with oil spill response guidance specific to the unique climatic and physiographic features of the Arctic environment.

2.1.2 Objectives

The Guide focuses on practical oil spill response strategies and tools for application to open water, ice and snow conditions in remote areas during cold weather. Information is provided relevant to the marine offshore and coastal environments, and to large rivers and lakes, where oil is transported and where spills pose a threat to the environment and public health.

2.1.3 Key Principles

A first principle of this Field Guide is to present information that can be used by technical managers and decision-makers, as well as by local community first responders, the general public and the media.

The Guide is not intended to duplicate existing manuals and reference documents, but rather to collate available information on the behaviour of, and response to, oil spills in ice and snow.

2.1.4 Background

Most oil spill response field guides focus on open-water conditions in nearshore and shoreline environments. Yet much of the Arctic is frozen for a large portion of the year. In addition, marine offshore environments are of great ecological importance in Arctic regions. Existing field guides do not address the unique physical, biological, oceanographic and atmospheric conditions of Arctic regions (Table 2 - 1), and are, therefore, not well-suited to spill response activities, including training.

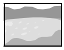
Table 2 - 1 Key features of Arctic regions

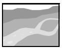
Environmental Factors
• high intensity of habitat use during summer season • extreme seasonal ecological sensitivity variations • unique shore types (ice shelves, glacier margins, ice foot features, tundra coasts: see Section 4) • unique oceanographic and shoreline seasonal changes (open water, freeze-up, frozen conditions, breakup) • slower weathering and longer persistence of spilled oil
Operational Considerations
• remote logistical support • need to improvise response using available means until support equipment arrives • safety in cold, remote areas • cold temperature effects on the efficiency of equipment and personnel • boat operations in ice-infested waters during transition periods, winter dynamic ice conditions • on-ice operations in winter • seasonal daylight variability • minimization of damage to permafrost during land-based staging and cleanup operations • need for aircraft for response logistics, surveillance, and tracking

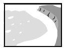
2.2 Scope and Contents

The water environments covered by this Field Guide are:

 marine seas

 lakes

 rivers

 shorelines

There is no universally accepted definition of the term ***Arctic*** and each of the AEPS countries has chosen to apply its own description. The following table is summarized from EPPR (1996).

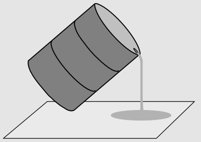
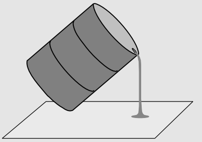
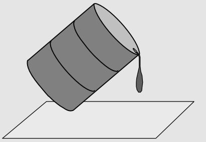
Table 2 - 2 The definition of Arctic for individual countries

Canada	(1) the Northwest Territories, Nunavut and the Yukon Territory, (2) the coastal zone and waters of Hudson Bay, James Bay, Quebec north of 60° and Ungava Bay and (3) all contiguous seas including the Arctic Ocean and the Beaufort Sea
Denmark	Greenland
Finland	the provincial district of Lapland that lies north of the Arctic Circle
Iceland	all of Iceland and the adjacent seas
Norway	Svalbard, Jan Mayen Island and a small area north of the Arctic Circle that includes the Saltfjellet-Svartisen National Park and the municipality of Rana
Russia	all territory north of a line from (1) the Arctic Circle on the Finnish border to just west of Usinsk, (2) then to the southwest to follow the Nizhnyaya River, then the Vilyuy and Alden Rivers, (3) crossing Shelikohova Bay south of Taygomos and (4) crossing the Kamchatka Peninsula just north of Karaginskiy Island
Sweden	the provincial district of Norrbottens Land that lies north of the Arctic Circle
U.S.A.	(1) all United States territory north and west of the boundary formed by the Porcupine, Yukon and Kuskokwim Rivers, (2) all contiguous seas, including the Arctic Ocean and the Beaufort, Bering and Chukchi Seas, and (3) the Aleutian Island chain

For this Field Guide, the EPPR Working Group has extended the geographic area to include other regions that typically have ice on the ocean, lakes or rivers for some part of the year. This extended definition of the region of Arctic waters allows the Field Guide to have application not only to the Arctic but also to other cold regions.

The Field Guide applies to all sizes of oil spills. For simplicity, the wide range of crude and refined oils have been grouped into three types, based primarily on viscosity (Table 2 - 3).

Table 2 - 3 Oil viscosity ranges

Viscosity Ranges		
light	**medium**	**heavy**
		
free flowing (like water)	**slowly pouring (like molasses)**	**barely flowing (like tar)**
♦ diesel ♦ gasoline ♦ heating oil ♦ kerosene	♦ Bunker A ♦ Fuel Oil No.4 ♦ lubricating oils ♦ medium crudes	♦ Bunker B and C ♦ Fuel Oil No.6 ♦ weathered crudes ♦ bitumen

In this Guide, three sea states are considered as shown below.

Table 2 - 4 Sea states

Response Environment	Significant Wave Height (m)	Wind Speed (km/h)
calm water	less than 0.3	less than 10
protected water	0.3 - 2	10 - 30
open water	2 or greater	30 or greater

Four seasons are addressed, namely, open water (no ice is present), freeze-up (new ice is forming), breakup (old ice is melting) and frozen conditions (solid, continuous ice has formed).

2.3 Applications of the Guide and Use of Local Knowledge

The Field Guide is intended for use in the decision process as an aid to the selection of appropriate, practical and feasible oil spill response strategies and techniques. Each oil spill is unique so that techniques, strategies or methods recommended in this Guide may not be applicable in some situations.

The Guide is not a technical manual. Technical experts should be consulted to advise on the application of strategies and techniques for local environmental conditions and for the specific type of oil that is spilled.

The tracking of oil on water or in ice should be initiated immediately following a spill so that support equipment and personnel can be deployed as soon as they arrive.

Knowledge of local conditions, priorities and resources is of primary importance in all response operations. Knowledge of local oil products or crude oils is essential in terms of safety and in the development of a Health and Safety Plan for first responders. This knowledge also is critical in any decision by first responders to burn spilled, contained or recovered oil.

2.4 Sources

2

This Field Guide has drawn on numerous sources and handbooks.

For countermeasures on oil/ice/water, references include *Oil Spill Response in the Arctic, Parts 2 and 3 (Oil Industry Task Group, 1983 and 1984), State-of-the-Art Review: Oil-in-Ice Recovery (Solsberg and McGrath, 1992), Proceedings of the International Oil Spill Conferences 1975 - 1997* and *Proceedings of the Arctic and Marine Oilspill Programme (AMOP) Technical Seminars (1978 - 1998)*. Participation in the Mechanical Oil Recovery in Ice Infested Waters (MORICE) program (SINTEF, 1995 through 1998) and a spill response study of the North Caspian Sea (*Shell, 1998*) provided additional insights.

Shoreline response methods (Sections 4.11 and 5.7) are based on the *US EPA Manual of Practice for Protection and Cleanup of Shorelines (Foget et al., 1979)*, which was revised and updated for Arctic regions by *Owens (1996)*. Additional sources of material used in these sections include *API (1985); API/NOAA (1994); CCG (1995a); CONCAWE (1981, 1983); EPRCo. (1992); ITOPF (1987); Kerambrun (1993); Michel, et al. (1994); MPCU (1994); NOAA (1994); and Owens (1994)*. Sources that relate to Arctic coasts (Section 8) include *Bird and Schwartz (1985)* and *Owens (1994)*.

2.5 Safety Considerations

Basic safety concerns of Arctic regions are snow, ice and cold temperatures. Oil spill response methods on open water or on shorelines are generally not significantly different from warmer latitudes but, in the Arctic, safety and practicality become important elements of the decision process, as described in Section 7. Safety concerns, in particular, are noted throughout the Field Guide and should be stressed in training.

The protection of human life and health is the highest priority in a spill response.

A key component of a spill response for all responders is the Health and Safety Plan, to ensure that the lives and health of all response personnel and the public are protected. Key safety considerations in Arctic areas include:

- cold temperatures and extreme weather conditions
- wind shifts that can cause ice leads to quickly open or close
- weight-bearing capacity of ice
- potential icing effects on vessels and small boats
- bears and sea mammals
- short daylight periods and long periods of winter darkness
- reduced operational efficiency of personnel and equipment, e.g., brittle failure of equipment, freezing of water or fuels, lower battery capacity and increased fuel consumption

Many Arctic locations are remote. Safety concerns therefore include precautionary operating procedures for travel, even over short distances, so that pedestrians and machinery follow safe, well-marked routes. Scheduled communications between field crews and an operation centre are also usually mandatory.

Appropriate safety procedures and proper equipment are particularly important on, in, or near ice. In many situations, the ice is dynamic and conditions may change rapidly. Open-water areas, called polynyas, can form in an ice field and then close. Freezing spray that forms ice on vessels is not uncommon. Personnel always need to pay close attention to changes in wind, temperature and weather.

2.6 The Decision Process and the Assessment of Feasibility, Benefits and Consequences

The decision process for a spill response operation involves the selection of appropriate, effective strategies to control, contain and recover the spilled oil. These decisions are developed in terms of safety, practicality and seasonal and local environmental conditions.

The selection of appropriate response strategies and techniques also involves an assessment of the benefits and consequences of the proposed actions. The objectives of response operations are to limit the spread of the oil and minimize the impacts of the spill, and to accelerate the natural recovery of the affected area and resources. If the proposed actions either would not achieve these objectives or would cause more damage than leaving the oil to weather naturally, then the proposed actions should be reconsidered. Also, possible secondary damage, such as the degradation of permafrost or the disturbance of tundra vegetation, must be included in this assessment.

The assessment process, also called the ***Net Environmental Benefit*** analysis, includes environmental and economic concerns. The potential effects of the spilled oil on subsistence or other economic activities are always of concern to local residents, and are included in the decision process for determining protection/response priorities.

In summary, the decision process to select appropriate response actions and priorities takes into account:

- safety concerns (oil type, weather, climate, wildlife, local hazards, etc.)
- practicality and feasibility
- local environmental, subsistence or economic concerns
- potential impact of response operations on wildlife and the environment (such as marshes, tundra, or permafrost)
- seasonal conditions

2.7 Organization and Format

The Field Guide has been organized so that in Part A each of three key operational sections can be used independently.

Section 3	This section is intended for first responders. It is based on seasonal conditions in Arctic waters. Actions that can be taken immediately to control the spread of the oil and to minimize the effects of the spill are summarized. Equipment and materials are briefly noted.
Section 4	Response strategies are described in the context of: • source control • the control of free oil • protection • shoreline treatment Marine, lake, river and shoreline environments are considered separately.
Section 5	Information is provided (related to the strategies described in Section 4) on response methods or tools for removing or treating oil on water, in ice or on shorelines.

Three sections in Part B provide support information that is vital to an understanding of the Arctic environment and to the development of an effective response.

Sections 6 & 7	The behaviour and fate of spilled oil are described as well as the notification and decision processes associated with the management of a response operation.
Section 8	The coastal character of the Arctic is summarized according to geographic regions.

Whenever possible, icons are used in the text, as well as in figures and tables, to provide a visual key and cross-reference system for the information. The icons are defined in Section 1 and are also included on the inside of the front and back covers.

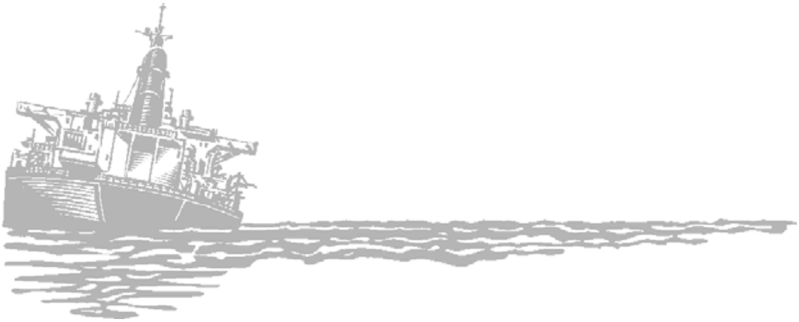
2

Part A

Operations

3 Initial Response Guide

3



3.1 Introduction

The overall objective of first response actions is to minimize the spread of oil, either at source or nearby. The procedure for developing the response follows the decision steps that are fully explained in Section 7. These include:

- Assess the situation. (A quick evaluation of the area is helpful and should consider knowledge of local currents and shorelines. Baseline videos are also useful.)
- Define immediate objectives.
- Develop practical, feasible strategies to meet the objectives.
- Select response methods using available resources.
- Contain the oil at or near the source.

For example, for an incident at sea, the first responder must initially define the type, amount and location of the spilled oil. Then, based on this information, the responder must decide on practical approaches to minimize the spread of oil with the resources available. To carry out such actions, the following general guidelines are provided:

- Think before you act.
- Notify a local supervisor according to area contingency plans.
- Always consider local interests and concerns.
- Identify priorities and strategies based on local concerns.
- Stop the discharge of oil, if possible and safe to do so.

A quick evaluation of an area is helpful:

- Know local currents and shorelines before a spill occurs.
- Baseline videos are helpful.

The text bullets in this, and subsequent, sections refer to various categories of advice to assist the first responder. They are as follows:

✚ safety considerations

⚓ operational considerations

✔ recommended strategies or techniques

✗ inappropriate techniques

Other icons are also used that refer to countermeasures methods. These are defined in Section 1 and explained in detail in Section 5. Their meaning is also indicated on the inside covers of this Guide.

This section provides practical countermeasure recommendations for first responders, i.e., personnel with a range of technical experience who serve as local, trained community responders and are required to be first at the scene of a spill. Because a responder might receive very limited information when alerted about a spill, this section has been organized on the basis of ***season*** (open water, freeze-up and breakup transition, and frozen conditions) as shown in Figure 3 - 1. ***Environment*** (seas, lakes and rivers) is a secondary index.

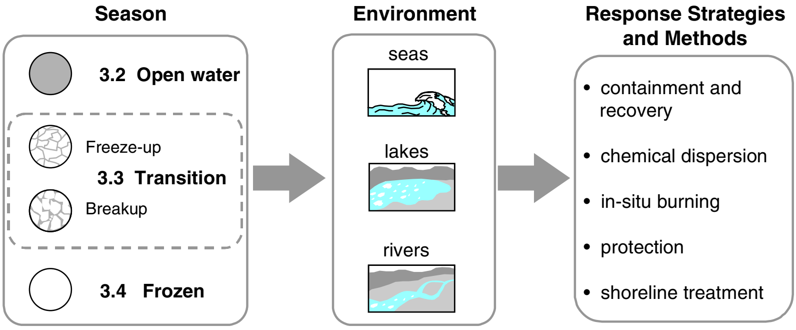


Figure 3 - 1 Section 3 organization

Seasons are defined as follows:

open water	Water is free of any ice forms.
freeze-up	New ice is forming.
breakup	Old ice is melting.
frozen	Solid, continuous ice is present.

The methods of containment and recovery, chemical dispersion, in-situ burning and shoreline treatment are used in the context of the four response strategies:

1 source control	A spill is controlled at or near its release point to prevent slicks from spreading.
2 control of free oil	Response operations focus on slicks that have spread some distance from the source.
3 protection	Measures are taken to prevent shoreline and other resources from being contaminated.
4 shoreline treatment	Oil that has come ashore is treated.

3.2 Spills During Open-water Season

3.2.1 Seas

3.2.1.1 General Guidelines

✚ Personnel who respond to northern spills must be trained in the hazards of exposure to low temperatures, accidental immersion in cold water and other causes of hypothermia.

⚓ The most effective way to minimize environmental damage is to focus on source control and to prevent oil from spreading.

⚓ Slick tracking and surveillance should utilize locally-available resources to determine optimum response strategies:

- Locate brown-coloured slicks to be skimmed, burned and/or dispersed.
- Leave shiny, rainbow sheens to disperse naturally but plan for shoreline protection/treatment, if appropriate.
- In breaking waves higher than 1 m, surveillance and monitoring might be the only practical response options.

Table 3 - 1 Open-water response at sea

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
source control		A B	A	A B	○
		C			●
control of free oil		A A	A	A B	○
		C			●
protection		F	A	A B	○
		C			●

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3.2.1.2 Response Strategies and Methods

Responding to spills from vessels, blowouts and pipelines can involve controlling slicks at source and removing oil that escapes initial containment. The objective of both operations is to minimize the spreading of spilled oil and subsequent environmental impacts. Control methods use similar approaches at source and to deal with remote slicks.

Containment and Recovery

Containment

- A Booms can be used at, and downdrift from, the release point to contain and concentrate oil.
- A Booms can be used in U, V or J configurations. Interception of free-floating, thin slicks is not as effective as containment and removal of oil at source.
- A Booms are effective in currents less than 0.5 m/s (1 knot) and winds less than 35 km/h (20 knots).

Recovery

- A Oleophilic skimmers (units with a recovery mechanism to which oil adheres) are useful: Disc, drum and rope mop skimmers can remove light and medium viscosity oils; brush and belt skimmers can collect heavy oils.
- A Large volume skimming weirs can be used when oil/water separation is available or when there are large accumulations of thick, unemulsified oil.
- C Spilled oil that might sink should be controlled before it submerges, if possible. Locating submerged oil is difficult, and control and collection is even more difficult.
- C If brush or belt skimmers cannot collect heavy, floating oil then trawl systems can be tried for recovery.
- ⚓ Planning adequate storage capacity is critical to the entire response operation to avoid operational bottlenecks.
- ⚓ Storage options include barges, towable tanks, tankers and/or other means that are appropriate for the type and volume of oil being recovered.

Dispersion

Spills must be assessed to determine if dispersants will be effective and then treated quickly by trained personnel:

- The oil should have a viscosity less than 10 000 cSt, i.e., it should be less viscous than molasses.
- The temperature of the water should be above the pour point of the oil, i.e., the oil should be freely flowing.
- Slick thickness should be more than 0.1 mm thick.
- Spraying operations should be conducted within 2 - 5 days of a spill occurring when the oil is unweathered and can be dispersed.

Both vessels and aircraft can be used to apply dispersants. Operations should be directed from aerial vantage points:

- Use stockpiles of chemicals located strategically to the spill site at dispersant-to-oil ratios of 1:10 to 1:100.
- Use fixed-wing planes and helicopters on offshore spills.
- Vessels are more practical for nearshore coastal waters.
- Record information on dosage rates, areas treated and apparent effectiveness so that the data can be transferred to subsequent responders.

In-situ Burning

In-situ burning must be quickly implemented, usually by trained personnel. In a remote area, the decision to burn should be based on the following factors:

- Emulsions should be at least approximately 75% oil.
- Slick thickness should be greater than 2-3 mm.
- Waves should be less than 2 m high and not breaking.
- Wind speed should be less than 35 km/h (20 knots).
- Crude oil should be burned within 2 - 5 days of the spill.

An ignition system is needed; fire-resistant boom and spotter aircraft should be used, if available.

✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

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✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

Protection

Protecting resources in the spill path usually involves the deployment of mechanical equipment but may be accomplished by chemical dispersion or burning. The objective of protection is to prevent or minimize contact between the spilled oil and the resources at risk.

Initially, estimate the direction and speed of movement of the oil. Then identify the resources at risk from the spill and evaluate whether protection operations can be effective. If protection actions are likely to be successful, then take the following actions for mechanical containment and removal strategies:

- Deploy booms with both top and bottom tension members and high reserve buoyancy to exclude or divert oil.
- Secure and then regularly monitor anchoring systems.

Use smaller oleophilic skimmers, e.g., disc, drum and rope mop units, to remove light and medium viscosity oils for storage in either water- or land-based storage systems.

In storm surges, protection strategies might not work if oil mixes in the surf zone and if booms fail.

In-situ burning is a possible protection option in nearshore waters, using an ignition device(s) in concentrated oil; fire-resistant boom and spotter aircraft should be used, if available.

A safety plan for the burn operation must be prepared that considers the potential impacts of the burn, amenities at risk and the possible health effects of the smoke plume, e.g., 10 km (6 mile) downwind exclusion zone, sulfur content of crude and the means to extinguish the fire.

Chemical dispersion is a possible protection technique in coastal waters characterized by:

- good flushing action
- water depth greater than 10 - 20 m

For effective dispersion, oil must meet the following criteria:

- Viscosity is less than 10 000 cSt, i.e., less viscous than molasses.
- The temperature of the water is above the pour point of the oil, i.e., the oil is freely flowing.
- Slick thickness is more than 0.1 mm thick.

Vessel application is likely to be as, or more effective than, aerial methods if:

- Dispersant is applied within 2 - 5 days of a spill.
- The spill covers a relatively small coastal area that can be readily treated with dispersants from vessels.
- Dispersant supplies and fuel are positioned on vessels and at selected sites onshore so that downtime is minimized.
- Good access to, and visibility of, slicks exists.

Information on dosage rates, areas treated and apparent effectiveness should be recorded so that the data can be transferred to subsequent responders.

Shoreline Treatment

First response activities usually take place on a shoreline only if available resources are not required for source control, recovery of free oil or protection. This might be the case for a land-based spill, e.g., a tank farm, or if all or most of the oil has washed ashore.

3 Washing is generally practical and effective before the oil has weathered, i.e., in the early stages of a spill, on:

- impermeable (bedrock, man-made) shore types
- fine sediment beaches or flats (sand, mud)
- vegetated shores (marshes, peat, low-lying tundra)

10 On sheltered, low wave-energy shores with fine sediments, trenching can be a rapid and effective method for containing stranded oil and preventing further redistribution. Oil in the trench can be removed by vacuum trucks.

9 11 On open beaches with wave action, often it is important to remove oil that is on the surface before the oil and sediments are reworked by wave action and the oil is possibly buried.

14 15 If oily waste generation and its disposal are issues (which is common in Arctic and many remote regions), mixing and sediment relocation on beaches are likely to be practical and highly effective since the oil would be relatively unweathered. Mixing (also known as tilling) and sediment reworking (surf washing) involve the use of earthmoving or agricultural equipment to move oiled sediments so that they are exposed to weathering processes, such as evaporation or wave action, to accelerate natural cleaning of an oiled beach. The techniques do not involve mechanical removal of oiled sediments from a beach for disposal.

✗ Land-based operations should avoid disturbances to the permafrost and the active layer above it, e.g., digging, the use of tracked vehicles and uncontrolled burns.

Table 3 - 2 indicates treatment methods appropriate for the initial response on the various shore types of Arctic coasts.

Table 3 - 2 Initial response shoreline treatment

Shore Type	Recommended Initial Treatment Methods
bedrock	3 9 10
man-made solid structures	3 9
ice or ice-covered shores	3 4 9 10 16
sand beaches	2 3 9 11 14 15
mixed-sediment beaches	2 3 9 11 14 15
pebble/cobble beaches	3 9 11 14 15
boulder beaches and rip-rap	3 9 13
sand flats	3 9 10 11
mud flats	3 9 10 11
salt marshes	2 3 9 10 13
peat shores	2 3 9 10 11
inundated low-lying tundra shores	2 3 9 10
tundra cliff shores	3 9 10 14 15
shorelines with snow	9 10 11 16

3.2.2 Lakes

3.2.2.1 General Guidelines

✚ Personnel who respond to northern spills must be trained in the hazards of exposure to low temperatures, accidental immersion in cold water and other causes of hypothermia.

⚓ The most effective way to minimize environmental damage is to focus on source control and to prevent oil from spreading.

⚓ Slick tracking and surveillance should utilize locally-available resources to determine optimum response strategies:

- Locate brown-coloured slicks to be skimmed, burned and/or dispersed.
- Leave shiny, rainbow sheens to disperse naturally but plan for shoreline protection/treatment, if appropriate.
- In breaking waves higher than 1 m, surveillance and monitoring might be the only practical response options.

✚ Waves can build quickly in shallow lakes, eliminating the opportunity to safely attempt spill control.

Table 3 - 3 Open-water response in lakes

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
source control		A B	A		○
		C			●
control of free oil		A A	A		○
		C			●
protection		F	A		○
		C			●

3.2.2.2 Response Strategies and Methods

Responding to spills in lakes from vessels, blowouts and pipelines can involve controlling slicks at source and/or remote from the release point. The objective of both operations is to minimize the spreading of spilled oil and subsequent environmental impacts. Control methods use similar approaches at source and to deal with remote slicks.

Containment and Recovery

Many of the criteria that are applied to spill response at sea are the same as those that apply to spill response in lakes. Releases from vessels, blowouts and pipelines usually require both source control and removal of oil that escapes initial containment. Source control and removal involve similar approaches.

Containment

- (A) Booms can be used at, and downdrift from, the release point to contain and concentrate slicks.
- (A) Booms can be used in U, V or J configurations.

Recovery

- (B) Oleophilic skimmers (units with a recovery mechanism to which oil adheres) are useful: Disc, drum and rope mop skimmers can remove light and medium viscosity oils; brush and belt skimmers can collect heavy oils.
- (A) Large volume skimming weirs can be used when oil/water separation is available or when there are large accumulations of thick, unemulsified oil.
- (C) If brush or belt skimmers cannot collect heavy oil, then trawl systems can be tried; however, submerged oil is difficult to locate and collect.
- ⚓ Collected liquid can be stored in barges, towable tanks, tankers and/or other vessels.
- ⚓ For smaller spills in lakes, self-inflating and/or skirt booms with round flotation are useful with small, oleophilic skimmers (B) deployed over-the-side from vessels of opportunity.

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Dispersion

Spills must be assessed to determine if dispersants will be effective and then treated quickly by trained personnel:

- The oil should have a viscosity less than 10 000 cSt, i.e., it should be less viscous than molasses.
- The temperature of the water should be above the pour point of the oil, i.e., the oil should be freely flowing.
- Dispersant should be applied within 2 - 5 days of a spill.

Dispersion is not usually considered in northern lakes due to low water circulation/dilution and potentially adverse environmental impacts. However, if used, both vessels and aircraft can be used to apply dispersants. Operations should be directed from aerial vantage points:

- Use stockpiles of chemicals located strategically to the spill site at dispersant-to-oil ratios of 1:10 to 1:100.
- Use fixed-wing planes and helicopters on offshore spills.
- Vessels are more practical for nearshore waters.
- Record information on dosage rates, areas treated and apparent effectiveness so that the data can be transferred to subsequent responders.

In-situ Burning

In-situ burning is possible with the following prerequisites:

- Emulsions should be at least 75% oil.
- Slick thickness should be greater than 2-3 mm.
- Waves should be less than 2 m high and not breaking.
- Wind speed should be less than 35 km/h (20 knots).
- Crude oil should be burned within 2 - 5 days of the spill.

An ignition system is always needed; fire-resistant boom is usually required and spotter aircraft should also be used, if available.

- ✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.
- ✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.
- ✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.
- ✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

Protection

Protecting resources using mechanical means involves deploying booms with both top and bottom tension members and high reserve buoyancy to exclude or divert slicks. The objective of protection is to prevent or minimize contact between the spilled oil and resources at risk.

(F) Once the direction, velocity and possible impacts of the spilled oil have been identified, evaluate whether protection operations can be effective. In storm surges, protection strategies might not work if oil mixes in the surf zone and booms fail. However, if the protection actions are likely to be successful, then take the following actions:

- Deploy booms to surround sensitive resources, if possible.
- Angle booms in currents or more than 0.4 m/s to divert slicks.
- Secure and then regularly monitor anchoring systems.

(B) Oil recovery using small, oleophilic skimmers (disc, drum, brush and rope mop units) and water or land-based storage systems are often required.

In-situ burning is a possible protection option in lakes, using an ignition device(s) in concentrated oil, usually in an embayment; fire-resistant boom and spotter aircraft should be used, if available.

A safety plan for the burn operation must be prepared that considers the potential impacts of the burn, amenities at risk and the possible health effects of the smoke plume, e.g., 10 km (6 mile) downwind exclusion zone, sulfur content of crude and the means to extinguish the fire.

Chemical dispersion is not generally considered to be a protection measure in lakes unless used well offshore in areas characterized by good flushing. The above-noted application criteria then apply.

Shoreline Treatment

First response activities on lake shores usually proceed only if available resources are not needed for source control, recovery of free oil or protection. This might be the case for a land-based spill, e.g., a tank farm, or if all or most of the spilled oil has come ashore.

Washing is generally practical and effective before the oil has weathered, i.e., in the early stages of a spill, on:

- impermeable (bedrock, man-made) shore types
- fine-sediment beaches or flats (sand, mud)
- vegetated shores (marshes, peat, low-lying tundra)

On lake shores with wave action, it is often important to remove surficial oil before the oiled sediments are reworked by wave action and are buried.

Lake shores generally are low wave-energy environments with fine sediments (sand and mud) where trenching can be a rapid and effective method for containing stranded oil and preventing further redistribution.

✔ Lake shoreline treatment methods appropriate for a first response are given in Table 3 - 2 (page 3 - 11).

14 15 The generation and disposal of oily materials are usually issues in Arctic and other remote areas. Mixing or sediment relocation on lake shore beaches often are practical options since the oil would be relatively unweathered. Mixing (also known as tilling) and sediment reworking (surf washing) involve the use of earthmoving or agricultural equipment to expose oiled sediments to weathering processes, such as evaporation or wave action, to accelerate natural cleaning of the oil. The techniques do not involve mechanical removal of oiled sediments from a beach and may be effective only on large lakes where there is relatively high-energy wave action, such as the Great Bear or Great Slave lakes in Canada.

✗ Land-based operations should be conducted to avoid effects on the permafrost and the active layer above it, e.g., minimize or eliminate digging, the use of tracked vehicles and uncontrolled burns.

3.2.3 Rivers

3.2.3.1 General Guidelines

Many northern rivers are fast flowing, have high sediment loads and feature long lengths of inaccessible shore. These factors often make it impractical to control oil spills, particularly during spring runoff.

✔ Spill response in rivers requires quick action if cleanup operations are to be successful.

⚓ Selected control points with good access and low currents can serve as equipment staging and deployment areas.

⚓ Booms deployed downstream from a transfer operation can be effective.

✚ Safety is the primary concern in fast-flowing northern rivers. Personnel should not be at risk when deploying equipment.

✔ Oil usually reaches shore rapidly, such that shore treatment often is the only response option.

Table 3 - 4   Open-water response in rivers

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
source control		A B	A		○
		C			●
control of free oil		A A	A		○
		C			●
protection		F	A		○
		C			●

3.2.3.2 Response Strategies and Methods

Responding to spills in rivers often involves the removal of slicks that have been transported downstream, sometimes for long distances. Response remote from the release point is required because source control operations might not be feasible, nor safe to conduct, particularly when a volatile oil has been released. However, containing slicks at source in large coastal rivers is sometimes possible at slack tide and should be considered when conditions are appropriate. In some cases, boom can be deployed downstream from transfer points to intercept slicks.

Containment and Recovery

Containment

Booms can be used in rivers to contain slicks when this is practical to do so:

- They should be deployed at an angle to the current and redirect oil to a recovery point.
- Generally, the maximum current should be less than 1 m/s (2 knots) for this strategy to be effective.

Booms must be used with the following design features:

- top and bottom tension members
- maximum height of approximately 70 cm
- heavy duty fabric

Potential hindrances to spill response in large coastal rivers that make locating slicks and deploying booms difficult include:

- reversing tides
- back eddies
- eroding banks
- high sediment load
- debris

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Ⓐ Deploying angled booms might not be practical when:

- The river is too wide to effectively divert slicks.
- There is insufficient time to set up booms.
- The oil disperses to thin, unrecoverable slicks.

⚓ Islands, channels and embayments can be used effectively to enhance response operations:

- Islands can act as natural barriers.
- Booms and channels can be used together to divert slicks and to protect resources.
- Oil can be directed to embayments for collection.
- Circular current patterns or eddies that commonly occur in river embayments can be used to facilitate oil collection.

Ⓕ The containment, redirection and recovery of heavy, viscous oils in rivers is generally difficult because the oil can submerge and be transported along or just above the river bed.

Ⓒ Submerged oil cannot easily be located due to its movement and to masking by suspended sediment.

Ⓒ Trawl or other netting systems can trap debris; these booms have a low probability of efficient oil capture in rivers.

Recovery

Ⓐ Booms are sometimes - but not always - used to concentrate oil for recovery in a river.

⚓ Often, natural recovery points are selected where oil accumulates. These are common in meandering rivers or streams, or where a narrow channel widens and currents are reduced.

Ⓑ Oleophilic skimmers (units with a recovery mechanism to which oil adheres) are useful: Disc, drum and rope mop skimmers can remove light and medium viscosity oils; brush and belt skimmers can collect heavy oils. Use vacuum and air conveyor trucks that can be readily deployed from shore or floating platforms (if available).

⚓ Water-based working platforms for oil recovery are useful when equipment cannot be readily set up on shore.

Dispersion

Spills must be assessed to determine if dispersants will be effective and then treated quickly by trained personnel:

- The oil should have a viscosity less than 10 000 cSt, i.e., it should be less viscous than molasses.
- The temperature of the water should be above the pour point of the oil, i.e., the oil should be freely flowing.
- Dispersant should be applied within 2 - 5 days of a spill.

Both vessels and aircraft can be used to apply dispersants. Operations should be directed from aerial vantage points:

- Use stockpiles of chemicals located strategically to the spill site at dispersant-to-oil ratios of 1:10 to 1:100.
- Use fixed-wing planes and helicopters.
- Vessels can serve as practical working platforms, positioned by spotter aircraft, if available.
- Record information on dosage rates, areas treated and apparent effectiveness so that the data can be transferred to subsequent responders.

Dispersant application in a coastal river is not generally considered to be an option if fish-rearing and feeding areas are located at or toward the river mouth. However, if used near the mouth of a river, dispersants can help dissipate oil into the larger, receiving body of water that the river enters:

- Deltaic or estuarine habitats could be adversely affected.
- The modification of surface tension by dispersants, in combination with sediment deposition, could result in oil persisting longer without undergoing degradation.

In-situ Burning

In-situ burning might be practical in a river if quick action is taken. Slicks must be intercepted at pre-selected points where burning can be conducted safely. Burn sites are usually in embayments with low currents.

Factors that result in successful burning in a river include:

- Emulsions should be at least 75% oil.
- Slick thickness should be greater than 2-3 mm.
- Waves should be less than 2 m and not breaking.
- Wind speed should be less than 35 km/h (20 knots).
- Crude oil should be burned within 2 - 5 days of the spill.
- Currents should be less than 1 m/s (2 knots).

An ignition system is always needed to conduct burning; fire-resistant boom and spotter aircraft should be used, if available.

✚ A safety plan for response workers is required that addresses the location of ignition, transport of oil in the river, downstream amenities at risk, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

Protection

Protecting resources in rivers usually involves the quick deployment of booms with top and bottom tension members and high reserve buoyancy to exclude or divert slicks. In large rivers, protection strategies might not work if oil were to mix with sediment and booms were to fail. The objective of protection is to prevent or minimize contact between the spilled oil and key resources at risk.

Once the speed of movement of the oil and the risks posed by the spill have been identified, evaluate whether protection operations can be effective. If the protection actions are likely to be successful, then take the following actions:

- Deploy booms to protect sensitive resources, if possible.
- Angle booms in currents 0.4 - 1 m/s to divert slicks.
- Secure and then regularly monitor anchoring systems.

Small, oleophilic skimmers, e.g., disc, drum, brush and rope mop units, can be used in contained, concentrated oil together with water- or land-based storage systems.

In-situ burning is a possible protection option in rivers using an ignition device in concentrated oil, usually in an embayment; fire-resistant boom and spotter aircraft should be used, if available.

A safety plan for the burn operation must be prepared that considers the potential impacts of the burn, amenities at risk and the possible health effects of the smoke plume, e.g., 10 km (6 mile) downwind exclusion zone, sulfur content of crude and the means to extinguish the fire.

Chemical dispersion is not generally considered to be a protection measure in rivers unless used near a river mouth in fresh, unemulsified oil (viscosity less than 10 000 cSt - slowly flows like molasses).

3

Shoreline Treatment

First response on river banks usually takes place only if available resources are not needed for source control, recovery of free oil or protection. This might be the case for a land-based spill, e.g., a tank farm, or if all or most of the spilled oil has stranded on the river banks.

3 Washing is generally practical and effective before the oil has weathered, i.e., in the early stages of a spill, on:

- impermeable (bedrock, man-made) shore types
- fine sediment beaches or flats (sand, mud)
- vegetated shores (marshes, peat, low-lying tundra)

9 11 Often, it is important to remove oil that is on the surface before the oil and sediments are reworked by current or wave action and the oil is possibly buried.

10 River banks generally are low-energy environments with fine sediments (sand and mud); trenching can be a rapid and effective method for containing stranded oil and preventing further redistribution.

14 15 The generation and disposal of oily material are often issues in Arctic and remote regions. Mixing and sediment relocation on river banks are likely practical options since the oil would be relatively unweathered; however, this method may not be as effective in accelerating the removal of oil when compared to higher energy open sea coasts. Mixing (also known as tilling) and sediment reworking (surf washing) involve the use of earthmoving or agricultural equipment to move oily sediments so that they are exposed to weathering processes, such as evaporation or current action, to accelerate natural cleaning of the oil. These techniques do not involve mechanical removal of oiled sediments from a river bank for disposal.

✗ Land-based operations should be designed to avoid disturbance to the permafrost and the active layer, e.g., minimize or eliminate digging, tracked vehicles and uncontrolled burns.

✔ Initial treatment methods for river banks are given in Table 3 - 2 (page 3 - 11).

3.3 Spills During Transition Seasons

3.3.1 Seas

3.3.1.1 General Guidelines

The transition seasons are characterized by a wide range of broken ice types and concentrations. During freeze-up, thinner, flatter ice, and sometimes smaller particles and crystals can form, whereas larger, thicker ice floes and pieces are usually present during breakup. ***Safety is the key response consideration in broken ice.***

- ✚ Do not deploy personnel or equipment on ice that might be too hazardous, i.e., moving, unstable, cracked, melting.
- ⚓ Plan booming and/or skimming operations in slicks of several millimetres or more in open water areas, whenever possible.
- ⚓ Ice movement is subject to changing wind conditions, which often requires relocation of equipment to newly-accessible slicks.
- ⚓ When possible, burn or skim oil that collects at ice edges.
- (C) In-situ burning, using simple, available ignition devices, often is the most effective response method - and sometimes is the only option - for removing oil spills during the transition seasons.
- ⚓ If oil is widely distributed throughout broken ice, no countermeasures methods might be practical.

Table 3 - 5 Transition season response at sea

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
source control		A B	A C	A B	○
		C			●
		E B	C		◒
control of free oil		A A	A C	A B	○
		C			●
		E B	C		◒
protection		E F	A C	A B	○
		C			●
		E	C		◒

3

3.3.1.2 Response Strategies and Methods

Response to spills in broken ice frequently requires strategies to deal with moving ice. Dramatic changes in ice concentration due to wind shifts should be expected. ***Safety is the key factor***.

During early freeze-up and the latter stages of breakup (up to 25-30% ice cover), open-water response techniques are often used. However, oil released during melting presents time and access problems. Diminishing open water, vessel mobility and mechanical recovery potential are concerns. Slush and broken ice can enter the water intakes of jet and propellor-type motors; screw-driven vessels are preferable. During late freeze-up, oil may become mixed or encapsulated in ice, making monitoring the preferable strategy. Cold temperatures may also limit operations during this season.

Containment and Recovery

Containment

A The source control of spills from tankers, blowouts and subsea pipelines involves the use of durable containment booms:

- Ice pieces must be small enough to be contained or deflected by booms; booms are of little or no use in large, moving ice floes or in ice concentrations greater than 30%.
- In winds greater than 35 km/h, impacts to the boom from small pieces of ice can occur.
- Booms made of conveyor belting are most likely to withstand ice; PVC and polyurethane materials are less durable.
- Wave-riding, reserve buoyancy and other design features of booms are less important than durability.
- Anchoring in broken ice can be difficult or impractical.
- Regular monitoring is essential once a boom is deployed to ensure that the boom remains in place and is not damaged by ice.

Recovery

Skimmers function best if positioned in oil concentration in open water and in leads between ice pieces:

- Time is generally less of a factor since oil would become trapped in ice. However, wind can cause ice pieces to move outside the recovery area.
- Vertical rope mops (operated from cranes), drum, brush, drum-brush and disc systems are the most useful skimmers.
- Belt skimmers can be used if ice pieces are manually removed from directly in front of the skimmer or if they are picked up by the belt.
- Expect minimal ice processing or deflection with most skimmers except brush and drum-brush units.
- The recovered fluid generally contains a significant amount of slurry and slush ice. This can be a problem unless sufficient storage capacity is available.

Dispersion

Dispersant use in high concentrations of broken ice is usually not practical due to a lack of wave energy, i.e., little mechanical mixing, and application difficulties. However, when dispersants can be applied to oil in low concentrations of ice in low waves, the likelihood of oil dispersion increases.

In-situ Burning

In-situ burning is the optimum response strategy for most spills in broken ice when the following conditions are met:

- Emulsions should be at least 75% oil.
- Slick thickness should be greater than 2-3 mm.
- Waves should be less than 2 m and not breaking.
- Wind speed should be less than 35 km/h (20 knots).
- Crude oil should be burned within 2 - 5 days of the spill.

An ignition system is always needed; fire-resistant boom is useful, as well as spotter aircraft, if available.

The deployment of fire-resistant boom will not always be feasible in broken ice unless positioned in the lee of an island or in another area that remains relatively ice-free.

✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

✚ Emergency escape routes must be planned.

Protection

Protection strategies in broken ice may not always be possible:

- If booms are deployed, they should be made of highly durable material (conveyor belting or logs). Ice movement could prevent exclusion or diversion of slicks.
- Movement of oil in broken ice at shorelines should be expected unless landfast ice remains intact.

Use smaller oleophilic skimmers, e.g., disc, drum, brush and rope mop units, to remove light and medium viscosity oils for storage in either water- or land-based storage systems

In-situ burning is a possible protection option in waters characterized by broken ice when an ignition device is available. Spotter aircraft should be used when available. A fire-resistant boom may not be needed:

- Fire-resistant booms are difficult to deploy in ice and can be damaged.
- Oil that concentrates at ice edges or is trapped in ice leads can be burned when at least 2 - 3 mm thick.

A safety plan for the burn operation must be prepared that considers the potential impacts of the burn, amenities at risk and the possible health effects of the smoke plume, e.g., 10 km (6 mile) downwind exclusion zone, sulfur content of crude and the means to extinguish the fire.

Chemical dispersion is unlikely to be effective in coastal waters with broken ice when there is low-mixing energy (small or no waves are present). Aerial application is likely impractical due to the difficulty of applying dispersant between floes.

Shoreline Treatment

Freeze-up Transition

During freeze-up, shore-fast ice (an ice foot) can develop in the intertidal zone. Oil on shore, on or in snow, or on existing ice, can become frozen into the ice foot during early freeze-up and remain there until the next thaw period.

If the oil cannot be recovered immediately, and it poses no threat to human health and safety or wildlife, the location can be marked and the oil can be removed during the frozen months (see Section 3.4 on page 3 - 45) or when the ice begins to melt during the next thaw period.

2 3 Selecting treatment methods appropriate for initial response is based on shore type, the amount and type of oil, and on the snow and ice conditions; if ice is present, flooding or low-pressure washing can be used to move the oil to a containment and recovery area, ***provided that the water does not freeze***.

9 10 16 Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum units or burning may be appropriate for the removal of pooled oil.

Breakup Transition

During the spring thaw or breakup transition, oil likely will be washed out of melting ice and redistributed unless contained or recovered.

2 3 Flooding or low-pressure washing can be used to move oil to a containment and recovery area, ***provided that the water does not freeze***.

9 10 16 Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum units or burning may be appropriate for the removal of pooled oil.

Treatment methods for ice or ice-covered shores are described in Section 4.11.3 and for shorelines with snow in Section 4.11.14.

3.3.2 Lakes

3.3.2.1 General Guidelines

The transition seasons are characterized by a wide range of broken ice types and concentrations. During freeze-up, thinner, flatter ice, and sometimes smaller particles and crystals can form, whereas larger, thicker ice floes and pieces are usually present during breakup. ***Safety is the key response consideration in broken ice.***

- ✚ Do not deploy personnel or equipment on ice that might be too hazardous, i.e., moving, unstable, cracked, melting.
- ⚓ Plan booming and/or skimming operations in slicks several millimetres or more thick in open water areas, if possible.
- ⚓ Ice movement is subject to changing wind conditions, often requiring the relocation of response operations to newly-accessible slicks.
- ⚓ When possible, burn or skim oil that collects at ice edges.
- (C) In-situ burning, using simple ignition devices, is often the most effective response method - and sometimes the only option - for removing oil spills in lakes during the transition seasons.
- ⚓ If oil droplets are widely distributed throughout broken ice, there may be no countermeasures method that is practical.

Table 3 - 6   Transition season response in lakes

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
source control		A (solid), B	A, C		○
		C (solid)			●
		E (solid), B	C		◒
control of free oil		A (solid), A	A, C		○
		C (solid)			●
		E (solid), B	C		◒
protection		E (solid), F (solid)	A, C		○
		C (solid)			●
		E (solid)	C		◒

3.3.2.2 Response Strategies and Methods

Similar criteria apply to spill response in lakes as to seas characterized by broken ice. Source control and removing slicks that have escaped initial containment generally involve skimming or burning concentrated oil.

Containment and Recovery

Containment

A Generally, it is difficult to use booms effectively in the presence of large, moving ice floes:

- Ice pieces must be small enough to be contained or deflected by booms; booms are of little or no use in large, moving ice floes or in ice concentrations greater than 30%.
- In winds greater than 35 km/h, impacts to the boom from small pieces of ice can occur.
- Booms made of conveyor belting are most likely to withstand ice; PVC and polyurethane materials are less durable.
- Wave-riding, reserve buoyancy and other design features of booms are less important than durability.
- Anchoring in broken ice can be difficult or impractical.
- Regular monitoring is essential once a boom is deployed to ensure that the boom remains in place and is not damaged by ice.

Recovery

B Skimmers positioned in oil accumulations between ice pieces can be effective in removing slicks:

- Vertical rope mops (deployed from cranes), drum, brush, drum-brush and disc systems are most useful.
- Belts can be used if manual removal of ice pieces on or in front of the belt is planned.
- Minimal ice processing, i.e., ice deflection, should be expected with most skimmers.
- Brush and drum-brush units are best for deflecting small ice pieces but will likely recover slush ice.

Dispersion

Dispersant application in lakes during the transition seasons is unlikely due to a lack of water circulation/dilution and to potentially adverse environmental effects.

In-situ Burning

In-situ burning is the optimum oil removal technique for most spills in broken ice, whether large or small:

- The oil content of emulsions should be at least 75%.
- Slick thickness should be at least 2 - 3 mm.
- Waves should be less than 2 m high and not breaking
- Wind speed should be less than 35 km/h (20 knots).
- Crude oil should be burned within 2 - 5 days of the spill.

An ignition system is always needed; spotter aircraft can be used, if required and available.

The deployment of fire-resistant boom is not always feasible in broken ice unless it is positioned in the lee of an island or in another area that remains relatively ice-free.

✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

✚ Emergency escape routes must be planned.

3

Protection

Protecting resources in lakes when broken ice is present is sometimes possible:

- Shoreline protection measures are not required if continuous landfast ice is present.
- Highly durable booms (conveyor belting or logs) should be used when deployment is possible.
- Anchoring boom in broken ice is usually difficult; once deployed, a boom must be regularly monitored.
- Damage to booms from ice impacts can still occur.
- Moving ice can prevent successful deflection, exclusion and diversion of slicks.
- Small, oleophilic skimmers, e.g., rope mop, disc, drum and brush units, can be used to recover oil.
- Water and/or land-based storage systems can be used to provide adequate volume for the collected slurry and slush ice.

In-situ burning is a possible protection option in lakes with broken ice when an ignition device(s) is available. Spotter aircraft should be used when available, but fire-resistant booms are not always needed nor useful:

- Fire-resistant booms may be difficult to deploy in ice and can be damaged by ice impacts.
- Sufficient oil might be concentrated at ice edges or contained within ice to initiate combustion, i.e., a minimum thickness of 2 - 3 mm.

A safety plan for the burn operation must be prepared that considers the potential impacts of the burn, amenities at risk and the possible health effects of the smoke plume, e.g., 10 km (6 mile) downwind exclusion zone, sulfur content of crude and the means to extinguish the fire.

Chemical dispersion is unlikely to be used due to a lack of water circulation/dilution and to potentially adverse environmental impacts.

Shoreline Treatment

Freeze-up Transition

During freeze-up, shore-fast ice (an ice foot) can develop at the water line. Oil on shore, on or in snow, or on existing ice, can become frozen into the ice foot during early freeze-up and remain there until the next thaw period.

If the oil cannot be recovered immediately, and poses no threat to human health and safety or wildlife, the location can be marked and the oil can be removed during the frozen months (see Section 3.4, Containment and Recovery) or when the ice begins to melt during the next thaw period.

2 3 Selecting treatment methods appropriate for initial response is based on shore type, the amount and type of oil, and on the snow and ice conditions; if ice is present, flooding or low-pressure washing can be used to move the oil to a containment and recovery area, ***provided that the water does not freeze***.

9 10 16 Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum systems or burning may be appropriate for removing pooled oil.

Breakup Transition

During the spring thaw or breakup transition, oil will likely be washed out of melting ice and be redistributed unless contained or recovered.

2 3 Flooding or low-pressure washing can be used to move oil to a containment and recovery area, ***provided that the water does not freeze***.

9 10 16 Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum systems or burning may be appropriate for removing pooled oil.

Treatment methods for ice or ice-covered shores are described in Section 4.11.3 and for shorelines with snow in Section 4.11.14.

3.3.3 Rivers

3.3.3.1 General Guidelines

Large, north-flowing rivers often have ice jams during the breakup transition season. This can result in widespread flooding and the subsequent spreading of spilled oil over a large area. Spill response can be a difficult and dangerous task.

3

- ✚ An objective of any response operation in a river with moving, broken ice should be the ***safe*** deployment of personnel and equipment.
- ⚓ Source containment and control may not be feasible when ice is present.
- ⚓ Ice and fast current often hinder or preclude downstream spill response.
- ⚓ When ice conditions allow, boom should be deployed downstream during transfer operations to intercept oil that escapes source control. Currents must be less than 1 m/s (2 knots).
- ⚓ Equipment should be staged and deployed at locations with good access and low currents.
- ⚓ Recovery sites should be located where oil has been contained downstream or has pooled naturally.

Table 3 - 7   Transition season response in rivers

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
control		E F B	A C		○
		C			●
		E B	C		◒
protection		E F	A C		○
		C			●
		E	C		◒

3.3.3.2 Response Strategies and Methods

A response to spilled oil in rivers containing ice floes and pieces is difficult and may not always be feasible.

Containment and Recovery

Containment

(A) Booms are unlikely to be practical to use in a river even if set at an angle to the current:

- Boom deployment in moving ice is often unsafe; boom survival is unlikely due to impacts from ice pieces.
- Reversing tides, eroding banks, high sediment load and debris are other factors that limit spill response in large coastal rivers.
- In addition to environmental factors, deployment of angled booms might not be practical in a river because:
    - The river is too wide to effectively divert slicks to one bank using booms.
    - There is insufficient time to set up booms.
- If used, booms should be fabricated from heavy-duty materials and incorporate top and bottom tension members.

Recovery

(B) If recovery of oil is attempted, small, oleophilic skimmers (units with a recovery mechanism to which oil adheres), particularly vertical rope mops, and/or vacuum and air conveyor trucks (where access allows), are likely to be the most useful oil removal devices.

3

Dispersion

Dispersant application in rivers with broken ice is unlikely due to a lack of effectiveness and to potentially adverse environmental effects.

In-situ Burning

In-situ burning is a possible oil removal technique for spills in rivers containing broken ice, but often will not be feasible:

- Crude oil should be burned within 2 - 5 days of a spill.
- Slick thickness should be at least 2 - 3 mm.
- The oil content of emulsions should be at least 75%.
- An ignition system and spotter aircraft are needed.
- The use of a fire-resistant boom is not likely to be feasible in broken ice unless the boom is deployed in an area that remains relatively ice-free, e.g., the lee of an island or of a point of land.
- Currents should be less than 1 m/s (2 knots).

✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

Protection

For rivers containing ice, the same techniques would be used for protecting resources as would be used to contain or control spills:

- Safety concerns and deployment difficulties in broken, moving ice are the two main factors that usually preclude protection activities.
- If in-situ burning were possible, this would likely be implemented more as an oil removal method than as a protection technique.

3

Shoreline Treatment

Freeze-up Transition

Typically, river levels fall during freeze-up; oil can be stranded above the zone of landfast ice formation and would be accessible for removal unless covered by snow.

Oil on shore, on or in snow, or on existing ice can become frozen into the ice foot during early freeze-up and remain there until the next thaw period.

If the oil cannot be recovered immediately, and it poses no threat to human health and safety or wildlife, the location can be marked and the oil can be removed during the frozen months (see Section 3.4 on page 3 - 45) or when the ice begins to melt during the next thaw period.

Selecting treatment methods appropriate for initial response is based on shore type, the amount and type of oil, and the snow and ice conditions; if ice is present, flooding or low-pressure washing can be used to move the oil to a containment and recovery area, ***provided that the water does not freeze***.

Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum systems or burning may be appropriate for the removal of pooled oil.

3

Breakup Transition

Breakup coincides with the spring thaw and rising river levels. Stranded oil would likely be either removed and carried downstream or reworked into sediments and covered by the rising waters; only heavy, viscous or sticky oils would remain undisturbed.

Flooding or low-pressure washing can be used to move oil to a containment and recovery area, ***provided that the water does not freeze***.

Alternatively, manual removal may be appropriate for the recovery of small amounts of oil, and vacuum systems or burning may be appropriate for the removal of pooled oil.

✚ The movement of broken ice downstream under high flow conditions during the breakup transition would present many operational and safety concerns.

Treatment methods for ice or ice-covered shores are described in Section 4.11.3, and for shorelines with snow in Section 4.11.14.

3.4 Spills in Frozen Conditions

3.4.1 Seas, Lakes and Rivers

Frozen conditions facilitate response operations in many ways, providing a solid working platform, reduced oil mobility and naturally-formed on and under-ice oil storage. However, darkness and extreme weather conditions make it necessary to maintain awareness of many safety factors.

3.4.1.1 General Guidelines

✚ Personnel must wear appropriate cold weather clothing, footwear and protective gear, and be able to recognize signs of frostbite, hypothermia and fatigue.

⚓ Diesel, heating and crude oils can stay unweathered and can be burned several months after being spilled.

⚓ Ice topography can be modified to contain spills.

⚓ In extremely low temperatures, engines are often run continuously, necessitating preplanning of fuel, lubricants and spare parts inventories.

⚓ Mechanical equipment functions less efficiently in cold weather; condensation, freezing and other problems occur.

✚ Winter darkness requires responders to take precautions, even when traversing short distances on ice: Pedestrian and machine travel should be restricted to safe, identified routes; operation of machinery requires strict attention.

✚ Knowledge of safety is critical in remote areas:

- first aid and Cardio-Pulmonary Resuscitation (CPR)
- hazards posed by extreme weather conditions, polar bears and other large mammals
- transportation/travelling options and restrictions
- weight-bearing capacity of ice
- use of portable radios and recharging systems

- increased fuel consumption, lower battery capacity
- operational constraints imposed by short daylight hours in winter

3.4.1.2 Response Strategies and Methods

The control of oil spills at sea, on lakes and in rivers is often readily possible on, in and under continuous ice, with or without snow cover.

Table 3 - 8 Frozen season response in seas, lakes and rivers

Environment		Response			
Response	Oil Location	Countermeasures			Feasibility
		contain/recover	burn	disperse	
control		D E B C	B		○
		E B C			●
		E B C	B		◒
protection		D E	B		○
		E			●
		E	B		◒

Various structures can be built or erected, or the ice can be excavated, to facilitate the containment and removal of spilled oil. The basic techniques described below can be adapted to meet the requirements of a specific situation.

Containment and Recovery

Containment

Ice usually is an effective oil barrier and snow is an effective oil sorbent. Equipment and manual methods can be used to mix and remove large quantities of oil and snow, although this mixture usually will have a low oil content.

D Graders and bulldozers, as well as shovels and rakes, can be used to move and place snow to create barriers:

- An impermeable berm or barrier results when a snow barrier is supplemented with more snow and sprayed with water to form ice.
- An impermeable liner, e.g., a plastic membrane, should be used when building a containment wall or dyke for diesel or other light oils which can penetrate snow.
- Collected oil can be pumped to storage.
- Often, ice formations such as hummocks and rubble fields occur and open-water leads form that interfere with response activities.
- Ice ridges and leads as well as other surface features must be considered when planning a response, together with the origin, size and pathway of the spill.

E Under-ice pockets of oil tend to accumulate in naturally-occurring surface depressions:

- Trenches or holes can be cut using an ice auger, chain saw, *Ditch Witch®*, bulldozer or backhoe to gain access to oil that has accumulated underneath the ice.
- A pump or skimmer can be used to remove the oil.
- In many cases, burning can be attempted.
- Slots cut in river ice at an angle to the current can be used to divert or contain oil in a manner similar to angling booms in open water to divert slicks.
- Boom can be positioned in the slots and left to freeze in place when the trench and boom are only used for deflection/containment (and not for burning).

Recovery

Vacuum systems and pumps are used to transfer oil from collection points to storage. Common problems include:

- ice pieces and slush blocking inlets and hoses
- indiscriminate pickup of oil, ice and water
- lines freezing due to water uptake
- freezing of the hose fittings
- brittle failure of hoses, connectors and fittings

Dispersion

Dispersants are generally not used in solid ice; however, they have been proposed as a means to disperse oil from a subsea blowout by injection into the escaping oil.

In-situ Burning

Burning oil on solid ice or on snow is usually feasible:

- within 2 - 5 days following a spill on ice
- within several months if the oil has spilled in or under ice
- when the oil is at least 2 - 3 mm thick

✚ A safety plan for response workers is required that addresses the location of ignition, burning and areas that would be affected by the smoke plume.

✚ Crude oil high in sulfur likely would present health and safety concerns either in an unburned state or upon ignition.

✚ A 10 km (6 mile) downwind exclusion zone provides adequate protection for response workers, the public and wildlife.

✚ Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn.

✚ Emergency escape routes must be planned.

Burning oil on ice requires one or more igniters:

- A propane torch can be used to ignite large areas of oil on ice or snow.
- The Heli-Torch® is useful for initiating multiple burns of oil on ice or pooled oil accessible only by air. Alternatively, hand-held igniters can be used.
- Oil accumulations that occur in depressions, or that have been exposed by cutting through the ice, may be ignited.
- Fuel can be added to initiate or promote combustion.
- When burning oil on ice, it is important to trench to contain the oil as large volumes of melt water are created.

Protection

Containment/Diversion

Barriers of ice or snow can be quickly created to divert or contain oil if the necessary equipment is readily available.

Graders and bulldozers, as well as shovels and rakes, can be used to move and place snow to create barriers:

- An impermeable berm or barrier results when a snow barrier is supplemented with more snow and sprayed with water to form ice.
- An impermeable liner, e.g., a plastic membrane, should be used when building a containment wall or dyke for diesel or other light oils that can penetrate snow.
- Collected oil can be pumped to storage.
- Often, ice formations such as hummocks and rubble fields occur and open-water leads form that interfere with response activities.
- Ice ridges and leads as well as other surface features must be considered when planning a response, together with the origin, size and pathway of the spill.

3

Shoreline Treatment

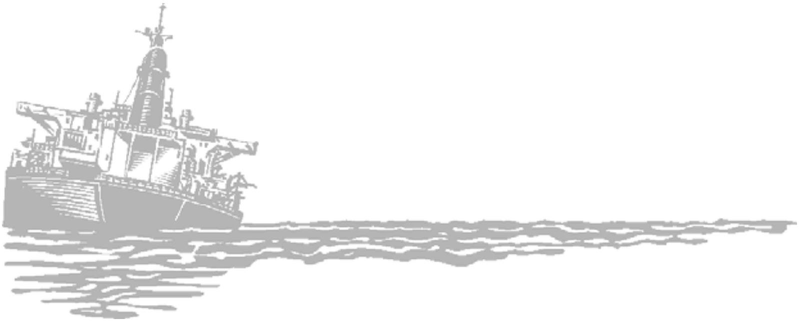
Oil on the ice surface or trapped within or beneath shore-fast ice (the ice foot) can be removed using the containment and recovery techniques described in more detail in this section.

9 10 11 16 Initial response techniques include manual removal, vacuum units, mechanical removal, or burning. Key considerations in selecting appropriate tools are the amount and type of oil, and the character of the ice surface.

✚ A zone of ice cracks at the landward margin of the ice foot is an important operational and safety factor in areas with a tidal range greater than 1 m, since the ice in this hinge zone moves up and down with the tide. Ice cracks are also a factor in areas where there are nearshore storm surges that change water levels at the coast.

Treatment methods for ice or ice-covered shores are described in Section 4.11.3 and for shorelines with snow in Section 4.11.14.

4 Response Strategies



4

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4

4.1 Introduction

Response strategies are discussed in this section in the context of environment, i.e., seas, lakes, rivers or shorelines (Figure 4 - 1).

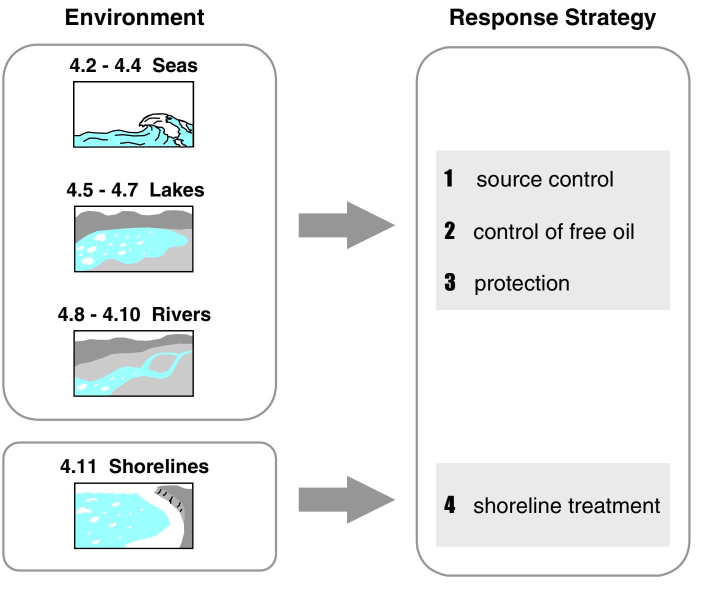


Figure 4 - 1 Section 4 organization

In most spills, initial response involves countermeasures to reduce impacts to the environment by implementing the following strategies:

Strategy 1	➡	source control
Strategy 2	➡	off-site control of free oil
Strategy 3	➡	protection

For each situation, a table identifies:

- ***environmental conditions***, i.e., season, water/ice conditions and oil location
- ***response techniques***, i.e., countermeasure options, the feasibility of those options and waste management issues

In each case, the table indicates possible response techniques, i.e., mechanical containment/recovery/protection, in-situ burning and chemical dispersion, as well as recommended methods for each response option. Each section includes a general description of operational, logistical and safety considerations specific to the strategy, including practical guidelines or "rules of thumb".

Text bullets used in Sections 4.2 - 4.10 refer to:

✚ safety concerns with respect to human life and health

⚓ operational considerations that might limit or enhance a response strategy or technique

Icons, e.g., A, are used that refer to countermeasures methods. The icons are defined in legends on the inside covers and in Section 1; corresponding countermeasures are explained in detail in Section 5.

On most large spills, and on some smaller ones, shoreline, lake shore or river bank treatment becomes the primary focus after the initial response. Treatment methods are selected on the basis of the physical characteristics of the oiled area, the oil properties, as well as other factors such as access and logistics. Response techniques for 14 shore types (Figure 4 - 2) are described in Section 4.11.

Strategy 4	➡	shoreline treatment

Details on each of the specific response methods or tools for each of the four strategies are provided in Section 5. Numbered icons, e.g., 9, refer to individual methods that are described in Section 5.

Text bullets in Section 4.11 refer to:

✔ recommended strategies or techniques

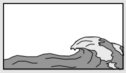
✗ techniques considered to be inappropriate

Note ***The limitations and constraints imposed on personnel, equipment and operations in Arctic conditions are detailed in Section 3. Regardless of the response option attempted, the first priority is the safety of the responders and the public.***

4

- **Impermeable or Solid Shores**
  - 4.11.1 Bedrock
  - 4.11.2 Man-made Solid Structures
  - 4.11.3 Ice or Ice-covered Shores
- **Unconsolidated or Sediment Shores**
  - **Beaches**
    - 4.11.4 Sand
    - 4.11.5 Mixed-sediment
    - 4.11.6 Pebble/Cobble
    - 4.11.7 Boulder and Rip-rap
  - **Flats**
    - 4.11.8 Sand
    - 4.11.9 Mud
  - 4.11.10 Salt Marshes
  - 4.11.11 Peat Shores
  - 4.11.12 Inundated Low-lying Tundra Shores
  - 4.11.13 Tundra Cliff Shores
  - 4.11.14 Shorelines with Snow

Figure 4 - 2 Shore types

4.2 Seas  Source Control

The objective of source control at sea is to contain the spill so that oil is prevented from spreading and environmental impacts are minimized. The control of spilled oil at or near the source should be possible during open-water, frozen and transition seasons.

4.2.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery at sea largely depends on the sea and wind conditions at the spill site. Containment and recovery are likely not possible, and are probably unsafe to attempt, in wave heights exceeding 2 m or in winds of more than 35 km/h. Containment booms and skimmers should be deployed as near as possible to the release point to minimize spreading (A) (B). Containment of submerged oil might be possible near or at the source using an oil trawl boom (C).

In the frozen or transition seasons, oil can sometimes be contained in ice slots, boomed ice slots (E) or in natural embayments. Although the use of booms is difficult in broken ice, oil submerged below solid ice can sometimes be contained using a boomed ice slot (E).

4.2.2 In-situ Burning

The in-situ burning of oil at or near the source of a spill can be effective on open water, in or on ice, or in a natural embayment (B) (C). In all cases, a device or system is needed to ignite the oil. In open water, fire-resistant booms can be used at a safe distance from the spill source. They are less effective in broken ice (A). In-situ burning on water is restricted to sea conditions in which containment and recovery are feasible, i.e., in waves less than 2 m and in winds less than 35 km/h.

4.2.3 Chemical Dispersion

Breaking waves higher than 1 - 2 m usually preclude the use of mechanical countermeasures and in-situ burning. In such sea conditions, in open water or in broken ice, chemical dispersants can sometimes be applied at or near the spill source. Dispersants can be applied to a relatively small area from a vessel (A) or, if broader area coverage is required, from a helicopter or fixed-wing aircraft (B).

4

4.2.4 Operational Considerations

There are a number of concerns when responding to spills at sea:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

- ⚓ In open-water conditions, short-period (1 - 2 seconds between crests), breaking waves often preclude successful containment, recovery and burning. Dispersants can be effective in such conditions when oil properties are appropriate (see Section 5.6). However, breaking waves usually provide sufficient mixing energy to distribute oil into the water column without dispersants.

- ⚓ In longer-period swells (wave period exceeds 6 seconds), mechanical containment and recovery, in-situ burning and dispersants are all possible options.

- ⚓ Booms should be deployed as quickly as possible downdrift of thick slicks. Observers in aircraft can provide guidance for positioning booms. When used, inflatable booms should be fully inflated. Skimmers and booms should be monitored frequently to ensure that they maintain functionality as oil properties and environmental conditions change.

- ⚓ Any countermeasures option is likely to be ineffective when oil droplets form or slicks thinner than 1 mm become widely distributed in open water or in broken or solid ice following a spill. Monitoring the spill may be the only practical option.

- ⚓ Dynamic (moving) broken ice usually interferes with, and prevents, the containment, removal and chemical dispersion of spilled oil. In contrast, solid ice facilitates oil containment, recovery and burning. Oil usually remains unweathered under ice; therefore, burning the oil (A) (B) may be possible several months following a spill if the oil can be collected and ignited.

Table 4 - 1 *Seas - source control*

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		A B	A	A B	○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		A B	A C	A B	○	• barge • tanker • workboat
			C			●	
			E B	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E B C	B		○	• drums • tanker truck • workboat • porta-tank
			E B C			●	
			E B C	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		A B	A C	A B	○	• barge • tanker • workboat
			C			●	
			E B	C		◐	

4

4.3 Seas  Control of Free Oil

The objective of the control of oil at sea is to reduce the spreading and impacts of slicks when source control cannot contain all of the oil. Control is achieved by interception, recovery, burning or treatment of free oil, i.e., oil remote from the spill source. The control of spilled oil at sea should be possible during open-water, frozen and transition seasons.

4.3.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery at sea depends on the sea and wind conditions at the spill site. Mechanical control options are likely not possible, and even unsafe to attempt, in wave heights greater than 2 m and in winds that exceed 35 km/h. In ice-free water, when feasible to do so, containment booms and skimmers should be deployed in a mobile or stationary mode to intercept, control and recover thicker slicks A A. Containment of submerged oil might be possible using an oil trawl boom C.

During transition seasons, containment might be possible in simple or boomed ice slots E or in natural embayments. During the frozen season, snow berms D or trenches E should prevent the spreading of oil. The containment of submerged oil below the ice might be possible using a boomed ice slot E.

4.3.2 In-situ Burning

The in-situ burning of free floating oil can take place on open water, in or on ice, or in a natural embayment B C. Burning can also involve anchoring fire-resistant booms a safe distance from the spill source A. In all cases, concentrated oil is ignited. In-situ burning is limited to sea conditions in which mechanical containment is feasible, i.e., in waves less than 2 m and in winds less than 35 km/h.

4.3.3 Chemical Dispersion

In many situations, in open water and broken ice, dispersants can be applied to a relatively small area from a vessel A or from a helicopter or fixed-wing aircraft B if broader area coverage is required.

4.3.4 Operational Considerations

Responding to large spills in coastal waters where the spill escapes source control often requires shoreline cleanup to be included as an integral part of the response operation. The following guidelines should facilitate the removal of free-floating oil:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine if ice will safely support equipment and personnel.

- ⚓ In open water, only thick slicks (several millimetres or more) should be intercepted, contained and recovered using booms and skimmers as described in Section 5. Spotter aircraft should be used to position equipment as quickly as possible following the spill. Effective dispersant application from aircraft and vessels requires similar direction from an aerial vantage point. Slicks thinner than 1 mm usually cannot be efficiently removed using mobile skimming or burning systems and will likely dissipate.

- ⚓ Generally, dispersant application and burning are feasible in colder climates for 2 - 5 days following a spill due to lower evaporation rates. Containment, recovery, burning and chemical dispersion can be attempted on unweathered, unemulsified oils in ocean swells but, typically, are not feasible options on highly viscous oil in short-period (1 - 2 second) breaking waves.

- ⚓ Spilled oil that becomes distributed in broken ice may be skimmed and burned only if slicks are sufficiently thick, i.e., at least 2 -3 mm. Removal of oil droplets, globules and particles mixed with broken ice using any response option (including chemical dispersion) is impractical unless melting creates concentrated slicks. Monitoring the spill may be the only practical option.

- ⚓ Dispersants should normally be applied at a rate of 20 - 90 L/hectare. Depending on slick thickness, this rate will result in an oil-to-dispersant ratio of 100:1 - 10:1. A ratio of 20:1 is often a good starting point for many fresh crude oils A B.

4

4

Table 4 - 2   Seas - control of free oil

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		A A	A	A B	○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		A A	A C	A B	○	• barge • tanker • workboat
			C			●	
			E B	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E B C	B		○	• drums • tanker truck • workboat • porta-tank
			E B C			●	
			E B C	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		A A	A C	A B	○	• barge • tanker • workboat
			C			●	
			E B	C		◐	

4.4 Seas Protection

The objective of protection at sea is to prevent or minimize contact between the oil and resources at risk in the anticipated spill path. Protection involves site-specific defensive strategies when source control or other on-water operations cannot intercept, contain, recover or divert slicks. All three spill response options (mechanical, burning and dispersion) may be applicable to protect sensitive or threatened areas.

4.4.1 Mechanical Diversion

The effectiveness of mechanical containment and recovery at sea depends on the sea and wind conditions at the spill site. Mechanical control is likely not possible, and may be unsafe to attempt, in wave heights greater than 2 m and in winds exceeding 35 km/h. In ice-free conditions, booms can be used to divert oil from sensitive areas F. The containment of submerged oil might be possible using an oil trawl boom C.

During transition seasons, the diversion of slicks might be possible by using angled or boomed ice slots E. Boom deployment in broken ice is difficult. During the frozen season, snow berms F or trenches E should prevent the spreading of oil. The diversion of oil submerged below the ice might be possible using a boomed ice slot E.

4.4.2 In-situ Burning

Oil slicks threatening a sensitive area can be burned on open water, in or on ice, or in a natural embayment C. Fire-resistant boom is difficult to deploy in broken ice and can only be used in currents less than 1 m/s and in wave heights less than 2 m.

4.4.3 Chemical Dispersion

Dispersants can be used in many situations involving open water and broken ice when a slick threatens a sensitive area. Dispersants can be applied to a relatively small area from a vessel A or from a helicopter or fixed-wing aircraft B if larger areas are involved. Note that sensitive resources below the water surface in shallow areas, e.g., shellfish, are vulnerable to dispersed oil.

4.4.4 Operational Considerations

Guidelines for protecting resources at risk from a spill that occurs at sea are similar to those employed for response operations at, and remote from, the source:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine if ice will safely support the weight of equipment and personnel.

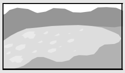
- ⚓ In ice-free water, excessive currents (over 1 m/s) and breaking waves eliminate booming, skimming and burning as feasible options. When large coastal spills occur, the protection of one shoreline area can result in the contamination of adjacent areas unless spilled oil is mechanically removed or burned.

- ⚓ Protection techniques, including chemical dispersion, may not be needed, nor be practical, in broken and solid ice. The natural barrier formed by ice, particularly continuous landfast ice, can protect resources from the impacts of spilled oil or reduce its effects. Burning concentrated oil remains the most effective response technique when conditions and safety allow. Slicks should be at least 2 - 3 mm thick.

- ⚓ Protection measures are not usually feasible when thin slicks (less than 1 mm), oil droplets and particles are widely distributed in ice-free conditions or throughout broken ice. Monitoring the spill may be the only practical option.

Table 4 - 3 Seas - protection

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		F	A	A B	○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		F E	A C	A B	○	• barge • tanker • workboat
			C			●	
			E	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E	B		○	• drums • tanker truck • workboat • porta-tank
			E			●	
			E	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		E F	A C	A B	○	• barge • tanker • workboat
			C			●	
			E	C		◐	

4.5 Lakes  Source Control

The objective of source control in lakes is to contain the spill to prevent oil from spreading so that environmental impacts are minimized. Source control in lakes should be possible during open-water, frozen and transition seasons.

4.5.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery on lakes depends on the wind and wave conditions at the spill site. Mechanical containment and recovery are likely not possible, and are probably unsafe, in waves over 2 m and in winds more than 35 km/h. Booms and skimmers should be deployed as near as possible to the release point to minimize spreading A B. The containment of submerged oil might be possible near the source using an oil trawl boom C.

In the frozen or transition seasons, oil often can be contained in ice slots, by boomed ice slots E or in natural embayments. The use of booms to contain slicks in broken ice is usually difficult. However, the containment of oil submerged below solid ice might be possible using a boomed ice slot E.

4.5.2 In-situ Burning

The in-situ burning of oil at or near the source of a spill can be effective on open water, in or on ice, or in a natural embayment B C. In all cases, a device or system is needed to ignite the oil. In open water, fire-resistant booms can be used at a safe distance from the spill source but their deployment in broken ice is very difficult A. In-situ burning on water is limited to wind and wave conditions in which containment and recovery are feasible, i.e., in waves less than 2 m and in winds less than 35 km/h.

4.5.3 Chemical Dispersion

Generally, dispersants are not recommended even in large lakes due to limited flushing and possible adverse environmental impacts.

4.5.4 Operational Considerations

There are a number of concerns when responding to spills in lakes:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine if ice will safely support the weight of equipment and personnel.

- ⚓ In large, unprotected lakes, short-period (1 - 2 seconds between crests), breaking waves often preclude successful containment, recovery and burning operations. Waves can build quickly, particularly in shallow (10 m) bodies of water.

- ⚓ Containment, recovery and in-situ burning are possible when long-period (greater than 6 second) waves form.

- ⚓ Booms should be deployed as quickly as possible downdrift of thick slicks. Observers in aircraft can aid in positioning so that recovery or burning operations are optimized. When used, inflatable booms should be fully inflated. Skimmers and booms should be monitored frequently to ensure that they are functional as conditions change.

- ⚓ Any countermeasures option is likely to be inefficient when oil droplets form or slicks thinner than 1 mm become widely distributed in open water or in broken or solid ice. Monitoring the spill may be the only practical option.

- ⚓ Moving, broken ice usually interferes with, and prevents, the containment and removal of spilled oil. In contrast, solid ice facilitates oil containment, recovery and burning. Oil usually remains unweathered under ice; therefore, burning the oil A B may be possible several months following a spill if the oil can be collected and ignited.

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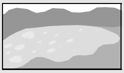
Table 4 - 4 Lakes - source control

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		A B	A		○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		A B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E B C	B		○	• drums • tanker truck • workboat • porta-tank
			E B C			●	
			E B C	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		A B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◐	

4.6 Lakes  Control of Free Oil

The objective of controlling free-floating slicks in lakes is to minimize spreading when source control cannot contain all of the spilled oil. Control is achieved by the interception, concentration and collection or treatment of the oil. The control of oil remote from a spill source in lakes should be possible during open-water, frozen and transition seasons.

4.6.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery on lakes depends on the wind and wave conditions at the spill site. Containment and recovery are likely not possible, and are probably unsafe, in waves greater than 2 m and in winds of 35 km/h or more. Booms and skimmers should be deployed to intercept, control and recover thicker slicks A A when possible. The containment of submerged oil might be possible using an oil trawl boom C.

In the frozen or transition seasons, oil can sometimes be contained in ice slots, boomed ice slots E or in natural embayments. However, booms are difficult to deploy in broken ice. During the frozen season, snow berms D or trenches E should prevent the spreading of oil. The containment of oil submerged below the ice might be possible using a boomed ice slot E.

4.6.2 In-situ Burning

The in-situ burning of oil remote from a spill source can be effective in open water, in or on ice, and in a natural embayment A B. An ignition system is always required. When used, a fire-resistant boom must be deployed at a safe distance from the spill source; however, its use in broken ice is difficult. Generally, in-situ burning on water is limited to wind and wave conditions in which mechanical containment is feasible, i.e., in waves less than 2 m and in winds less than 35 km/h.

4.6.3 Chemical Dispersion

In general, dispersants are not recommended even in large lakes due to limited flushing and possible adverse environmental impacts.

4.6.4 Operational Considerations

Responding to spills that escape source control in lakes, often requires shoreline cleanup to be planned integral to the response operation; however, a number of considerations will facilitate the removal of free-floating oil:

✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

⚓ Only thick slicks (several millimetres or more) should be intercepted, contained and collected using booms and skimmers (see Section 5). Spotter aircraft should be used to position equipment as quickly as possible following the spill. Slicks thinner than 1 mm will likely dissipate and usually cannot be efficiently removed using mobile skimming or burning and boom systems.

⚓ Medium and heavy oils, as well as diesel, will persist in lakes for a considerable time, particularly in colder weather, making the necessity of shoreline protection/treatment likely.

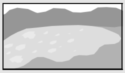
⚓ Generally, burning is not feasible in ice-free conditions more than 2 - 5 days following a spill due to oil weathering and emulsification. Containment, recovery and burning can be attempted on unweathered oils but, typically, are not feasible options in short-period (1 - 2 second), breaking waves.

⚓ Spilled oil that becomes distributed in broken ice may be skimmed or burned if sufficiently thick. Removal of oil droplets, globules and particles mixed with broken ice using any response option is impractical unless melting results in concentrated slicks. Monitoring widely-distributed small oil droplets in broken ice is usually the only option.

Table 4 - 5 Lakes - control of free oil

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		A (solid), A (outline)	A		○	• barge • tanker • workboat • towable tank
			C (solid)			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		A (solid), A (outline)	A, C		○	• barge • tanker • workboat
			C (solid)			●	
			E (solid), B (outline)	C		◒	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D (solid), E (solid), B (outline), C (outline)	B		○	• drums • tanker truck • workboat • porta-tank
			E (solid), B (outline), C (outline)			●	
			E (solid), B (outline), C (outline)	B		◒	
	• open water • ice floes • broken ice • melt pools • leads		A (solid), A (outline)	A, C		○	• barge • tanker • workboat
			C (solid)			●	
			E (solid), B (outline)	C		◒	

4

4.7 Lakes  Protection

The objective of protection in lakes is to prevent or minimize contact between the oil and resources at risk in the anticipated spill path. Protection involves site-specific defensive strategies when source control or on-water operations cannot intercept, contain, recover or divert the spilled oil. Both mechanical diversion and in-situ burning can be used to protect sensitive areas from approaching slicks.

4.7.1 Mechanical Diversion

The effectiveness of mechanical containment and recovery in lakes depends on the wave and wind conditions at the spill site. Mechanical containment and recovery are likely not possible, and are probably unsafe to attempt, in wave heights greater than 2 m and in winds exceeding 35 km/h. In ice-free conditions, containment booms can be used to divert oil from sensitive areas F. The containment of submerged oil might be possible using an oil trawl boom C.

During transition seasons, oil can sometimes be diverted using angled ice slots or booms placed in ice slots E. However, booms are difficult to deploy in broken ice. During the frozen season, snow berms D or trenches E should prevent the spreading of oil on ice. Diversion of oil submerged below the ice might be possible using a boomed ice slot E.

4.7.2 In-situ Burning

The in-situ burning of oil slicks threatening a sensitive area can be successful in open water, in or on ice, and in a natural embayment A B. An ignition system is always required. When used, a fire-resistant boom must be deployed at a safe distance from the spill source (deployment in broken ice is difficult). Generally, in-situ burning on water is limited to wind, current and wave conditions in which mechanical containment is feasible, i.e., in waves less than 2 m, in currents less than 1 m/s, and in winds less than 35 km/h.

4.7.3 Chemical Dispersion

In general, dispersants are not recommended even in large lakes due to limited flushing and possible adverse environmental impacts.

4.7.4 Operational Considerations

Guidelines for protecting resources at risk from a spill that occurs in lakes are similar to those employed for response operations at, and remote from, the source:

✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

⚓ In ice-free water, currents greater than 1 m/s and breaking waves eliminate booming, skimming and burning as feasible options. When large nearshore spills occur, the protection of one shoreline segment will likely result in the contamination of adjacent areas unless the oil is mechanically removed or burned.

⚓ Protection techniques may not be needed nor be feasible in broken and solid ice. The natural barrier formed by ice can protect resources from the impacts of spilled oil or reduce its effects. Burning concentrated oil remains the most effective response technique when conditions and safety allow. Slicks should be at least 2 - 3 mm thick.

⚓ Protection measures are not usually feasible when thin slicks (less than 1 mm), oil droplets and particles are widely distributed in ice-free conditions or throughout broken ice. Monitoring the spill may be the only practical option.

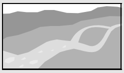
⚓ In many cases, deployment of equipment from shore may be safer and more practical, eliminating or reducing the need for response vessels and manpower.

⚓ Sorbent booms or sweeps are sometimes effective in protecting shorelines, but should be inspected regularly and replaced when saturated with oil. The use of sorbent boom is only recommended in quiet, low-current (0.1 - 0.2 m/s) water.

4

Table 4 - 6 Lakes - protection

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		F	A		○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		E F	A C		○	• barge • tanker • workboat
			C			●	
			E	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E	B		○	• drums • tanker truck • workboat • porta-tank
			E			●	
			E	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		E F	A C		○	• barge • tanker • workboat
			C			●	
			E	C		◐	

4.8 Rivers  Source Control

The objective of source control in rivers is to contain a spill so that oil does not spread and environmental impacts are minimized. The control of spilled oil at or near the source in a river may be possible during open-water, frozen and transition seasons.

4.8.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery in rivers highly depends on current speed. In large rivers, wind can also be a factor. Containment and recovery are likely not possible, and are probably unsafe to attempt, in currents greater than 1 m/s and in winds exceeding 35 km/h. In ice-free conditions, booms F and stationary skimmers B should be deployed as near as possible to the release point to minimize spreading. The containment of submerged oil might be possible near the source using an oil trawl boom C but deployment difficulties are likely.

In the frozen or transition seasons, boom deployment is difficult but containment may be possible using angled ice slots or booms placed in ice slots E or in natural embayments. The containment of oil submerged under ice might be possible using a boomed ice slot E.

4.8.2 In-situ Burning

The in-situ burning of oil at or near the source of a spill can be successful in open water, in or on ice, and in a natural embayment A B. An ignition system is always required. In-situ burning that depends on a fire-resistant boom to concentrate the oil is limited to ice, current, wave and wind conditions in which the deployment of conventional boom is feasible. When used, a fire-resistant boom must be anchored a safe distance from the spill source. Burning at source is most likely to be successful in frozen conditions when the spill can be contained naturally or using one of the above methods.

4.8.3 Chemical Dispersion

Chemical dispersants normally would not be applied in rivers because of limited effectiveness and possible adverse environmental effects.

4.8.4 Operational Considerations

There are a number of concerns when containing spills at their source in rivers:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

- ⚓ In large, fast-flowing rivers, currents that exceed 1 m/s preclude successful containment, recovery and burning.

- ⚓ In currents 0.4 - 1 m/s, diversion of the oil to shore may be possible using angled booms F.

- ⚓ Booms should be deployed as quickly as possible downdrift of thick slicks. When used, inflatable booms should be fully inflated, and skimmers and booms should be monitored frequently to ensure that they retain their efficacy as oil properties and environmental conditions change.

- ⚓ In cases of very thin oil slicks, i.e., when oil droplets or slicks are less than 1 mm thick, response is likely to be inefficient using any countermeasures option. Monitoring the spill may be the only practical alternative.

- ⚓ Dynamic (moving) broken ice usually interferes with, and prevents, the containment, diversion, interception and removal of spilled oil. In contrast, solid ice facilitates oil containment, recovery and burning. Oil usually remains unweathered under ice for several months following a spill. Therefore, burning the oil A B may be possible, if the oil can be contained.

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Table 4 - 7 *Rivers - source control*

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		F B	A		○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		E F B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◐	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E B C	B		○	• drums • tanker truck • workboat • porta-tank
			E B C			●	
			E B C	B		◐	
	• open water • ice floes • broken ice • melt pools • leads		E F B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◐	

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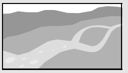
4.9 Rivers  Control of Free Oil

The objective of controlling free-floating oil in rivers is to minimize the spread of the spill to downstream areas and resources, when source control does not contain all of the oil. Control is achieved by the interception of slicks or the collection of oil where slicks have concentrated. Controlling oil remote from a spill source in rivers may be possible during open-water, frozen and transition seasons.

4.9.1 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery in rivers depends mainly on current speed. Mechanical containment and recovery are likely not possible, and are probably unsafe to attempt, in currents greater than 1 m/s. In ice-free conditions, booms and stationary skimmers should be deployed to intercept, contain and recover thick slicks. The containment of submerged oil is not likely possible but can be attempted using an oil trawl boom.

During transition seasons, containment may be possible in angled ice slots, boomed ice slots, or in natural embayments. During the frozen season, snow berms, or trenches should prevent the spreading of oil. The containment of oil submerged below the ice might be possible using a boom placed in an ice slot.

4.9.2 In-situ Burning

The in-situ burning of oil remote from a spill source in a river would involve the use of natural embayments, ice slots, or fire-resistant booms anchored a safe distance from the spill source. In-situ burning that depends on mechanical containment to concentrate the oil is limited to ice-free water and currents less than 1 m/s, i.e., conditions in which the deployment of conventional booms is feasible. Frozen conditions likely present the best opportunity for burning oil that has been previously contained using one of the techniques described above. Since oil can remain unweathered under ice for several months until it is exposed to atmosphere, burning oil that has naturally pooled under ice in a river is also sometimes possible.

4.9.3 Chemical Dispersion

Chemical dispersants normally would not be applied in rivers because of limited effectiveness and possible adverse environmental effects.

4.9.4 Operational Considerations

Responding to spills that escape source control in rivers, usually requires river bank cleanup. However, various considerations will affect the removal of free-floating oil:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.

- ✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

- ⚓ Attempts to control moving oil should be considered only on slicks several millimetres or more thick using booms and skimmers as described in Section 5. Observers in spotter aircraft may be of assistance to position equipment on spills in large rivers. Slicks thinner than 1 mm will likely dissipate, and usually cannot be efficiently removed using mobile skimming or burning and boom systems.

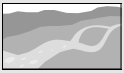
- ⚓ Medium viscosity and heavy oils, as well as diesel, persist for a considerable time in colder weather, making the necessity of river bank protection/treatment likely.

- ⚓ Generally, burning is not feasible in ice-free conditions more than 2 - 5 days following a spill because of oil weathering and emulsification. Interception, containment, recovery and burning can be attempted on unweathered oils but, typically, are not feasible in currents exceeding 1 m/s and in breaking waves.

- ⚓ Spilled oil that becomes distributed in broken ice may be skimmed and burned if sufficiently thick (2 - 3 mm). Removal of thin slicks (less than 1 mm), oil droplets, globules and particles mixed with broken ice using any response option is impractical, unless melting results in concentrated slicks. Monitoring the spill may be the only practical response alternative.

Table 4 - 8 Rivers - control of free oil

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures: contain/recover	Countermeasures: burn	Countermeasures: disperse	Feasibility	Waste Management
	• no ice • open water		F B	A		○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		E F B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◒	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E B C	B		○	• drums • tanker truck • workboat • porta-tank
			E B C			●	
			E B C	B		◒	
	• open water • ice floes • broken ice • melt pools • leads		E F B	A C		○	• barge • tanker • workboat
			C			●	
			E B	C		◒	

4.10 Rivers  Protection

The objective of protection in rivers is to prevent or minimize contact between the oil and resources at risk in the anticipated spill path. Protection involves site-specific defensive strategies when source control or on-water operations cannot intercept, contain, recover, or divert the oil on the water. Both mechanical diversion and in-situ burning can be used to protect sensitive areas in the event of a spill.

4.10.1 Mechanical Diversion

The effectiveness of mechanical containment and recovery in rivers mainly depends on current speed. Containment and recovery are likely not possible, and are often unsafe, in currents greater than 1 m/s. In ice-free water, booms F should be deployed to divert oil from sensitive areas. An oil trawl boom C may be an effective exclusion or diversion protection barrier for submerged oils.

During transition seasons, diversion may be possible using angled ice slots or boomed ice slots E. During the frozen season, snow berms D, or trenches E should prevent oil from spreading. The diversion of oil submerged below the ice might be possible using a boomed ice slot E or an oil trawl boom deployed in an ice slot.

4.10.2 In-situ Burning

Burning slicks threatening a sensitive area can involve the use of fire-resistant booms and/or an igniter A or a natural embayment. In-situ burning that depends on mechanical containment to concentrate the oil is limited to ice-free water and currents of less than 1 m/s in which the deployment of conventional booms is feasible. In-situ burning is limited to conditions in which oil has been contained using one of the methods described above. Burning is most likely to be effective in frozen conditions B and during open water A but is unlikely to be conducted during transition seasons because of moving ice.

4.10.3 Chemical Dispersion

Chemical dispersants normally would not be applied in rivers, particularly as a protection technique, because of limited effectiveness and possible adverse environmental effects.

4.10.4 Operational Considerations

Guidelines for protecting resources at risk from a spill that occurs in rivers are similar to those employed for response operations at, and remote from, the source:

- ✚ Conditions must be safe if a response is to be attempted. Monitors must be used to safeguard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur, volatile crude oils.

- ✚ When required, specialists should determine whether ice will safely support the weight of equipment and personnel.

- ⚓ In ice-free water, currents greater than 1 m/s eliminate booming, skimming and burning as feasible options. The protection of one shoreline segment will likely result in the contamination of downstream areas unless the oil is mechanically removed or burned.

- ⚓ Protection techniques may not be needed, nor be feasible, in broken and solid ice. The natural barrier formed by ice can protect resources from the impacts of spilled oil or reduce its effects. Burning concentrated oil remains the most effective response technique when conditions and safety allow. Slicks should be at least 2 - 3 mm thick before burning would be feasible.

- ⚓ Protection measures usually are not feasible when thin slicks (less than 1 mm), oil droplets and particles are widely distributed in ice-free conditions or throughout broken ice. Monitoring the spill may be the only practical option.

- ⚓ In many cases, the deployment of equipment from shore may be safer and more practical, eliminating or reducing the need for response vessels and manpower.

- ⚓ Sorbent booms or sweeps are sometimes effective in protecting shorelines in quiet, low-current areas, but should be inspected regularly and replaced when the sorbent material becomes saturated with oil.

Table 4 - 9 Rivers - protection

Environment			Response				
Season	Water/Ice Conditions	Oil Location	Countermeasures			Feasibility	Waste Management
			contain/recover	burn	disperse		
	• no ice • open water		F	A		○	• barge • tanker • workboat • towable tank
			C			●	
	• open water • ice floes • broken ice • frazil/grease ice • slush • pancake ice		E F	A C		○	• barge • tanker • workboat
			C			●	
			E	C		◒	
	• solid ice • multi-year ice • ice floes • broken ice • brash ice • ice hummocks		D E	B		○	• drums • tanker truck • workboat • porta-tank
			C E			●	
			E	B		◒	
	• open water • ice floes • broken ice • melt pools • leads		E F	A C		○	• barge • tanker • workboat
			C			●	
			E	C		◒	

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4.11 Shoreline Treatment

The objective of treating oiled shorelines is to either accelerate natural recovery or remove the stranded oil. Treatment involves the use of one or more of 20 physical, biological and chemical techniques that are described in Section 5.7.

In this section, strategies and techniques are outlined for 14 shore types that have been defined for ocean coasts, lake shores and river banks of Arctic regions.

The 14 shore types are based on the permeability of the substrate (Figure 4 - 2 on page 4 - 6) as follows:

- Impermeable or solid shorelines have no surface sediments; they are (except for ice) stable. Oil cannot penetrate below the surface.

- Permeable or unconsolidated shorelines contain organic or inorganic sediments, are mobile, and oil can penetrate into, or be buried below, the surface materials. (This category includes snow on shorelines.)

For permeable shorelines, the size of the materials and the primary coastal land form are used to further subdivide shoreline types. The shore types are illustrated in photographs in Section 8.9.

Shoreline treatment or cleanup normally would take place during ice-free conditions. However, a shoreline may be oiled during thaw or freeze-up when ice and/or snow are present on the shore. For all of the shoreline types, the strategies that are appropriate for freeze-up, winter or for snow and ice conditions are addressed in Sections 4.11.3 (Ice or Ice-covered Shores) and 4.11.14 (Shorelines with Snow).

Text bullets in this section refer to:

✔ strategies or techniques recommended for a given scenario

✗ techniques considered to be inappropriate and therefore not recommended for a given scenario

4.11.1 Shoreline Treatment Bedrock

- Bedrock is impermeable so that stranded oil remains on the surface.
- On coasts where ice is common, the biological community for the most part is scraped off the bedrock each year, so there are few attached intertidal organisms or plants. Plants and animals can only survive in cracks and crevices that offer protection from scouring. Overall, ice-scoured bedrock outcrops do not have extensive, diverse or rich biological communities.
- Where present, biological communities usually are more prolific in the subtidal or lower intertidal zones.

Oil on Bedrock Shores

- Oil is more likely to be deposited in the upper half of the intertidal zone:
    - Viscous or weathered oils would smother any organisms in this zone and likely would have a lower impact on biological communities in the lower intertidal zone.
    - Light products or fresh crudes can easily flow downslope into the lower intertidal zone and can affect biological communities, often upon contact, due to the higher level of toxic components in these oil types.
- Intertidal biological communities are more affected by:
    - large amounts of oil rather than small oil concentrations
    - light refined oils (diesel, Fuel Oil No. 2, etc.) rather than heavy oil products (bunker fuels) or weathered crudes

- The lower half of the intertidal zone in bedrock areas usually stays wet, even when exposed, so that oil often would not adhere to the bedrock or plants. Oil might be deposited and persist in cracks and crevices where neither wave nor ice action can reach. On platforms or ramps oil can collect in hollows or tidal pools.

Oil Persistence

- On exposed coasts, oil often does not strand due to wave reflection. If stranded, the oil may be washed off rapidly (days to weeks) by wave action.

- Oil may be splashed above the limit of normal wave action and persist there for weeks to months or years, even on exposed coasts.

- Oil that comes ashore in sheltered locations is likely to be deposited on the upper intertidal zone as a band near the last high-water level.

- On coasts with relatively low wave-energy conditions, heavy oils or weathered crudes that are not removed by wave action or ice scraping may persist for a considerable time (years) since there is insufficient wave action to naturally remove the oil.

- Light oils likely would be washed off the bedrock in a short time (days to weeks).

Preferred Response Options for Open-water Conditions

✔ Natural recovery (1) is the preferred option on exposed coasts, particularly early in the open-water season. This method is less appropriate for heavy oils or weathered crudes on a sheltered coast, where the oil is likely to persist longer or may not be removed from the bedrock by wave or ice action. Natural recovery may not be appropriate immediately prior to freeze-up, as the oil would be covered and frozen in the ice and potentially be remobilized during the next thaw.

✔ No action is the safest option for light, volatile oils, such as gasoline. If there is a need to remove this type of oil, treatment can be achieved by one of the cold-water washing techniques, conducted from a safe distance (fumes, ignition and flashback are safety factors to consider), provided that low temperatures do not freeze the water. Removed oil should be contained and collected by booms and sorbents or skimmers.

✔ Flooding is appropriate for light oils, such as diesel, but is of little practical value for very viscous or semi-solid oils.

✔ Low-pressure, cold-water washing of light and some medium oils can minimize ecological impacts (see below for applications to avoid). If water depths allow, washing from a boat or barge avoids damage to shore-zone organisms by foot traffic.

✔ High-pressure, cold-water washing and low-pressure, warm/hot-water washing may be useful for more viscous oils that cannot be removed by low-pressure, cold-water washing.

✔ Manual removal is recommended for small amounts of medium and heavy oils. Manually-deployed vacuum systems can be effective to remove light, e.g., diesel or medium/heavy oils collected in tidal pools and hollows. Vacuum techniques are not applicable to gasoline for safety reasons. In all applications of manual techniques, foot traffic should be minimized in areas where organisms could be crushed or trampled.

✔ Sorbents can be deployed passively to collect light and medium oils. Sorbents are recommended for small amounts of oil.

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✔ Dispersants 17 can be used on a flooding tide on appropriate oil types. Dispersants can be effective for small amounts of oil if applied correctly. The use of any chemical agent usually requires permission from a government agency.

✔ Shoreline cleaners 18 can be used in conjunction with flooding or low-pressure washing to remove and collect the oil. The use of any chemical agent usually requires permission from a government agency.

Typical Combinations of Response Methods

- Manual removal 9 of oiled debris can be followed by manual removal of oil using hand tools, vacuum systems 10 or sorbents 13 in tidal pools (being careful not to trample organisms).
- Flooding 2 and low-pressure washing 3 can be combined with collection and recovery.
- The use of shoreline cleaners 18 can be combined with flooding 2 and/or low-pressure washing 3 and oil collection and recovery.

What to Avoid

✚ On steep bedrock outcrops, care should be exercised to avoid falls and slips, particularly on exposed shorelines (open coasts) where there is strong wave action or ice.

✗ In areas where there are plants (seaweeds) and animals (barnacles, mussels, etc.) in the shore zone, avoid washing oil from the upper to lower intertidal zones. Frequently, the lower intertidal zones are not oiled and more damage can be caused by cleanup if oil is washed downslope or if foot traffic leads to trampling. Working only during the upper half of the tidal cycle (during the flooding tide from mid-tide to high-tide and during the ebb from high-tide to mid-tide) avoids such damage since the lower tidal zones are always under water.

- ✗ High-pressure, warm/hot-water washing (including steam cleaning and sandblasting) 6 7 8 should be avoided as such methods can remove healthy organisms. Spot washing may be used to remove oil if no organisms are present, or if the oil already has smothered or killed the biological community; however, removal of the plants and animals, even if killed by the oil, may delay recolonization due to habitat modification.

- ✗ Avoid spraying freshwater on intertidal communities.

- ✗ Avoid vegetation cutting 12 as it may kill the plants and remove the protective cover for smaller organisms and wildlife.

Summary for Bedrock Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on bedrock shores. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have long oil residence times (months to years).

- The type of oil (heavy or light): Light oils are less persistent on most bedrock shores than heavy oils and weathered crudes.

On steep slopes, response may be limited to washing from a boat or barge.

Table 4 - 10   Appropriate treatment methods for bedrock shores

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	
2	flooding	○	○	
3	low-pressure, cold-water	○	○	◒
4	low-pressure, warm/hot-water		○	◒
5	high-pressure, cold-water			◒
6	high-pressure, hot-water			◒
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	◒
13	sorbents	◒	◒	
17	dispersants		◒	
18	shoreline cleaners		◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.2 Shoreline Treatment — Man-made Solid Structures

- Solid, man-made structures are very similar to bedrock shorelines. In particular, the substrate is impermeable so that stranded oil remains on the surface. Examples of this shore type include retaining walls, harbour walls and solid breakwaters. Open, i.e., permeable, structures, constructed of materials such as rip-rap, are discussed in Section 4.11.7.

- On coasts where ice is common on water or on shore, the biological community usually is scraped off the surface each year, so that plants and animals can only survive in cracks and crevices that offer protection from scouring. Overall, ice-scoured surfaces do not have extensive, diverse or rich biological communities.

- During cleanup, special attention must be paid to historic structures and archaeological or historic sites in backshore areas that may become oiled.

Oil on Man-made Solid Structures

- Solid man-made structures can include a wide range of materials such as concrete, metal and wood. Each of these materials has a different surface texture and roughness; some oil types may not stick to a smooth, sloping metal surface but may stick to a vertical, rough concrete surface, for example.

- The lower half of the intertidal zone usually stays wet, particularly where plants are present. Oil often does not adhere to the surface. Oil is more likely to be deposited in the upper half of the intertidal zone.

- The biological communities generally are not as abundant compared to bedrock shorelines since the surface is usually steeper and smoother and there is less room for organisms to attach.

- On sloping surfaces or ramps, oil may collect in hollows.

Oil Persistence

- On exposed coasts, oil often does not strand due to wave reflection. If stranded, the oil may be washed off rapidly (days to weeks) by wave action.

- Oil may be splashed above the limit of normal wave action and persist there for weeks, months or years, even on exposed coasts.

- Oil that comes ashore in sheltered locations is likely to be deposited as a band near the last high tide level.

- In low wave-energy conditions, heavy oils or weathered crudes may persist for a considerable time (years), as there is insufficient energy for natural removal.

- Light oils likely would be washed off the surface of most man-made surfaces in a short time (days to weeks).

Preferred Response Options for Open-Water Conditions

✔ Natural recovery (1) is the preferred option on exposed coasts. This method is less appropriate for heavy oils or weathered crudes on a sheltered coast where the oil is likely to persist longer. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be covered and frozen in the ice and potentially remobilized during the next thaw.

✔ No action (1) is the safest option for light, volatile oils, such as gasoline. If there is a need to remove this type of oil, treatment can be achieved by one of the cold-water washing techniques (3) (5), conducted from a safe distance (fumes, fire and flashback are safety factors to consider), provided that the water does not freeze. Removed oil should be contained and collected by booms (A) and sorbents or skimmers (B) (C).

✔ Flooding (2) is appropriate on sloping surfaces for light oils, such as diesel but is of little practical value for heavy or semi-solid oils.

- ✔ Low-pressure, cold-water washing (3) of light and some medium oils can minimize ecological impacts (see following section for applications to avoid). Man-made surfaces often are steep, so that washing from a boat or barge is preferred if water depths allow. Oil should be contained and collected by booms (A) and sorbents or skimmers (B) (C).

- ✔ High-pressure, cold-water washing (5) and low-pressure, warm/hot-water washing (4) may be useful for more viscous oils that cannot be removed by low-pressure, cold-water washing. High-pressure, warm/hot-water washing (6) techniques (with the spray nozzle held approximately 10 cm from the oiled surface) have been used successfully to remove viscous oils on historic stonework and plaster.

- ✔ On surfaces where no organisms are present, such as on ice-scoured man-made surfaces, high-pressure washing techniques (5) (6), steam cleaning (7) or sandblasting (8) may be appropriate.

- ✔ Manual removal (9) is recommended for small amounts of medium and heavy oils, but foot traffic should be minimized in areas where organisms could be trampled.

- ✔ Sorbents (13) can be deployed to passively collect small amounts of light and medium oil.

- ✔ Dispersants (17) and shoreline cleaners (18) can be used on oil types for which the product is designed, and can be effective for small amounts of oil if properly applied. The use of any chemical agent usually requires permission from a government agency.

Typical Combinations of Response Methods

- Flooding (2) and low-pressure washing (3), with collection and recovery for oil that is easily mobilized, can be followed by higher- pressure and/or higher-temperature techniques (4) (5) (6) (7) (8) to remove any residues.

- Shoreline cleaners (18) can be used in conjunction with flooding (2) or low-pressure washing (3) to remove and collect the oil.

What to Avoid

✚ On steep or flat, narrow, man-made structures, care should be exercised to avoid falls and slips, particularly on open coasts where there is strong wave action or ice.

✗ In areas where there are plants (seaweed) and animals (barnacles, mussels, etc.) in the intertidal zone, avoid washing oil from the upper to lower intertidal zones. Frequently, the lower intertidal zones are not oiled and more damage can be caused by cleanup if oil is washed downslope. This possible damage can be avoided 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 from high-tide to mid-tide) so that the lower tidal zones are always under water.

✗ High-pressure, warm/hot-water washing (including steam cleaning and sandblasting) 6 7 8 should be avoided as such methods can remove healthy organisms. Spot washing may be used to remove oil if no organisms are present or if the oil already has smothered or killed the biological community; however, removal of the plants and animals, even if killed by the oil, may delay recolonization due to habitat modification.

✗ Avoid spraying fresh water on intertidal plants and animals.

✗ High-pressure, warm/hot-water washing techniques on historic stonework and plaster may be appropriate provided that abrasives 8 and chemicals 17 18 are avoided since these agents could damage the cements.

The cleaning of historic structures, such as old wooden or stone work, must be treated as a special case. Cleaning should only be conducted after consultation with national and/or local government agencies responsible for their preservation.

Summary for Man-made Solid Structures

There is little difference in the treatment techniques used for large versus small amounts of oil on man-made solid structures. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have long oil residence times (months to years).
- The type of oil (heavy or light): Only very light oils, e.g., diesel, can penetrate most man-made solid structures.

On steep man-made slopes, a response may be limited to washing from a boat or barge.

Table 4 - 11 Treatment methods for man-made solid structures

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	
2	flooding	○		
3	low-pressure, cold-water	○	○	◒
4	low-pressure, warm/hot-water		○	◒
5	high-pressure, cold-water			◒
6	high-pressure, hot-water			◒
7 8	steam, sand blasting			◒
9	manual removal		◒	◒
13	sorbents	◒	◒	
17	dispersants		◒	
18	shoreline cleaners		◒	

○ good ◒ fair (for small amounts of oil only)

4.11.3 Shoreline Treatment Ice or Ice-covered Shores

- Ice is relatively impermeable but oil can become encapsulated within ice as the water freezes and thaws.

- Ice shorelines occur where a glacier or ice margin extends onto the ocean. Ice may form seasonally on any of the shoreline types on coasts, lakes and rivers. The shore ice cover will persist until the following thaw. In some high Arctic regions, such as the most northern coasts of Canada, Greenland and Franz Joseph Land, the shore ice cover may not melt each year.

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Seasonal ice can assume a number of forms at the shore:

- Freezing waves and spray can build a landfast ice cover in the intertidal zone (the ice foot, Figure 4 - 3).

- Ice floes can become stranded in the intertidal zone and become incorporated into the landfast ice, or may be remobilized by wave action.

- Groundwater in the beach can freeze.

- The character of the ice surface can be highly variable, ranging from dry snow to wet slush and from dry ice to wet (melting) ice.

- Snow-covered ice and slush are discussed in Section 4.11.14, Shorelines with Snow.

- An ice shoreline may be vertical if the glacier or ice margin is calving, or it may be at a low angle if melting. The character or form of seasonal shore-zone ice is primarily a function of the tidal range and of the wave and weather conditions during freeze-up. In areas with a small tidal range (less than 2 m) the ice features are confined initially to a relatively narrow shore band. As the tidal range increases, the width of the shore zone ice band increases and the tendency for broken ice to form also increases.

- If shore ice forms in relatively calm wave conditions, then a continuous, simple rampart (or ice foot, Figure 4 - 3) covers the upper intertidal zone. Storm waves or a storm surge during the early stages of freeze-up can produce a complex mixture of ice floes freezing to the shore and a confused pattern of broken and solid ice.

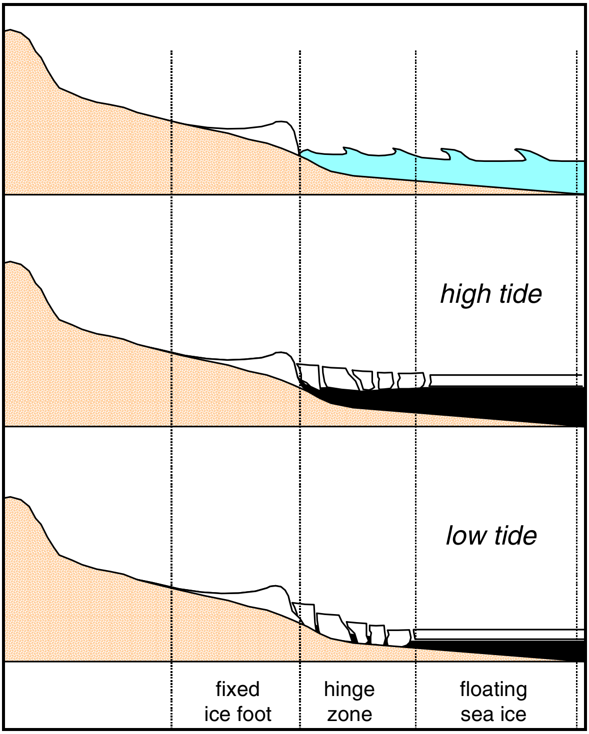

Figure 4 - 3 An ice-foot develops when waves or water freeze at the water line (top). In tidal areas, a zone of cracks separates the fixed ice foot from the nearshore floating ice (middle - at high tide, bottom - at low tide).

- Shore-fast ice in the intertidal zone and nearshore ice on the adjacent waters normally are separated by a zone of tidal cracks seaward of the low-tide level or in the lower section of the intertidal zone. Shore-ice formation often precedes the formation of sea ice and the ice foot may persist after the decay or removal of nearshore ice.

Oil on Ice or Ice-covered Shorelines

In most instances, the presence of ice in the shore zone or on the adjacent nearshore water acts to prevent oil on the surface of the water from making contact with the shoreline substrate.

- Where oil is washed onto exposed ice surfaces, the oil is unlikely to adhere except in cold temperatures when the air, water and oil surface temperatures are below 0°C.
- During freeze-up, oil present 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 would remain on the water surface or in shore leads. Oil may be splashed over the ice edge or be stranded above the limit of normal wave action. The stranded oil can then be incorporated into the shore-fast ice if temperatures fall again below freezing.
- In broken ice, without a landfast ice cover, oil may reach the shore and be stranded on the substrate in between the ice floes.
- If continuous shore-fast ice (an ice foot) is present, the ice may protect the shore zone, but if the ice foot has extended beyond the shore zone to include a floating ice layer, oil can migrate through ice cracks and accumulate under the ice.
- Ice in beach sediments (frozen groundwater) can prevent the penetration of stranded oil.

Preferred Response Options

✔ Natural recovery (1) is the preferred option on exposed coasts. This method is less appropriate for heavy oils or weathered crudes on a sheltered coast where the oil is likely to persist. Natural recovery may not be appropriate immediately prior to freeze-up, as the oil would be covered and incorporated into the ice, and potentially be remobilized during the next thaw.

✔ Physical washing can be practical and efficient but shore-fast ice edges often are steep, so washing from a boat or barge is preferred if water depths allow. Oil should be contained and collected by booms (A) and sorbents or skimmers (B) (C).

✔ Washing (flushing and collection) may be useful if water does not freeze and encapsulate the oil.

✔ Flooding (2) is appropriate on sloping ice surfaces for light oils, such as diesel but is of little practical value for heavy or semi-solid oils.

✔ Sorbents (passive use (13) or sorbent skimmers), vacuum units (10) or burning (16) all have potential application. Where access permits, vertical rope-mop skimmers (B) may be able to sweep ice surfaces or collect oil from cracks, crevices and leads. Rope mops can be deployed by crane from the backshore, a barge or even from an on-ice location.

✔ Oil/snow mixtures would be relatively easy to remove manually (9), or possibly mechanically (11) if accessible.

Typical Combinations of Response Methods

- On wet ice, low-pressure washing (3) can be combined with the collection and recovery of oil that is easily mobilized, followed by the manual removal (9) of residue using hand tools, vacuum systems (10) or sorbents (13).
- Mechanical scraping or removal (11) can be followed by manual removal (9) of any residues or spillage.

What to Avoid

There are many operational obstacles associated with ice conditions; worker safety is the most important concern.

✚ Wet ice is very slippery and caution must be exercised if personnel are working where there are leads, thin ice or mobile ice. In addition, machines generally are less efficient and reliable in cold, snow or ice conditions, and personnel are less effective.

- ✚ On steep or shelving ice, care should be exercised to avoid falls and slips, particularly on open coasts where there is strong wave action.

Summary for Ice and Ice-covered Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on ice or ice-covered shores. The primary factors in selecting a response method are:

- The air temperature: Melting ice requires different response strategies than does newly-forming ice.
- The nature of the ice surface: Smooth surfaces require different response methods than rough ice.
- Ice features: On steep ice or ice-covered slopes, response may be limited to washing from a boat or barge.
- The type of oil (heavy or light): All but the more viscous and/or sticky oils can penetrate most ice-covered shores.

Table 4 - 12 Treatment methods for ice or ice-covered shorelines

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	
2	flooding	○		
3	low-pressure, cold-water	○	○	◒
4	low-pressure, warm/hot-water		○	○
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal	○	○	○
13	sorbents	◒	◒	
16	in-situ burning	○	○	○

○ good ◒ fair (for small amounts of oil only)

4.11.4 Shoreline Treatment Sand Beaches

- Sand beaches are permeable for all light and some medium oils. They can have a very dynamic, mobile, unstable surface layer.

- There is a distinction between fine and coarse-grained sand beaches:
  - Coarse-sand beaches (sediment diameter 0.5 to 2 mm) usually have steep slopes and poor traction.
  - Fine-sand beaches (sediment diameter less than 0.5 mm) have flatter slopes and usually are firmer with better traction for vehicles.

- Granules (sediment diameter 2 to 4 mm) or pea gravel are usually considered “coarse sediments” and are addressed in Section 4.11.6.

- Traction usually is good on sand beaches for most types of vehicles. Traction can be a problem in the lower intertidal zone, where there are water-saturated sediments, or above the normal intertidal zone, because of soft wind-blown sands. A small reduction in tire pressure can partially compensate for low bearing capacity.

- Sand is very mobile on exposed coasts, and is continuously redistributed in sheltered areas, even with only minor wave action.

- Relatively few species of mobile (burrowing) animals can live in this unstable environment. Biological productivity is generally low, except in protected, low wave-energy environments.

- Sediment supply to sand beaches is highly dependent on local source and supply conditions.

Oil on Sand Beaches

- The small pore spaces in sands restrict oil penetration. Medium and heavy oils are unlikely to penetrate more than 25 cm.

- Light oils may readily penetrate a medium or coarse-grained sand beach and then mix with groundwater. Light oils also can be refloated and transported by changing tidal water levels.

- Oil is less likely to stay stranded in the lower intertidal zones since these remain wet due to backwash and to 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. They would concentrate on the upper beach.

- Relatively little wave action, e.g., wave heights of 10 to 30 cm, can easily change the surface level on a sand beach by as much as 10 cm in one tidal cycle. Large waves generated during storms 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. Similarly, stream or river currents and waves continuously rework oiled sediments at the water line on river banks.

- The frost table in a sand beach acts as a lower limit for the penetration of light oils into the sediments. The depth to the frost table varies seasonally from as little as a few centimetres to 1.0 m or more in summer months.

Preferred Response Options

✔ Natural recovery (1) is recommended for small spills, light oils or on exposed coasts and/or in remote areas. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be covered by, and incorporated into, newly-forming ice and potentially remobilized during the next thaw. Release of oil may be acceptable in fall or winter months (the die-back phase of vegetation) but is less acceptable during spring and summer growth periods.

✔ Flooding (2) and low-pressure cold-water washing (3) can remove light and medium oils. These techniques become ineffective as the viscosity, penetration or burial of the oil increases.

✔ Manual removal (9) is preferred for medium and heavy oils, since little non-oiled material is removed. Effectiveness decreases as the area of oiled sediments increases or where oil has become buried or reworked into the sediments. Straight-edge shovels are more effective than pointed shovels for removing or scraping surface oil on a sand beach.

✔ Mechanical removal (11) often is appropriate for long sections of beach where the oil is present in high concentrations and is on the beach surface. The removal of oil that has been reworked or buried can involve the transport and disposal of large volumes of material with low concentrations of oil.

✔ Graders, operated to scrape only a thin layer of oiled sand, are the heavy equipment that are preferred. Front-end loaders have less depth-of-cut accuracy. Bulldozers should only be used as a last resort. Windrows made with graders can be removed by front-end loaders.

✔ Factors in the decision process to select manual and mechanical removal techniques for oiled sand beaches include:

- size of the area to be cleaned
- time available for treatment
- amount of oiled sediment that requires handling, transfer and disposal

✔ Sorbents (13) may be useful to collect oil that washes ashore. Sorbent effectiveness decreases with increasing oil volume. Use of large amounts of sorbent material can generate a waste disposal problem.

✔ Mixing (14) or sediment relocation (15) accelerate the weathering of light oils. Sediment relocation, in particular, may be an important polishing step for stained sands that remain after other treatment has removed bulk oil.

Typical Combinations of Response Methods

- Flooding (2) or floating of oil into lined collection trenches or sumps, which have been dug by a backhoe, can be followed by the recovery of the oil with vacuum units (10) or skimmers (B).

- Mechanical removal (11) can be followed by mixing (14) or sediment relocation (15).

What to Avoid

✗ Excessive removal of sediment is often a concern on this type of beach, as natural replacement rates can be slow in many areas. Excessive removal could lead to retreat of the beach, i.e., erosion.

✗ Treatment or cleanup activities should be planned to avoid mixing clean and oiled sediments. In particular, mixing oil into clean subsurface sediments should be avoided except as part of a planned mixing or sediment relocation strategy.

✗ Because oil-in-sediment concentrations typically are low, mechanical or manual sediment removal methods can generate a large volume of lightly-oiled waste, which will then require transfer and disposal.

✗ The spillage from graders can increase when passes are made over side-cast oiled sediments. If more than one machine is used, the graders should generate separate windrows rather than trying to move windrows successively up a beach.

✗ Avoid tracking oil into clean areas. Vehicles and personnel should always work from a clean area toward an oiled area to avoid cross-contamination.

✗ During manual treatment, avoid over-filling collection bags or containers to minimize spillage and to prevent bags or containers from breaking.

Summary for Sand Beaches

There are differences in the types of techniques used to remove large versus small amounts of oil on sand shores. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil persistence (months to years). Mixing and sediment relocation are more effective on shores with wave action.
- The extent of the oiled area: Mechanical recovery and mechanical in-situ techniques become more practical with increasing amounts of, and areas covered by, stranded oil.
- The type of oil (heavy or light): Only very light oils, e.g., diesel, can penetrate most sand sediments.

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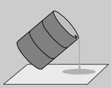
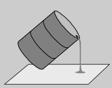
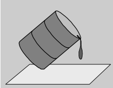
Table 4 - 13   Treatment methods for sand beaches

Treatment Method		light oil 	medium oil 	heavy oil 
1	natural recovery	○	○	
2	flooding	○	○	
3	low pressure, cold-water	○	○	
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal	◒	○	○
13	sorbents	◒	◒	
14	mixing	◒	◒	
15	sediment relocation	◒	◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.5 Shoreline Treatment Mixed-sediment Beaches

- Mixed-sediment beaches (also referred to as gravel beaches) are composed of sands, granules, pebbles and cobbles. The surface layer usually is dynamic, mobile and unstable and often has predominantly coarse sediments with increasing amounts of sand in the subsurface. Boulders may be scattered on the beach surface.

- On Arctic coasts, in low-lying areas, mixed-sediment or gravel deposits may be pushed on to the backshore by wave action. These perched beaches rest directly on the vegetation or peat mat, which often is exposed on the seaward face of the beach ridge.

- In river or delta environments, the channel margins or mid-channel bars frequently are characterized by pebble and cobble sediments from which most of the sand has been washed out to leave a coarse-sediment surface layer underlain by mixed sediment. The sand and other fine sediments tend to accumulate where the currents slow down, particularly on the inside of a river bend, i.e., point bars, or at the mouth of a river, i.e., deltas.

- Few animals or plants can survive the continuous reworking of the coarse sediments, so that exposed beaches support little life, particularly in the upper intertidal zone. Sediments in the lower sections of the beach or in sheltered wave environments tend to be more stable, and organisms are more likely to be present in this zone.

- This beach type typically has a steep section in the upper half of the intertidal zone. The coarse sediments provide poor traction for vehicles and, sometimes, for workers. Similarly, in river channels the bank edges frequently are steep due to undercutting by stream flow.

- The natural supply of the coarse sediments to this type of beach is usually a very slow process. In most cases, oiled sediment that is removed may be replaced only at a very slow rate (decades) or not at all.

Oil on Mixed-sediment Beaches

The coarser fractions (pebbles and cobbles) are infilled with the finer sands and granules so that these beaches are permeable only for some medium oils and all light oils. These beaches can have a dynamic, mobile surface layer.

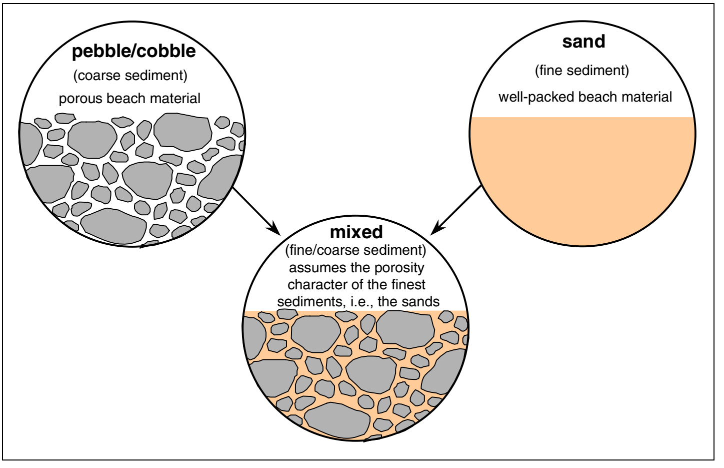


Figure 4 - 4 Beach types

- From an oil fate and persistence perspective, i.e., in terms of oil penetration, this beach type is similar to a sand beach, but for response operations (in terms of traction and treatment techniques), this beach type is more similar to a pebble/cobble beach.
- Depth of oil penetration is primarily a function of the oil type. Depth of burial or reworking of oiled sediments is primarily a function of wave-related beach erosion and recovery processes.
- Oil residence time or persistence is primarily a function of the oil type, depth of penetration or burial, retention factors and the wave or stream-energy levels on the beach.
- Light oils may 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 mixed sediments less readily than on a coarse-sediment beach; however, oil that can penetrate is more likely to be retained in the subsurface of a mixed-sediment beach.

- Oil is less likely to stay stranded in the lower beach zones that remain wet due to wave action and to 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; as a result, oil is more likely to concentrate on the upper intertidal zone.

- Usually, only the surface layer of sediments is reworked by normal wave or stream action. Oil that penetrates below the surface may not be physically reworked except during infrequent, high-energy storms or run-off events.

- The frost table in a beach acts as a lower limit for oil penetration into the sediments. During the first weeks of summer, after the ice foot or fast ice melts, the depth of thaw may be only a few centimetres to as much as 0.5 m. As the summer progresses, and as the ice in the beach melts, the depth to the frost table increases to as much as 1.0 m, and sometimes more, by mid-to-late August. The frost table nears the surface again with the onset of freezing temperatures.

- Asphalt pavements commonly develop in upper-intertidal zones, or above the normal tidal zone, where weathered medium and heavy oils form a stable oil-sediment conglomerate.

Preferred Response Options

✔ Natural recovery (1) may be an acceptable option for small spills, light oils or on exposed coasts and/or in remote areas. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be covered by, and incorporated into, newly-forming ice, and may be remobilized during the next thaw.

- ✔ Flooding (2) is a non-intrusive technique that can wash mobile oil from surface sediments, and light oil from surface and subsurface sediments, for collection. Effectiveness decreases with increasing viscosity and stickiness of oil, and usually is low for buried oil or oiled sediments.
- ✔ Low-pressure, cold-water washing (3) can flush mobile oil from surface and surface sediments for collection. This technique is more effective for viscous oils than flooding but effectiveness decreases with increasing viscosity and stickiness of oil and with burial.
- ✔ Manual removal (9) can minimize the amount of oiled and un-oiled sediment that is recovered, and can be appropriate for removal of surface oiled sediments. This technique is not very practical for deeply-penetrated or buried oil. Manual removal is appropriate for removing asphalt pavement patches, tar patties and small-size oiled debris. Practicality decreases as the amount of oiled shoreline or sediment increases. Pointed shovels are most effective for removing oiled sediments on mixed sand/pebble/cobble beaches.
- ✔ Mechanical removal (11) can be effective if a large amount of semi-solid oil is to be recovered. ***Equipment that removes as little un-oiled sediment as possible is recommended***. Because of the generally poor traction on this type of sediment, front-end loaders would be the equipment of choice, with a backhoe as an alternative.
- ✔ Sorbents (13) may be useful for recovering small volumes of light and medium oils.
- ✔ Mechanical mixing [14] is appropriate for light oils in surface or subsurface sediments.
- ✔ Sediment relocation [15] is appropriate on exposed coasts after any mobile oil has been removed, or for small amounts of oiled sediment. This approach minimizes the possibility of erosion. Sediment relocation may be appropriate for oil that has penetrated or become buried. The effectiveness of sediment relocation depends on the availability of wave or stream energy to abrade, redistribute and replace the sediments, or on the presence of fines (clays and silts) to remove oil.

Typical Combinations of Response Methods

- Flooding (2), with trenches or sumps to collect oil that is floated, can be used with vacuum systems (10) to recover the oil.

- Mechanical mixing (14) can be followed by sediment relocation (15) and/or bioremediation (20).

What to Avoid

✗ Excessive removal of coarse sediment is a concern on this type of beach, as natural replacement rates usually are very slow (decades). This can lead to retreat of the beach, i.e., erosion.

✗ Because oil-in-sediment concentrations usually are very low, mechanical or manual sediment removal methods generate a large volume of waste that contains a relatively small amount of oil.

✗ Flushing or sediment relocation techniques should avoid spreading oil onto the un-oiled lower tidal zones.

✗ 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 (4) (6) 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 as it makes contact with cool or cold groundwater, may cause the oil to be redeposited at a lower level in the beach.

Summary for Mixed-sediment Beaches

There are differences in the types of response techniques used for large versus small amounts of oil on mixed-sediment shores. The primary factors in selecting a response method are listed on the following page.

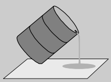
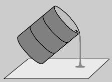
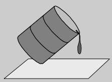
- The shoreline exposure: Shorelines in exposed, high-energy locations, will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years); mixing and sediment relocation are more effective on shores with wave action.

- The extent of the oiled area: Mechanical recovery and mechanical in-situ techniques become more practical with increasing amounts of, and areas covered by, stranded oil.

- The oil location: If the oil has been buried or has penetrated into the sediment, mixing or sediment relocation are preferred to mechanical removal.

- The type of oil (heavy or light): Only very light oils, e.g., diesel, can penetrate most mixed sediments with sands.

Table 4 - 14 Treatment methods for mixed-sediment beaches

	Treatment Method	light oil 	medium oil 	heavy oil 
1	natural recovery	○	○	
2	flooding	○	○	
3	low pressure, cold-water	○	○	
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal	◒	○	○
13	sorbents	◒	◒	
14	mixing	◒	◒	
15	sediment relocation	◒	◒	

○ good ◒ fair (for small amounts of oil only)

4.11.6 Shoreline Treatment Pebble/Cobble Beaches

- Pebble/cobble beaches (also known as coarse-sediment beaches) are permeable to all but the semi-solid oils, and can have a dynamic, mobile, unstable surface layer. Boulders may be scattered on the beach surface.
- Pebbles have a grain-size diameter of 4 - 64 mm; cobbles are in the 64 - 256 mm range. Coarse-sediments also usually include granules (pea gravel) 2 - 4 mm diameter.
- Pebble/cobble beaches include some man-made structures, such as rip-rap or sandbag walls, with material in the size range of 2 to 256 mm; above 256 mm, the materials are defined as boulders and are considered in Section 4.11.7.
- Few animals or plants can survive the continuous reworking of the sediments, so that exposed beaches support little life, particularly in the middle and upper intertidal zones. Sediments in the lower sections of the beach or in sheltered wave environments tend to be more stable, and organisms are more likely to be present.
- Typically, this beach type is characterized by a steep section in the upper half of the intertidal zone that provides poor traction for vehicles and (sometimes) for cleanup workers. Similarly, in river channels, the bank edges frequently are steep due to undercutting by stream flow.
- Sediment supply to this type of beach usually is very slow. Oiled sediment that is removed may be replaced only at a very slow rate (decades) or not at all.

Oil on Pebble/Cobble Beaches

- Pebble/cobble beaches are distinguished from mixed-sediment or gravel beaches (Section 4.11.5) as the interstitial or pore spaces between the individual pebbles or cobbles are open, rather than being filled by sand.
- Stranded oil can more easily penetrate into the subsurface sediments on pebble/cobble beaches but less easily on mixed-sediment beaches.

- Depth of oil penetration is a function of the oil type and the sediment size. The larger the particle size, the easier oil can penetrate. However, oil retention also is relatively low so that the oil can be flushed naturally from these coarse sediments.

- Oil residence time or persistence is primarily a function of the oil type, depth of penetration, retention factors and wave or stream-energy levels on the beach.

- Light or non-sticky oils may be easily flushed out of the surface or subsurface sediments by tidal pumping.

- Usually, only the surface layer of sediments is reworked by normal wave action. Oil that penetrates below the surface may not be reworked physically except during infrequent high-energy storms or run-off events.

- Oil is less likely to stay stranded in the lower intertidal zone which remains wet due to backwash and to 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, therefore, is more likely to concentrate on the upper beach.

- 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.

Preferred Response Options

✔ Natural recovery (1) is preferred, particularly for small spills of light oils or on exposed coasts and/or in remote areas. Natural recovery may not be appropriate immediately prior to freeze-up since the oil would be covered by, and incorporated into, newly-forming ice, and potentially remobilized during the next thaw.

✔ Flooding (2) is a non-intrusive technique than can flush mobile oil from surface and subsurface sediments for collection. Effectiveness decreases with increasing viscosity and stickiness.

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- ✔ Low-pressure, cold-water washing (3) can flush mobile oil from surface and subsurface sediments for collection. This technique is more effective for viscous oils than flooding; however, effectiveness decreases with increasing viscosity, stickiness and depth of penetration.

- ✔ Manual removal (9) can minimize the amount of oiled and un-oiled sediment that is collected and can be appropriate for removal of surface oiled sediments. This method is not very practical for deeply penetrated or buried oil. Manual removal is appropriate for removing asphalt pavement patches, tar patties and small-size oiled debris, but the practicality decreases as the amount of oiled shoreline or oiled sediment increases. Pointed shovels are more useful than straight-edge shovels for removing oiled pebbles and cobbles.

- ✔ Mechanical removal (11) can be effective if a large amount of semi-solid oil is to be recovered. ***Equipment that removes as little un-oiled sediment as possible is recommended***. Because of the generally poor traction on this type of sediment, front-end loaders are the equipment of choice, with a backhoe as an alternative.

- ✔ Sorbents (13) may be useful for recovering small volumes of light and medium oils.

- ✔ Mechanical mixing (14) is appropriate for light oils in surface or subsurface sediments. This method can be used in combination with sediment relocation.

- ✔ Sediment relocation (15) is appropriate on exposed coasts after any mobile oil has been removed. Relocating sediment also is useful for small amounts of oiled sediment. This approach minimizes the possibility of erosion and may be appropriate for oil that has penetrated or become buried. The effectiveness of sediment relocation depends on the availability of wave or stream 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.

Typical Combinations of Response Methods

- Oiled debris can be removed followed by manual removal 9, vacuum units 10 or the use of sorbents 13 on surface oil patches.
- Flooding 2 can be combined with low-pressure washing 3.
- Mechanical mixing 14 can be followed by sediment relocation 15 and/or bioremediation 20.

What to Avoid

✗ Excessive removal of sediment can lead to retreat of this beach type, i.e., erosion. Erosion often is a concern as natural replacement rates usually are very slow (decades).

✗ Because oil-in-sediment concentrations usually are very low, mechanical or manual sediment removal methods generate a large volume of waste that contains a relatively small amount of oil.

✗ Avoid flushing or sediment relocation techniques that spread oil onto the un-oiled lower intertidal zones.

✗ 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 4 6 may temporarily mobilize viscous oil that can then possibly 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 cold groundwater, may cause the oil to be redeposited at a lower level within the beach.

Summary for Pebble/Cobble Beaches

There may be differences in the types of treatment techniques used for large versus small amounts of oil on pebble/cobble shores. The primary factors in selecting a response method are noted on the following page.

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years); mixing and sediment relocation are more effective on shores with wave action.
- The extent of the oiled area: Mechanical recovery and mechanical in-situ techniques become more practical with increasing amounts of, and areas covered by, stranded oil.
- The oil penetration: If the oil has been buried or has penetrated into the sediment, mixing or sediment relocation are preferred to mechanical removal.
- The type of oil (heavy or light): Only very light oils, e.g., diesel, can penetrate most pebble/cobble beaches.

Table 4 - 15   Treatment methods for pebble/cobble beaches

	Treatment Method	**light oil**	**medium oil**	**heavy oil**
1	natural recovery	○	○	
2	flooding	○	○	
3	low-pressure, cold-water	○	○	
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal	◒	◒	○
13	sorbents	◒	◒	◒
14	mixing	◒	◒	
15	sediment relocation	◒	◒	
20	bioremediation	◒	◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.7 Shoreline Treatment — Boulder Beaches and Rip-rap Shores

- Boulder beaches are permeable and have a stable surface layer.

- Boulders are, by definition, greater than 256 mm in diameter and are moved only by ice, man and extreme wave conditions. Man-made breakwaters or harbour walls constructed with boulder-size materials (rip-rap) behave in a manner similar to boulder beaches.

- Boulder beaches frequently are characterized by mud or sand tidal flats in the lower intertidal zone.

- This beach or shore type is stable, so that attached animals and plants may be common on or between boulders, except in areas where boulders may be abraded or moved each winter by ice action.

- Boulder barricades are common in eastern Canada and the Baltic; boulder barriers can be created by both ice rafting and ice pushing. They form linear ridges across or along the intertidal zone.

4

Oil on Boulder Beaches or Rip-rap

- The large spaces between individual boulders allow all types of oil to be carried into the sediments.

- Oil residence time or persistence is primarily a function of the oil type and wave or stream-energy levels on the beach. Light or non-sticky oils may be flushed easily out of the surface or subsurface sediments by tidal pumping.

Preferred Response Options

✔ In some respects, boulder beaches are similar to a bedrock outcrop so that surface areas may be cleaned in the same way as bedrock. However, oil can penetrate into the underlying sediment.

- ✔ In most cases, all but surface oil is difficult to collect and natural recovery (1) is the preferred option, in particular for small amounts of oil. There is probably little that can be done practically to recover or treat heavy or semi-solid oils that penetrate into the large void spaces. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.

- ✔ Flooding (2) can flush mobile oil from surface and subsurface sediments for collection. The effectiveness of flooding decreases with heavier oils.

- ✔ Low-pressure, cold-water washing (3) can flush mobile oil from surface and subsurface sediments for collection. This technique is more effective for heavy oils than flooding but effectiveness decreases with increasing viscosity, stickiness and depth of penetration.

- ✔ Manual removal (9) can be appropriate for surface oil but is not practical for subsurface oil. Manual methods are appropriate for removing tar patties and small-size oiled debris but the practicality decreases as the amount of oiled shoreline increases.

- ✔ If oil leaching is of concern, the boulders (or man-made rip-rap) could be lifted out mechanically (11) (either from the land side or from a barge), and the subsurface oil could then be removed or treated and the boulders replaced.

- ✔ Sorbents (13) may be useful for recovering light and medium oils at or near the surface. This technique is recommended also for small amounts of oil. On man-made rip-rap shorelines, sorbent materials (pads, pillows, etc.) can be stuffed in cracks to prevent oil from penetrating into the structure; however, this approach is fairly labour-intensive.

Typical Combinations of Response Methods

- The removal of oiled debris can be followed by the manual removal 9 of surface oil or the application of sorbents 13.
- Flooding 2 3 can be combined with low-pressure washing.

What to Avoid

✗ Removal of sediment is neither practical nor effective for this shore type in many cases. A significant concern is that boulder-size sediments form a strong armour layer and would not be replaced naturally. Removal without replacement, therefore, could lead to beach, shore or river bank erosion.

✗ Avoid flushing or washing techniques that spread oil onto the un-oiled lower tidal zones.

✗ Flushing techniques that only move the oil deeper into the sediments, without flushing the oil out of the beach for recovery, are not appropriate. Warm or hot water 4 6 may temporarily mobilize viscous oil that would then penetrate more deeply into the beach. The loss of heat as the oil moves through the beach, or as it makes contact with cool or cold groundwater, may cause the oil to be redeposited at a lower level within the beach.

Summary for Boulder Beaches and Rip-rap

There would be little difference in the treatment techniques used for large versus small amounts of oil on boulder and rip-rap shores. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years).

- The oil penetration: If the oil has penetrated into the boulder or rip-rap, flushing with cold water may be the only effective option.

- The type of oil (heavy or light): All but the more viscous and/or sticky oils can penetrate most boulders or rip-rap material.

On steep boulder or rip-rap shores, response may be limited to washing from a boat or barge.

Table 4 - 16 Treatment methods for boulder beaches or rip-rap shores

Treatment Method	light oil	medium oil	heavy oil
1 natural recovery	○	○	◒
2 flooding	○	○	
3 low-pressure, cold-water	○	○	◒
9 manual removal	◒	◒	○
13 sorbents	◒	◒	◒

○ good ◒ fair (for small amounts of oil only)

4.11.8 Shoreline Treatment Sand Flats

- Sand flats usually:
  - are wide
  - feature a flat surface or have low-angle slopes
  - are permeable for some medium and all light oils
  - contain large amounts of silt
  - have a very dynamic and unstable surface layer
- Sand flats commonly form adjacent to low-lying areas, lagoons and river mouths (deltas).
- These shorelines often are an important bird habitat during the Arctic summer in many areas, as migrant species feed on zooplankton, insects, larvae and worms.
- On low-lying sections of Arctic Ocean coasts, such as the Beaufort, Chukchi, Laptev and Kara Seas, strong winds can either lower the normal water level by tens of centimetres and expose the flats, or move the water line several hundreds of metres seaward.
- The bearing capacity of sand flats is usually poor for both personnel and vehicles.
- The surface of a sand flat is dynamic. Migrating waves or ripples of sand are common. Sediment movement due to wind-generated wave action or high stream-flow conditions, can result in surface changes of several centimetres during a single tidal cycle.
- Tidal flats often have ridges, grooves, furrows, craters and other drag, roll or skip marks resulting from ice action.

Oil on Sand Flats

- Sand flats do not fully drain at low water and many sections are water-saturated at or just below the surface of the sediments. Oil penetration is therefore limited, although low-viscosity oils can mix with the waters in the sediments.

- All but heavy oils would be refloated on a rising tide and be moved by currents and winds. Therefore, oil is 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.

- Burial is possible but is only likely for heavy oils. Oil may penetrate the subsurface through the holes of burrowing animals and persist in the subsurface sediments for long periods (months to years).

- The impact of non-persistent, light oils can be immediate (on contact with animals), and heavier oils could fill burrows and smother organisms.

Preferred Response Options

✔ Treatment of sand flats usually is difficult from an operations standpoint and response activities may cause more damage than the oil. Natural recovery 1 is the preferred option where this choice exists, in particular for small amounts of oil. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would become encapsulated by ice and potentially be remobilized during the next thaw.

✔ Flooding 2 and collection with sorbents 13 may be effective for light or medium oils.

✔ Manual removal 9 or vacuum systems 10 may be effective for smaller amounts of oil that have pooled or have collected in natural depressions.

✔ Heavy oils may be removed mechanically 11 where the bearing capacity allows safe access.

✔ Methods of trapping or containing oil (trenches and ditches) for collection on a falling (ebb) tide may be effective.

Typical Combinations of Response Methods

- Manual removal with hand tools can be combined with vacuum units or sorbents.
- Low-pressure washing toward depressions or lined trenches can allow recovery by vacuum systems or skimmers.

What to Avoid

✚ Operations in the intertidal zone must be planned in concert with the changing water levels. Although tides can be accurately predicted at a particular site, wind and wave action can alter actual water levels. Surges or set-downs are common in all low-lying coastal environments so that actual, rather than predicted, conditions must be factored into schedules and work plans.

✗ The bearing capacity of a sand flat may vary from one place to another, and may not support the weight of a person or vehicles in some areas.

✗ Barges or flat-bottomed boats may be used to support operations and personnel. These can ground on falling tides or water levels and be refloated by the flood tide. They also provide a form of transport in unforeseen conditions, such as an unexpected surge condition.

✗ Mixing of oil into sediments must be avoided. Subsurface oil could remain for a very long time (years). Sediment disturbance can have an impact even in the absence of oil; thus, all movement (personnel and vehicles) must be carefully controlled in oiled and unoiled areas.

Summary for Sand Flats

There may be differences in the types of response techniques suitable for large versus small amounts of oil on sand flats. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years); mixing and sediment relocation are more effective on flats with wave or current action.
- The extent of the oiled area: Mechanical recovery and mechanical in-situ techniques become more practical as the amount and area of stranded oil increase; this option would have to be assessed in terms of possible additional damage caused by the use of equipment on the flats.
- The wetness of the oiled area: Wetness affects traction, the bearing capacity and the penetration of light oils.
- The type of oil (heavy or light): Only very light oils, such as diesel, can penetrate most dry sand sediments.

Table 4 - 17   Treatment methods for sand flats

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	○
2	flooding	○	○	
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal			○
13	sorbents	◒	◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.9 Shoreline Treatment Mud Flats

- Mud flats usually:
  - are wide
  - feature a flat surface or have low-angle slopes
  - generally are water-saturated and not permeable
  - have a very mobile surface layer
- Mud flats commonly occur adjacent to low-lying areas, lagoons and river mouths (deltas), and frequently are relatively sheltered environments, i.e., subject to low wave or current-energy levels.
- These shorelines often provide important bird habitat during the Arctic summer in many areas, as migrant species feed on zooplankton, insects, larvae and worms.
- On low-lying sections of the Arctic Ocean coasts, such as the Beaufort, Chukchi, Laptev and Kara Seas, strong winds can either lower the normal water level by tens of centimetres and expose the flats, or move the water line several hundred metres seaward.
- The surface of a mud flat is very dynamic, and elevation changes of several centimetres may occur during a tidal cycle, following periods of wind-generated wave action, or with high stream-flow conditions.
- Mud flats usually are very productive biological habitats with many burrowing animal species, e.g., snails, worms and clams, that often are a food source for birds and man.
- Steep-sided creeks or drainage channels may be present that can hinder access.
- These sediments generally have a low bearing capacity for both personnel and vehicles.
- Tidal flats often have ridges, grooves, furrows, craters and other drag, roll or skip marks resulting from ice action.

Oil on Mud Flats

- Mud flats are frequently water-saturated at, or just below, the surface of the sediments. The potential for oil penetration is limited, although light oils can mix with the waters in the sediments.

- All but highly-viscous or dense oils would be refloated by a rising tide or water level and moved by currents and winds. As a result, oil is more likely to concentrate in the upper tidal zones or on the crests of dry ridges rather than in the lower, water-wet or water-saturated areas.

- Burial is possible with heavy or dense oils. Oil may enter the subsurface through mud cracks or the holes of burrowing animals, e.g., clams and worms, and persist for a long time (months to years).

- The impact of non-persistent oils can be immediate (on contact with animals), and heavier oils can fill burrows and smother organisms.

Preferred Response Options

✔ Natural recovery (1) is the preferred option where this choice exists. Treatment usually is difficult from an operations standpoint, and response activities may cause more ecological damage than the oil. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be encapsulated by ice and potentially be remobilized during the next thaw.

✔ In practical terms, few techniques can be effective in this type of shoreline environment. Less intrusive strategies, such as herding by flooding (2) or washing (3) and collection using sorbents (13) or vacuum systems (10) may have some applicability.

✔ Barges or flat-bottomed boats may be used to support operations and personnel. Barges can provide a form of transport in unforeseen conditions, such as during an unexpected surge condition.

Typical Combinations of Response Methods

- Manual removal 9 with hand tools can be used with vacuum units 10 or sorbents 13.
- Low-pressure washing 3 toward depressions or lined trenches can allow recovery by vacuum systems 10 or skimmers B.

What to Avoid

✚ Operations in the shore zone must be planned to deal with changing water levels. Although tides can be accurately predicted at a particular site, the effects of winds and wave action can alter water levels significantly. Surges or set-downs are common in all low-lying coastal environments. Potential changes in water level, rather than predicted conditions, must be factored into schedules and work plans.

✗ The 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.

✗ Mixing of oil into sediments must be avoided since subsurface oil can remain for a very long time (years). Sediment disturbance can have an impact even in the absence of oil. Therefore, all movement of personnel and vehicles must be carefully controlled in oiled and unoiled areas.

Summary for Mud Flats

There is little difference in the techniques used for large versus small amounts of oil on mud flats. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years).
- The extent of the oiled area: Manual techniques become less practical as the size of the oiled area increases.
- The wetness of the oiled area: Wetness affects traction, the bearing capacity and the penetration of light oils.
- The type of oil (heavy or light): Only very light oils, such as diesel, can penetrate dry mud sediments.

Table 4 - 18 Treatment methods for mud flats

Treatment Method	light oil	medium oil	heavy oil
1 natural recovery	○	○	○
2 flooding	○	○	
3 low-pressure, cold-water	○	○	
9 manual removal			◒
10 vacuum systems	○	○	
13 sorbents	◒	◒	◒

○ good ◒ fair (for small amounts of oil only)

4.11.10 Shoreline Treatment Salt Marshes

- Marshes usually:
    - are permeable to spills of light oils
    - support a stable surface vegetation cover and root system
    - may be fringed by muddy tidal creeks or mud tidal flats

- Marshes are not common in the Arctic but are important from a biological standpoint. Marshes are distinguished from the wet, low-lying inundated and vegetated tundra shores (Section 4.11.12) as the latter have salt-tolerant rather than saline-adapted plant species.

- Marsh types vary from narrow fringing marshes to wide salt-marsh meadows. Usually, the marsh meadows are above the normal high-tide water level and flooded only during spring tides or storm surges.

- Marsh habitats are extremely productive in terms of plant and micro-animal life, and are important to large migratory bird populations. The productivity, actual number present and sensitivity of birds vary with the seasons.

- Ice action can tear large clumps or slabs of marsh vegetation and deposit them on lower tidal zones, leaving behind bare soil or mud craters.

Oil on Salt Marshes

- Oil can impact the fringe of a marsh during neap high tides or normal 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 on the meadow area, exposed to little or no current and wave action, may weather slowly.

- Light oils can penetrate into marsh sediments or fill animal burrows and cracks. Medium and heavy oils are more likely to remain on the surface and can have a smothering effect on plants and animals.

- The presence of the frost table for most of the year limits the depth of oil penetration. During summer months, the surface of the frost table is lowered to a depth of 1.0 m or more.

- Natural recovery rates vary depending on the oil type, total area affected, oil thickness, plant type and growth rates, and the season during which the oiling occurred. Recovery may take only a few years following light oiling but can take decades in extreme circumstances (extensive, thick deposits of viscous oil).

Preferred Response Options

✔ Natural recovery should be considered as the preferred option, particularly for small amounts of spilled oil. Factors that influence the decision include:

  - the rate of natural recovery
  - the possible benefits of a response to accelerate recovery
  - any damage or delays to recovery that may be caused by response activities

  Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be encapsulated by ice and, potentially, be remobilized during the next thaw. Treatment during winter months can be considered as this might minimize root disturbance due to the frozen condition of the soil.

✔ The preferred strategy for treatment involves flooding and washing techniques that herd oil into collection areas without extensive disturbance to the vegetation cover.

✔ Low-pressure, cold-water washing ③ can remove light or medium oils without incurring damage, particularly if the operation is carried out from a boat and/or crane, and if it does not involve foot or vehicle traffic on the marsh.

✔ For small amounts of oil, sorbents ⑬ can be placed on the marsh fringe to collect the oil. Sorbents should be deployed and retrieved without disturbance to the marsh surface.

Typical Combinations of Response Methods

- Flooding ② and low-pressure, cold-water washing ③ can be used with rope mop skimmers Ⓑ, or with sorbents ⑬ for smaller amounts of light and medium oils.
- Manual removal ⑨ can be combined with vegetation cutting ⑫ of stems on marsh edges, or for heavy, viscous oils.

4

What to Avoid

✗ Most activities that involve people or machinery in a marsh delay natural recovery.

✗ Cutting oiled plants ⑫ usually delays recovery and only should be considered if the risk of leaving the oil poses a threat to other resources, e.g., migratory or nesting birds. Cutting usually involves people and equipment in the marsh and could disrupt the plant root systems unless carried out from a boat.

✗ Burning may be considered as an option; however, the damaging effects can be significant, as most plants or animals could be killed. Burning 16 should be avoided if the lower stems and roots of a plant are dry and therefore are not insulated from the heat.

✗ Sediment removal ⑨, mixing or disruption of the root systems, such as compaction by machinery or trampling by workers, can significantly delay recovery.

✗ Removal techniques should be considered only if the recovery of the marsh is expected to take decades, as might be the case for thick deposits of heavy or viscous oils.

Summary for Salt Marshes

There is little difference in the treatment techniques used for large versus small amounts of oil on salt marshes. The primary factors in selecting a response method are that:

- Natural recovery is preferred in almost all cases for oiled salt marshes; usually treatment will only delay, rather than accelerate, natural recovery.
- When large amounts of viscous oil are stranded, or where oil is stranded on the interior of a marsh, other techniques (see below) can be used.

Table 4 - 19   Treatment methods for salt marsh environments

Treatment Method	light oil	medium oil	heavy oil
1 natural recovery	○	○	◒
2 flooding	○	○	
3 low-pressure, cold-water	○	○	
9 manual removal			◒
12 vegetation cutting		◒	◒
13 sorbents	◒	◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.11 Shoreline Treatment Peat Shores

- Peat is a spongy, compressible, fibrous material that is formed by the incomplete decomposition of plant materials. Peat is common along low-lying Arctic coasts.
- Peat can have a high water content (80 - 90% by weight) so that it can behave like a liquid. Very low cohesion gives peat a very low load-bearing capacity.
- Peat is eroded from tundra cliffs, which make up about 50% of the coast of the southern Beaufort Sea and are common on the coasts of the Chukchi, Laptev, Kara and Barents Seas. Eroded peat tends to accumulate primarily in low-energy, sheltered areas (where spilled oil is also likely to accumulate).
- Peat deposits may occur as:
    - a mat on a beach
    - a mobile slurry

  Usually, the inorganic content of peat deposits is either very low or completely absent.
- Peat mats may be wet or dry (dewatered) and are easily eroded and redistributed by wave or current action.
- Peat slurry, which may appear 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 may be greater than 0.5 m thick and 5 to 10 m wide.
- Typically, shallow nearshore waters limit water access, and make land access, and possibly temporary roadways or access paths, necessary.

Oil on Peat

- Heavy oils (such as weathered crude) will not penetrate far into a peat mat, even if dry or dewatered, but may be buried or become mixed with peat wherever the oil is reworked by wave or stream action.

- Light (refined) products will likely penetrate peat. If oil does penetrate into the peat mat, there may be relatively little recoverable oil on the surface.

- Dry peat can hold large amounts of oil - between 1 and 5 kg of oil per kg of dry peat.

- Oils that make contact with peat slurry are likely to be mixed and remain mixed, especially in the low wave-energy areas where these slurries typically accumulate. The slurry has an effect similar to that of a loose granular sorbent, and it partially contains and prevents the oil from spreading.

Preferred Response Options

✔ Natural cleaning (1) often is the least damaging alternative for treating light and moderate oiling in inaccessible areas. Peat shorelines may erode at rates generally greater than 1 m/year; oil likely will have a short residence time in these areas. Natural cleaning may not be appropriate immediately prior to freeze-up, as the oil would be encapsulated by ice and potentially be remobilized during the next thaw.

✔ Vacuum systems (10), in combination with booms (A) and skimmers (B), can be used to recover deep pools of mobile oil if the oil is not too full of debris, nor too viscous. Quickly-deployed vacuum systems 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 be used to 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 can be used to recover free oil in peat slurries where oleophilic disc skimmers B cannot be deployed or are not effective.

✔ Low-pressure, cold-water flooding 2 and/or washing 3 can raise the local water table to float oil and peat downslope into a boomed A area for recovery. These methods would probably erode large quantities of peat for subsequent transport and disposal. Customized net panels in shore-fast booms A help to retain oiled peat slurries.

✔ Sorbents 13, such as peat itself, are effective for fresh crude and light 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 a more effective sorbent on fresh crude and fuels than on aged oils, but becomes less oleophilic when wet. Generally, loose natural sorbents are more difficult to recover than the oil alone. However, in peat-dominated areas, there may be no additional impact in failing to recover all of the peat moss, if used as a sorbent, provided the most severely oiled patches of peat are recovered.

✔ Direct removal 9 11 of peat and peat slurries can be appropriate under some conditions and where temporary, non-intrusive access can be created. Peat can be stacked and dewatered before being moved to a disposal site.

✔ Sediment relocation 15 and mixing 14 can be considered if these actions disperse oil without re-oiling the site or oiling adjacent areas.

4

Typical Combinations of Response Methods

- Manual methods [9] can be used to remove the most oiled portions of peat mats by raking, followed by mixing [14] of any remaining materials to accelerate physical and biological cleaning processes.

- Low-pressure, cold-water washing [3] can be used with sorbents [13] or rope mop skimmers [B] for recovery.

What to Avoid

✗ Trampling vegetation and the use of heavy machinery [11] must be avoided where such actions are likely to incorporate oil deeply into peat. The load-bearing capacity of peat shores is low during the open-water season but increases following freeze-up. For summer treatment, crews can use plank walkways or snowshoes to minimize damage and trampling. Vehicle access can be created using roll-out tracks or similar, temporary, non-intrusive surfaces.

✗ Manual oil removal, recovery of sorbents and washing, although recommended methods, require protecting peat from damage due to foot traffic.

✗ Where the peat is found in association with tundra (which is a living plant community), substrate removal [9] and vegetation cropping [12] should be minimized unless there is very heavily oiling. If removal of peat on sediment is undertaken, only the top 2 – 5 cm should be removed, whenever possible.

✗ Avoid raking loose sorbents/peat slime on living bog plants.

✗ Minimize peat erosion by using only low-pressure flushing techniques.

✗ Avoid burning [16] peat or oiled debris near living plant communities. Fires can quickly spread.

✗ Drainage and nutrient application [20] to low-lying peat shores during treatment reverses the conditions responsible for peat formation.

Summary for Peat Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on peat shores. The primary factors in selecting a response method are:

- The extent of the oiled area: Manual techniques become less practical as the size of the oiled area increases.
- The wetness of the peat: Wetness affects the penetration of medium oils.
- The type of oil (heavy or light): Only very light oils, such as diesel, can penetrate wet peat.

Table 4 - 20   Treatment methods for peat shores

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	
2	flooding	○	○	
3	low-pressure, cold-water	○	○	○
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal		○	○
13	sorbents	◒	◒	
14	mixing		◒	
15	sediment relocation		◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.12 Shoreline Treatment — Inundated Low-lying Tundra Shores

- Many sections of the Arctic Ocean coasts of the Beaufort, Chukchi, Laptev, Kara and Barents Seas are very low-lying. Often, these areas have been recently flooded by the sea, due to subsidence from natural melting of the ground ice (permafrost) or from regional geological subsidence.
- Low-lying areas not normally in the intertidal zone frequently are inundated by salt water at times of spring high (tidal) water levels or wind-induced (meteorological) surges. Strong westerly winds on the low-lying coasts of the Arctic Ocean coasts can raise the normal water levels by a metre or more and inundate these low-lying areas to strand oil several hundreds of metres inland. The landward limits of past surge events usually are marked by log or debris lines.
- These low-lying areas often have a complex and convoluted shoreline that results from the breaching of thermokarst lakes or the flooding of polygonal patterned ground. The shore character is a combination of vegetated flats, peat mats, brackish lagoons and small streams. Where present, vegetation is salt-tolerant and may be more adapted to drier conditions than the aquatic plants of Arctic salt marshes.
- These areas may include subsiding tundra or vegetated river banks and deltas. Areas of flooded tundra polygons have a very complex configuration of interconnected ridges with pools that are underlain by decomposing vegetation.
- These shorelines are important bird habitats during the Arctic summer since the migrant species feed on fish, insects, insect larvae and worms.
- Sand or gravel deposits may be pushed on to the backshore by wave action. These perched beaches rest directly on the vegetation or peat mat, which often is exposed on the seaward face of the beach ridge. These beaches would be treated as either sand (Section 4.10.4), mixed-sediment (Section 4.10.5) or pebble/cobble (Section 4.10.6) beaches, depending on their character.

- Typically, shallow nearshore water levels limit water access, and makes land access, and possibly temporary roadways or access paths, necessary.

- Access and movement on the land also may be difficult due to the complicated character of the shoreline and the presence of many water-saturated sections.

Oil on Inundated Low-lying Tundra Shores

- During the summer season, the sediments and/or peat deposits are often water-saturated so that oil may be restricted to surface areas only.

- Where the tundra surface is peat, heavy oils (such as weathered crude) will not penetrate far into the peat mat, even if dry or dewatered.

- Light (refined) products will likely penetrate. If oil does penetrate into the peat mat, there may be relatively little recoverable oil on the surface.

- Dry peat can hold large amounts of oil - between 1 and 5 kg of oil/ kg of dry peat.

- Where the inundated area is characterized by mud flats, these areas frequently are water-saturated at, or just below, the surface of the sediments. The potential for oil penetration in these situations is limited, although light oils can mix with the waters in the sediments.

- All but highly-viscous or dense oils on lowland flats would be refloated and carried landward by rising tide or water levels. As a result, oil is more likely to concentrate in the upper tidal zones or on the crests of dry ridges rather than in the lower, water-wet or water-saturated areas.

Preferred Response Options

✔ Natural cleaning is often the least damaging alternative for treating light and moderate oiling, particularly where access is limited or difficult, as is usual in this type of environment. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be encapsulated by ice and potentially remobilized during the next thaw.

✔ Vacuum systems, in combination with booms and skimmers, can recover pools of mobile oil if they are not too full of debris nor too viscous. Quickly-deployed vacuum systems are particularly appropriate for thick pools of oil stranded in lagoons or ponds.

✔ Rope mops may be useful in recovering free oil on water surfaces or from the surface of water-saturated sediments where vacuum units or disc skimmers cannot be deployed or are not effective. Vertical rope mops can be deployed from cranes or similar equipment.

✔ Low-pressure, cold-water flooding and/or washing can raise the local water table to float and direct oil toward a boomed area for collection.

✔ Sorbents are suitable for recovering fresh crude oil and most petroleum products. The most effective technique on fresh oils in a peat-rich environment might be to use natural peat as a sorbent and remove the most heavily oiled fraction. There would likely be no additional impact in failing to recover all the peat moss. (Loose natural sorbents are more difficult to recover than oil alone.) Dry peat should be used since it becomes less oleophilic when wet.

✔ Manual methods can be applicable for small, heavily oiled areas.

✔ Treatment during winter can be considered, as this might minimize disturbance due to the frozen condition of the soil.

Typical Combination of Response Methods

- Flooding (2) or low-pressure, cold-water washing (3) can be combined with berms or shore-seal booms for containment, and with sorbents (13) or rope mop skimmers (B) for recovery.

What to Avoid

✗ Trampling vegetation and the use of heavy machinery should be avoided, as these actions are likely to incorporate oil more deeply into sediments. The load-bearing capacity of these low-lying areas frequently is low during the open-water season but increases following freeze-up. For summer treatment, crews can use plank walkways or snowshoes to minimize damage and trampling, and temporary vehicle access can be created using tracks or similar non-intrusive surfaces.

✗ Manual oil removal, recovery of sorbents and flushing, although recommended methods, are also likely to promote foot traffic in these areas and should be minimized as much as possible.

✗ Where the tundra (which is a living plant community) has been oiled, minimize substrate removal (9) and vegetation cropping (12) unless very heavily oiled. If removal of vegetation sediment is undertaken, only the oiled surface, the top 2 – 5 cm, should be picked up, whenever possible, to avoid root damage.

✗ Avoid raking and trampling oil into living plants.

✗ Minimize intrusion of the tundra by using only low-pressure, hydraulic-washing techniques.

✗ Avoid burning (16) near living plant communities. Fires can quickly spread in dry tundra.

Summary for Inundated Low-lying Tundra Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on inundated low-lying tundra shores. The primary factors in selecting a response method are:

- The extent of the oiled area: Manual techniques become less practical as the size of the oiled area increases.
- The wetness of the tundra: Wetness affects the bearing capacity of the tundra.
- The type of oil (heavy or light): Only very light oils, such as diesel, can penetrate wet tundra surfaces.

Table 4 - 21   Treatment methods for inundated low-lying tundra shores

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	
2	flooding	○	○	
3	low-pressure, cold water	○	○	○
9	manual removal		◒	◒
10	vacuum systems	○	○	
13	sorbents	◒	◒	

○ good   ◒ fair (for small amounts of oil only)

4.11.13 Shoreline Treatment Tundra Cliff Shores

- Tundra cliffs are an erosional feature composed of a tundra (vegetation) mat that usually overlies peat and exposed ground ice. Ice-rich tundra cliffs are distinct and different from ice-poor unconsolidated sediment cliffs that are predominantly exposed sediment.

- Ice-rich tundra cliffs have a cliff face of predominantly exposed ground ice that is eroded by thermal action. On low cliffs (less than 3 m high), thermal and wave or stream erosion at the base creates a notch that results in the eventual collapse of the undercut tundra. On high ice-rich cliffs (greater than 3 m), melting of ice in the cliff face causes slumping and sliding. In both cases, little sediment is added to the shore zone, and waves or currents quickly remove ice and peat so that intertidal beaches often are narrow or absent.

- Ice-poor tundra cliffs contain predominantly unconsolidated sediments (sands and silts), which may have peat and/or exposed ice in the upper sections. These tundra cliffs are eroded by wave or stream-related processes and often have a sand beach at the base. In coastal regions where the backshore tundra has well-developed polygonal ice features, a notched or “saw tooth” cliff form is created where the ice wedges of the polygons intersect the cliff face.

- Erosion rates vary considerably depending on ice content of the exposed cliff, exposure to waves during the open-water season and the height of the cliff. Low erosion rates approximate 0.5 m/year, i.e., less than 0.2 m/month during the open-water season, with high rates in excess of 4.0 m/year (1.0 to 1.5 m/month during the open-water season). Extreme rates exceeding 25 m in one open-water season have been reported at locations in the Canadian Beaufort Sea and in the Laptev Sea.

- Because tundra cliffs often are undercut and naturally unstable, safety is a primary concern during operations on these shorelines.

Oil on Tundra Cliff Shores

- Oil that is washed up onto exposed ground ice is unlikely to stick and will flow back down onto the beach 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. Oil is likely to pool at the top of a beach where both oil and peat blocks would tend to accumulate.
- Oil may be splashed over a low cliff onto the tundra surface where it will persist beyond the reach of wave or water action. On exposed coasts, sediment is often deposited on the tundra (sometimes as perched beaches) during periods of storm wave action or wind surges.
- Oil persistence usually would be short due to natural erosion. Oil on the cliff or the slumped tundra blocks (that also erode rapidly) would be reworked and remobilized by wave action.

Preferred Response Options

✔ Natural recovery is the preferred option due to the rapid natural erosion of 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, likely will be naturally removed within a very short time (weeks) provided that the oil is not stranded at the onset of freeze-up. Natural recovery may not be appropriate immediately prior to freeze-up as the oil would be encapsulated by ice and potentially be remobilized during the next thaw.

✔ During periods of little wave action in the open-water season, cliff retreat occurs as a result of warm air melting the exposed ice. At these times, oil removed from an eroding cliff by ice melting could be contained at the base of a cliff by a berm or by passive sorbents.

✔ Oil can be washed from the cliff face by low-pressure (cold-water) washing, and be contained and collected at the base of a cliff by a berm or by passive sorbents.

✔ Manual removal of oil or oiled tundra/peat at the base of a cliff is practical for small amounts of oil.

- ✔ Mechanical removal 11 using a large or small front-end loader is more practical for larger amounts of oil or oiled material.
- ✔ Sediment relocation 15 and mixing 14 can be considered if these actions disperse oil without re-oiling the site or oiling adjacent areas.
- ✔ Oil that has been splashed over the cliff onto the top of a tundra surface would be above the normal limit of wave action and can be treated in the same manner as an on-land spill.

Typical Combinations of Response Methods

- Flooding 2 or floating 3 of oil into lined collection trenches or sumps, dug by a backhoe, can be followed by recovery with vacuum systems 10 or skimmers B.
- Mechanical removal 11 can be followed by mixing 14 or by sediment relocation 15.

What to Avoid

- ✗ Because erosion of the cliffs by natural processes is normal, treatment activities, such as low-pressure washing, that result in additional erosion of the cliff face are not considered to be damaging; however, care should be taken to minimize accelerated erosion that is caused by any treatment method as the vegetation on the tundra is a living community.
- ✗ Activities should be restricted to the base of the cliff, wherever possible, to avoid trampling or other damage to the tundra surface.
- ✗ In many areas, the beaches that front a tundra cliff are very narrow or absent so that there may be little working area or room to stage equipment.
- ✚ Tundra cliffs are an eroding and often unstable coastal feature. Block falls, slumping and mud flows present potential safety hazards during any response operations, particularly in areas where cliff heights are greater than 2 m. These events may occur suddenly without warning.
- ✚ Flushing or washing activities may trigger unexpected block falls, slumping or mud flows.

Summary for Tundra Cliff Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on tundra cliff shores. The primary factors in selecting a response method are:

- The shoreline exposure: Shorelines in exposed, high-energy locations will likely have relatively short oil persistence (days to weeks), whereas sheltered, low-energy shorelines will generally have longer oil residence times (months to years); mixing and sediment relocation are more effective on shores with wave action.
- The extent of the oiled area: Mechanical recovery and mechanical in-situ techniques become more practical as the size of the oiled area increases.
- The type of oil (heavy or light): Only very light oils, such as diesel, can penetrate most sands.

Table 4 - 22   Treatment methods for tundra cliff shores

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	○	○
3	low-pressure, cold-water	○	○	○
9	manual removal		◒	◒
11	mechanical removal		○	○
13	sorbents	◒	◒	
14	mixing	◒	◒	◒
15	sediment relocation	◒	◒	◒

○ good   ◒ fair (for small amounts of oil only)

4.11.14 Shoreline Treatment   Shorelines with Snow

- Snow is common on all Arctic and cold-climate shores. The behaviour and spreading of oil on a snow-covered shore depends on:
  - the type of snow (fresh or compacted)
  - the air temperature
  - the surface character of the shore (flat or sloping)

Oil on Snow

- Conditions under which oil would be spilled on a snow-covered shore normally would be associated with a land-based spill, in which the oil spreads or flows to the shore from a back-shore location, or washes ashore during cold temperatures.

- Oil stranded on a snow-covered shore likely would be partially contained by the snow. Snow is a good, natural oil sorbent. The oil content may be very low (less than 1%) in the case of light oils, as well as if the oil has spread over a wide area.

- Oil-snow proportions depend on the oil type and the snow character, the oil content being highest for medium crudes rather than for light products. 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 moves more quickly in snow and over a larger area. Light oils can move upslope in snow through capillary action as they spread.

- Fresh snow that blows over oil tends to stick and migrate down into the oil, causing an increase in the volume of material to be recovered.

- Snow falling onto oil tends to accumulate on the oil surface.

Practical Response Options

- ✔ Natural cleaning usually is preferred for light oils that would evaporate during thaw periods.
- ✔ Manual removal, using shovels and rakes, is appropriate for small amounts of surface or subsurface oil, but practicality decreases as the amount of oiled area and the volume of oiled snow increases.
- ✔ Pooled, low and medium oil on the surface of a snow-covered area, or which has been collected in trenches or by containment berms, can be recovered by vacuum systems.
- ✔ On flat surfaces, or where a mechanical arm can reach the oiled area, mechanical techniques can scrape snow-covered areas for removal and disposal. These techniques could include melting, to separate the oil and snow, or burning.
- ✔ Surface light or medium oil can be removed by sorbents, but sorbent effectiveness decreases as the oiled area or volume of oiled snow increases, or in low temperatures that cause the oil to reach or fall below its pour point.
- ✔ Pooled oil on the snow surface, or oil that has been contained by berms, can be removed by burning.

Typical Combinations of Response Methods

- Manual removal, using hand tools can be used with vacuum systems and sorbents.
- Mechanical scraping or removal can be followed by manual removal of any residues or spillage.

What to Avoid

- ✗ Avoid collecting large volumes of oiled snow. Melting the snow to separate oil and water, and then burning the oil, may require fuel and containers not available in remote areas.
- ✚ Snow can be slippery on sloping surfaces, particularly if there is ice below the snow. Care should be exercised so that falls and slips may be avoided.

Summary for Snow-covered Shores

There is little difference in the treatment techniques used for large versus small amounts of oil on snow-covered shores. The primary factors in selecting a response method are:

- The air temperature: Melting snow requires response techniques different than those used for dry snow.
- The nature of the snow surface: Response methods depend on whether the snow is smooth or rough, soft or compacted, or steep or flat.
- The type of oil (heavy or light): All but the most viscous and/or sticky oils can penetrate most snow-covered shores.

On steep snow-covered slopes, response may be limited to washing from a boat or barge.

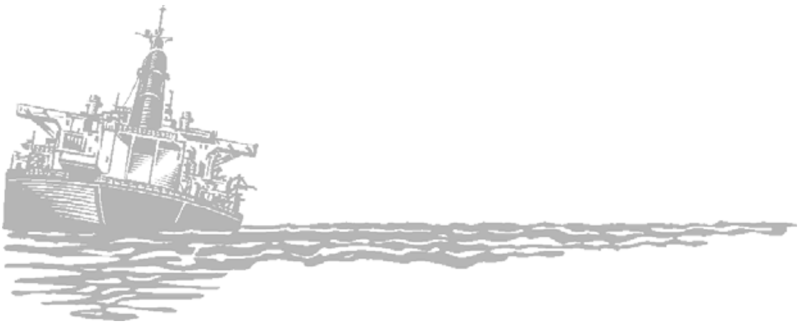
Table 4 - 23 Treatment methods for snow-covered shores

	Treatment Method	light oil	medium oil	heavy oil
1	natural recovery	○	◒	
9	manual removal	◒	◒	◒
10	vacuum systems	○	○	
11	mechanical removal	◒	○	○
13	sorbents	◒	◒	◒
16	in-situ burning	○	○	

○ good ◒ fair (for small amounts of oil only)

4

5 Response Methods



5

5.1 Introduction

Specific spill response methods must be used to implement the strategies outlined in Section 4, i.e., source control and off-site control of free oil, protection, and shoreline treatment for seas, rivers and lakes. In this section, practical information is provided on the application of 34 methods that can be used, individually or in combination, when planning or conducting response operations. Devices and techniques are detailed for each method. The response methods have been grouped into ten operational categories (Table 5 - 1), each with its own sub-groupings. The latter comprise the specific countermeasures tools used to clean up spills. Although usually warranted, monitoring the trajectory and fate of spilled oil is not included in this Guide.

Table 5 - 1 Response method categories

On Water or Ice	
A - E	mechanical containment
F	mechanical diversion
A - C	mechanical recovery
A - C	in-situ burning
A - B	chemical dispersion
On Shorelines	
1	natural recovery
2 - 8	washing/recovery
9 - 13	removal
14 - 16	in-situ treatment
17 - 20	chemical/biological

5.2 Mechanical Containment A - E

The objective of mechanical containment is to concentrate the oil (unless naturally contained), using various mechanical aids, to achieve a slick thickness that permits recovery.

There are five basic methods that can be used to mechanically intercept, control, contain and concentrate spreading oil:

- A **mobile floating barriers (containment boom, logs, etc.)**
- B **stationary barriers (filter fence, inverted weir)**
- C **subsurface barriers (oil trawl or V-sweep)**
- D **berms (snow or earth)**
- E **excavated structures (ice trench)**

Whichever method is selected, practical aspects must be considered to ensure that oil can be contained in recoverable quantities for the anticipated duration of the operation. The following criteria should facilitate mechanical containment:

- Thick slicks should be contained as quickly as possible following a release; multi-colour sheens less than 1 mm generally are not recoverable.
- The selected barrier or structure must be monitored for ongoing oil concentrations as well as for physical integrity and required repairs, and for the need to reposition to enhance effectiveness.
- The actual use, positioning and features of the devices discussed below may differ from those that can be implemented in the field. Good judgement must be used when choosing and using materials to ensure that they will survive Arctic conditions and permit the control and recovery of spilled oil.
- Changing weather and sea conditions, as well as changing oil properties, may result in the need to modify containment techniques within short periods of time.
- Simple methods that do not rely on complex mechanical systems can work best.
- Fuel, lubricants, spare parts and tools must be planned when conducting oil spill containment operations in remote areas.

5.2.1 Mobile Floating Barriers

A

5.2.1.1 Containment Boom

Containment of oil on water almost always requires the use of some type of mechanical barrier. The principle of mobile floating barriers is based on the use of a barrier on the water surface to intercept, control, contain and/or recover floating oil. A large number of containment booms are commercially available; these generally can be grouped into four categories (Figure 5 - 1):

- internal flotation
- pressure inflatable
- self-inflating
- fence

In each case, the boom extends above (sail) and below (skirt) the water surface. Larger-size, mobile floating barriers are designed for open-water conditions, whereas smaller types are intended for use in sheltered or calm environments.

Internal flotation booms are probably the most common, least expensive and easiest to deploy. Typically, they are constructed of PVC or polyurethane-coated fabric enclosing flexible foam floats. Some models have a single tension member at the bottom, while others have a second tension member along the top.

Pressure inflatable booms are constructed of PVC, neoprene, nitrile rubber-nylon, or polyurethane-coated material, with either segmented or continuous, manually-inflated air chambers.

Self-inflating booms are constructed of PVC or polyurethane-coated material with air chambers that are normally compressed when stored, and inflate through air intake valves when deployed.

Fence booms are constructed of a rigid or semi-rigid fabric with flotation provided by foam blocks, bolted-on blocks or outrigger floats.

In many cases, it might be necessary to improvise and fabricate a floating barrier from available materials, i.e., logs or conveyor belting (Figure 5 - 1). If logs are used, they should be connected by chains, and sorbent or other material should be placed between the ends of the logs to minimize oil loss. Logs are simple, durable and effective in low currents (less than 0.2 - 0.3 m/s).

ASTM boom connectors are standard devices that allow the connection of sections of the same or different boom types to each other.

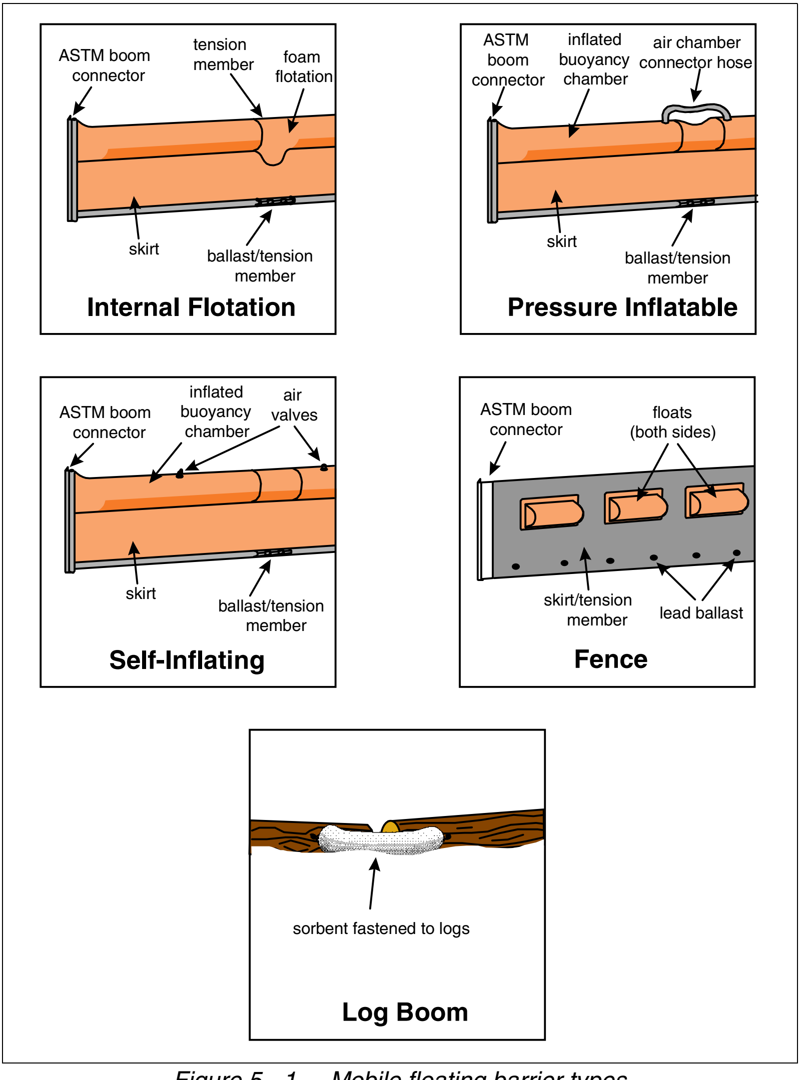


Figure 5 - 1   Mobile floating barrier types

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5.2.1.2 Booming Methods

Once a slick has reached open water or broken ice, oil can spread quickly with winds and current, and it might be very difficult to intercept, contain and recover. The presence of ice will slow the spread of spilled oil and provide some containment; however, oil can become trapped in freezing ice, spread amongst brash ice or adhere to ice chunks. These effects make oil recovery very difficult. If waves or other turbulence are present, oil can mix and disperse into the water column, making recovery impractical. For these reasons, it is important that mechanical containment be attempted as close to the source as possible, when safety permits.

The use of containment boom in scattered ice is more difficult than in open-water conditions. Generally, heavy duty or more durable booms are required in ice to withstand additional wear. In open-water and light ice conditions, containment boom often can be used effectively in currents of less than 0.5 m/s. The use of boom, however, is not usually feasible in ice concentrations greater than 60 - 70%.

Ideally, boom can be used to completely enclose a spill source. If there is an explosion risk in the vicinity of the spill source, or the spill has moved, boom can be used to collect oil downdrift of the original release point. However, safety concerns can preclude any response efforts.

Catenary Booming

Booms are used in various configurations to contain and recover slicks. Two vessels can tow a boom in a catenary or U-configuration to collect oil. This is accomplished by drifting downstream, holding in a stationary position or moving upstream toward the spill source.

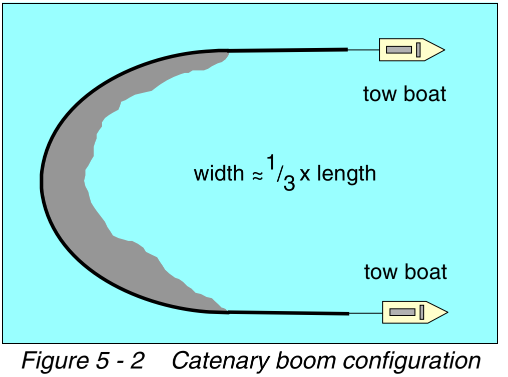

Figure 5 - 2 Catenary boom configuration

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V-Booming

Booms can be deployed in a V-configuration using three vessels and a skimmer or two boats and a trailing skimmer.

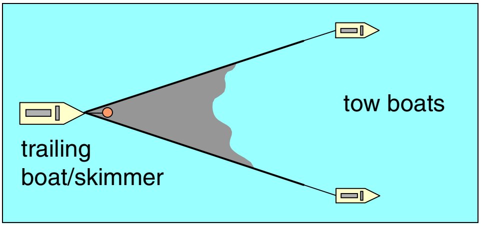

Figure 5 - 3   V-boom configuration

J-Booming

Booms can be towed in a J-configuration that diverts the oil to a skimmer to allow simultaneous containment and recovery.

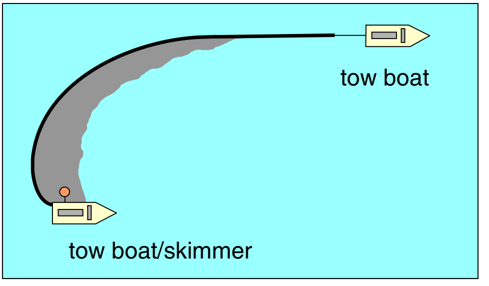

Figure 5 - 4   J-boom configuration

Table 5 - 2 shows each of the four basic boom types in each configuration and their applicability in calm, protected and open water, and in broken ice.

Table 5 - 2   Boom type versus configuration

Boom Use		Internal Flotation	Pressure Inflatable	Self-Inflating	Fence
calm water	U/V	◒	○ - ◒	◒	●
	J	○	○	●	◒
protected water	U/V	○	○ - ◒	◒	●
	J	○	○	●	◒
open water	U/V	◒	○	●	●
	J	○	○	●	●
broken ice	U/V	◒	◒	●	◒
	J	◒	◒	●	◒

○ good   ◒ fair   ● poor

5.2.2 Stationary Barriers

The objective of using stationary barriers is to stop and concentrate moving oil for collection while allowing water to continue to flow unimpeded. Typically, these barriers are used as spill control devices in streams, channels or inlets where there is a constriction through which the oil must pass. Many stationary barriers are constructed of locally-available materials. Ice, snow and cold temperatures can adversely affect these techniques.

Filter Fence

In small, slowly-flowing rivers or streams, wire mesh or netting, anchored by stakes as a back-stop for sorbent, can control the movement of oil. A second mesh can be deployed slightly upstream of the first to act as a debris screen. Sorbent material can be placed between the two mesh screens. Double-fencing is particularly suitable in tidal channels where current directions reverse. To allow changing soiled or saturated sorbents, without the escape of oil, additional fences can be constructed downstream or upstream of the second screen. The use of filter fences is limited to ice-free conditions.

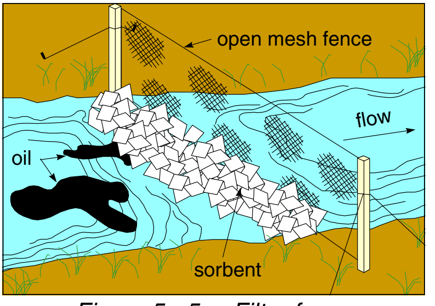

Figure 5 - 5   Filter fence

Culvert Block

Boards or other devices can be used to halt the flow of oil in drainage systems or culverts, where the water flow must be maintained. The culvert opening can be partially blocked with plywood that holds back the surface oil but permits water to pass below. The position of the plywood can be adjusted vertically to maintain the water at the desired level. When ice is present, both oil and ice pieces can jam at the barrier making the recovery of the oil difficult.

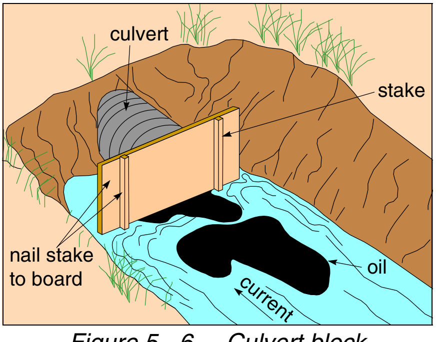

Figure 5 - 6   Culvert block

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Inverted Weir

Inverted weirs (also called siphon dams) can be used to retain oil and allow the continuous flow of water in a small river or stream. One or more pipes are placed at an angle through a soil or sandbag dam, with the upstream end of the pipe being close to the bottom of the ditch or stream, and the downstream end at a level that permits water to drain away. When more than one pipe is used, the pipes should be placed at slightly different angles.

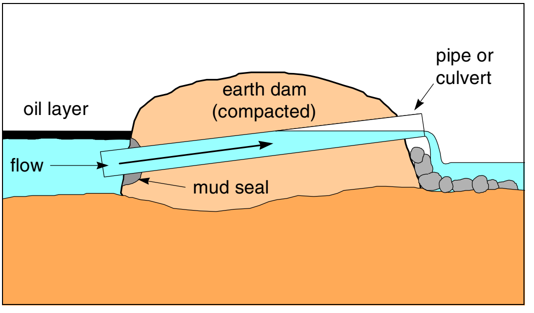


Figure 5 - 7   Inverted weir

Barriers can be constructed from snow, earth or boulders, although if large cobbles or boulders are used, plastic sheets or packed mud should be added to ensure that a good seal is made.

Choosing and positioning the pipe(s) is critical to effective operation of the weir. The pipe should be low enough at the inlet end to ensure that oil is not carried through the pipe. Larger pipes that allow greater volume (and slower) flows will minimize the tendency of oil to become entrained in the water at the inlet side. The outlet end of the pipe should be positioned to create a continuous, smooth flow.

Ideally, a shallow-angled pipe should run at a high flow rate without reducing the water level. Any other pipes should be angled to compensate for blockages in the primary pipe (caused by debris or ice) or increased water levels (caused by rainfall). A simple weir holds back surface oil - and ice, if present - and allows water underflow. Several weirs can be quickly placed in a small stream or ditch as they are relatively easy to install using plywood or a board. The sides should be cut well into the banks, otherwise oil can escape around the ends. Sorbents can be used to plug any gaps. A pump can also be used to maintain the proper water level, if required.

Although designed primarily for ice-free conditions, a siphon dam can be effective when broken ice is present. Ice pieces can be cleared immediately upstream of the dam to facilitate oil removal. However, freezing at the downstream end of the pipe can impede water flow.

Flume

When a slick or contaminated soil threatens a small river or creek, a flume can be built to contain the oil, while allowing the water flow to be maintained. Snow or earth berms should be positioned to allow a sufficiently-large containment area within the constraints of the pipe length used.

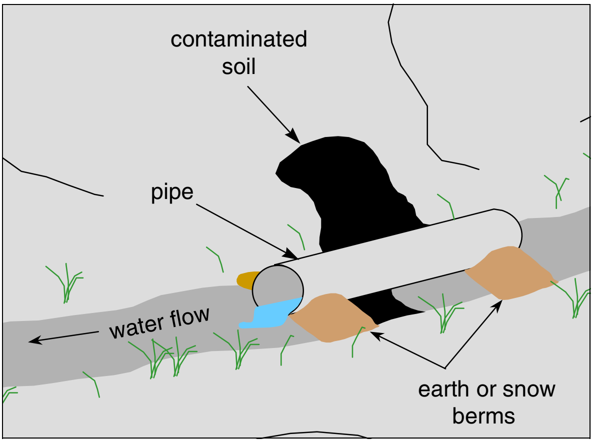


Figure 5 - 8   Flume

The berms should be compacted to ensure a good seal is made with the pipe or culvert to avoid seepage. It is possible to protect a stream using a flume in broken ice conditions if water flow is maintained.

5

5.2.3 Subsurface Barriers

Subsurface barriers are intended to intercept, contain and/or recover oil that is below the water surface. They were designed for use in open water.

Trawl Boom

In the event that there is sufficient open water to deploy a boom, an oil trawl can be used to attempt collection of the submerged oil.

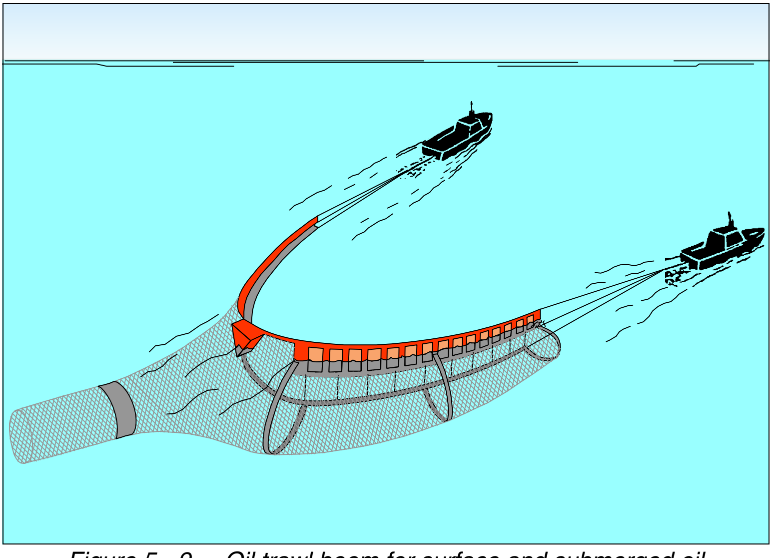


Figure 5 - 9   Oil trawl boom for surface and submerged oil

At a towing speed of 1 - 2 m/s, submerged and floating oil is forced into the net tunnels (one on each side), which extend 4 metres below the conventional containment boom. Oil then moves along the tunnels into a funnel located behind the apex of the boom. A series of up to 8 funnels, each containing 2 - 4 tons of oil, can be tied off and removed when full.

V-Sweep

Other designs include a V-boom configuration with a mesh slung from the bottom connecting the two boom sides.

5.2.4 Berms

On solid surfaces, barriers can be constructed of snow, earth or other materials, creating a berm to block the flow and spreading of oil. Unlike the stationary barriers described in Section 5.2.2, snow and earth barriers are not constructed to separate oil from flowing water.

Snow Berm

On solid ice, surface roughness and snow act as natural barriers that limit the spread of spilled oil and may provide sufficient containment of the oil for mechanical recovery or in-situ burning. When additional containment is required, snow can provide a quick and efficient berm construction material. Snow is also a good oil sorbent.

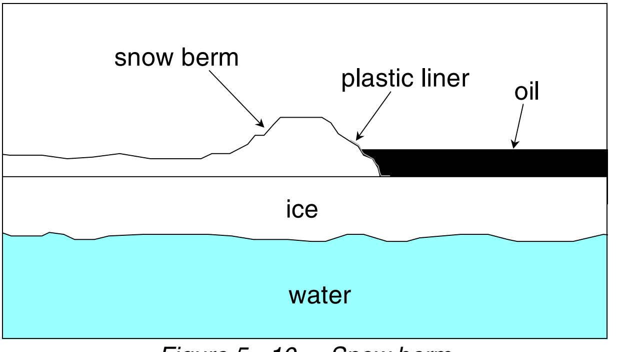


Figure 5 - 10 Snow berm

The snow should be well packed. Water can be sprayed to form an ice layer on the top and sides to make the berm impermeable to the spilled oil. For spills of diesel and light oil, a snow berm should be lined with plastic, or a plywood barrier should be used, to prevent seepage of the oil by capillary action (diesel can migrate uphill due to the capillary action of snow). A berm can be used in combination with trenches to stop and collect spreading oil.

Earth Berm

Earth berms should be compacted and, if time permits, lined with plastic sheets to make them impermeable. The berm/trench should be located sufficiently downslope of the release point to intercept the oil.

5.2.5 Trenches or Slots

On land or solid ice surfaces, trenches, slots or pits can be excavated to intercept, contain and collect spilled oil.

Ice Trench

On solid ice, a trench can effectively intercept, divert or collect spilled oil.

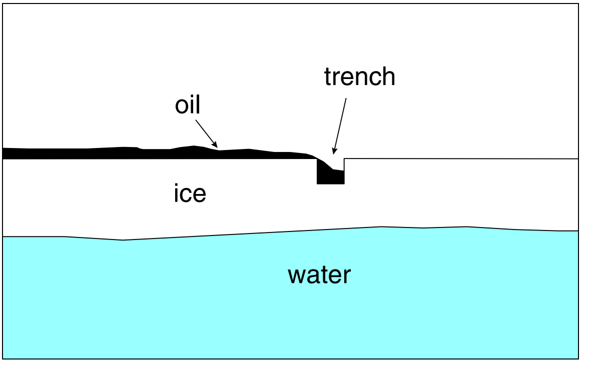


Figure 5 - 11   Ice trench

Boom/Ice Trench

Conventional containment boom can be placed in a trench and frozen in place to create a barrier to divert or halt the spread of oil during winter conditions or spring melts.

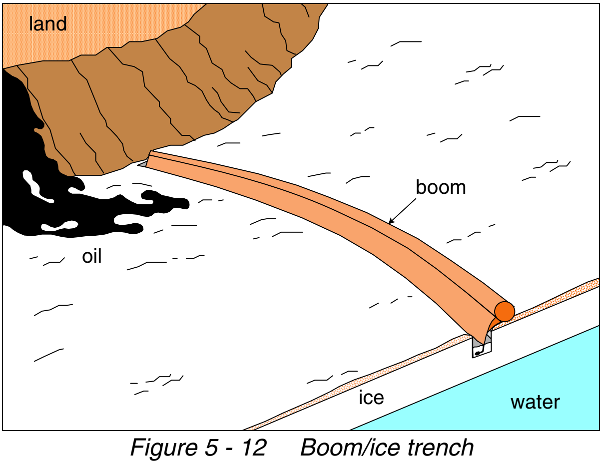


Figure 5 - 12   Boom/ice trench

Ice Slots

Naturally-occurring subsurface depressions and pockets under the ice provide areas where oil can accumulate. Ice slots can also be cut in the ice using an ice auger or chain saw, allowing the oil to pool at the surface and be recovered or burned. The slots can be lined with oil-impermeable plastic when used for recovery.

Placing an insulating material, such as snow or foam, on a growing ice sheet creates a pocket beneath the ice where oil can collect.

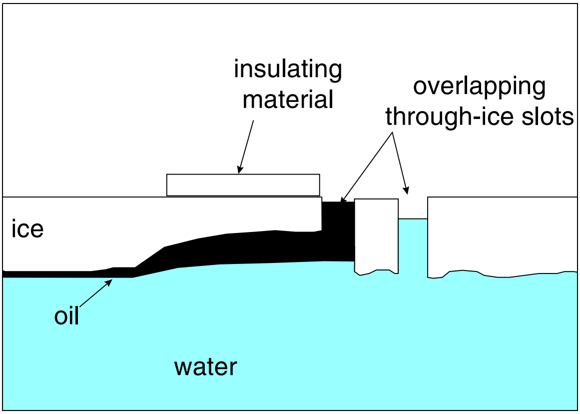


Figure 5 - 13 Ice slots

When currents exceed 0.4 m/s, the slots should be angled (similar to a boom being angled in a current) to allow the oil to rise up into the slots rather than flow underneath.

Boom/Ice Slots

A fence, internal flotation boom, or sheets of plywood, plastic or metal, can be placed in slots to create a subsurface barrier to prevent the further spreading of oil beneath the ice.

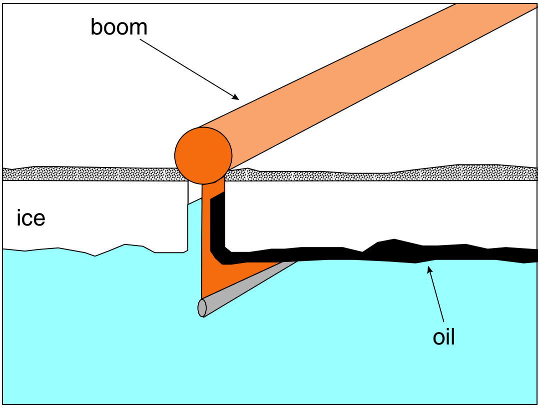


Figure 5 - 14 Boom/ice slot

5

5.3 Mechanical Diversion

5.3.1 Diversion Booming

When placed at an angle to the slick travel, the mechanical containment booms described in Section 5.2 can be used to divert oil away from sensitive areas or toward sacrificial areas for collection and recovery. This method is useful in currents of up to approximately 1 m/s. Table 5 - 3 shows boom angles and additional lengths of boom (versus the length of shoreline being protected) required to reduce the relative velocities of five different current velocities to required operational levels. There is limited application of this technique in broken ice.

Table 5 - 3   Boom requirements in high currents

Current Velocity (m/s)	Required Angle	Extra Boom Required (%)
0.4	0°	0
0.5	40°	33
0.6	55°	67
0.8	60°	100
1.0	70°	167

In some cases, it may be possible to divert oil using a single boom. In the example (right) the diversion angle is approximately 60°.

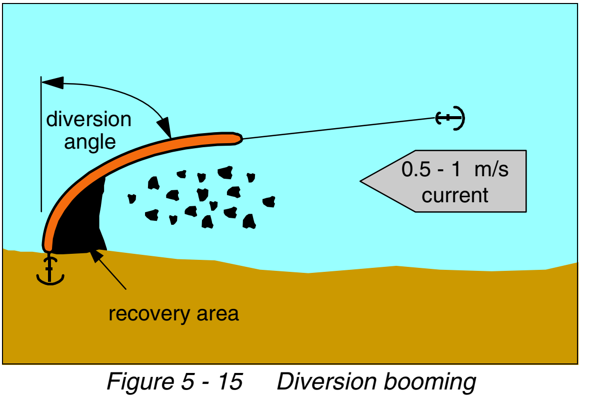


Figure 5 - 15   Diversion booming

Typically, in fast moving currents, or where the area requiring protection is extensive, a number of cascading booms are required to divert the oil.

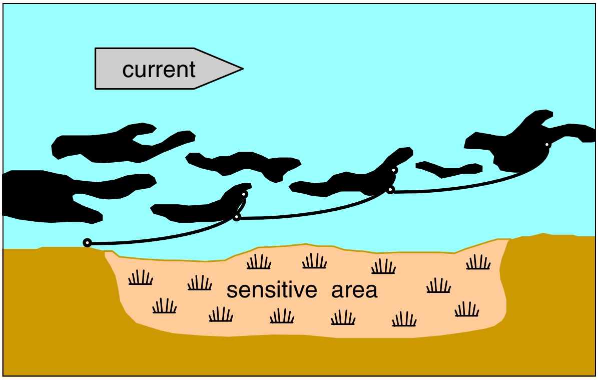


Figure 5 - 16 Cascading diversionary booming

This method can be applied during the open-water season to divert slicks away from sensitive areas.

Table 5 - 4 shows each of the four basic boom types and their applicability in calm, protected and open-water diversion applications.

Table 5 - 4 Boom type versus water conditions - diversion at sea

Conditions	**Internal Flotation**	**Pressure Inflatable**	**Self-Inflating**	**Fence**
calm	○	○	◒	◒
protected	○	○ - ◒	●	●
open water	○	○	●	●

○ good ◒ fair ● poor

Ice has not been included as a factor in Table 5 - 4 because of the difficulties that would be encountered in both deploying and maintaining a conventional diversion or exclusion boom. The use of a string of logs or other mechanical barrier could be considered to achieve the same effect in broken ice, if conditions allow safe placement and effective application.

River Diversion

There are a number of commercially-available booms that have been specially designed for operation in rivers. These river booms feature both top and bottom tension members to provide vertical stability (and improved oil deflection capability) in relatively high current, i.e., up to approximately 1 m/s. Such booms can be effective in a river where there is uni-directional flow. In a large, coastal river with reversing tides, repositioning a boom can be difficult and time-consuming. The deployment of booms in rivers when broken ice is present is also of questionable value, because debris or ice can damage the boom fabric.

When current speeds exceed 0.4 m/s, it is necessary to angle the boom (including river booms) to reduce the current relative to the boom (Table 5 - 3). Angling the boom also allows oil to be diverted to shore where it can be collected.

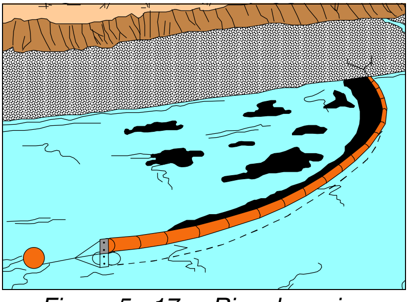


Figure 5 - 17   River booming

Table 5 - 5 shows each of the four basic boom types and their applicability to calm and protected river situations.

Table 5 - 5   Boom type versus water conditions - diversion in rivers

Conditions	Internal Flotation	Pressure Inflatable	Self-Inflating	Fence
calm	○	○	◒	◒
protected	○	○ - ◒	●	●

○ good   ◒ fair   ● poor

Again, ice has not been considered because of the limited effectiveness of deploying and using booms in broken ice in a river.

Diversion Booming in Intertidal Areas or at River Banks

In intertidal areas, or at river banks where water levels fluctuate during the period of deployment, shore-seal booms (Figures 5 - 18 and 5 - 19) can be used to ensure that an effective seal is maintained at the waterline.

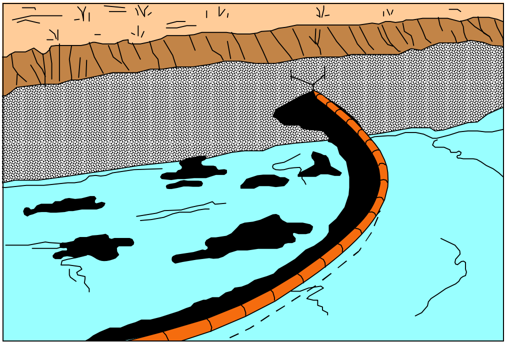


Figure 5 - 18 Shore-seal boom

These booms employ water-filled lower and air-filled upper chambers that adjust to changing water levels (Figure 5 - 19).

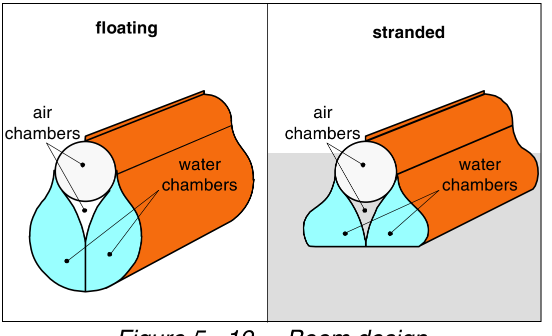


Figure 5 - 19 Boom design

When deploying shore-seal booms, the final position should be known before the boom is placed and anchored since redeployment is difficult, if not impossible, once the water-filled chambers have settled on the shore. Also, ensure that the water chambers of the boom are fully filled or water will collect in the lower boom sections (below the low tide mark) leaving the higher-elevation sections only partially full or empty.

Sites with boulders, sharp protrusions, rip-rap or other features that will result in oil leaking under the boom when the tide changes should be avoided. Shore-sealing booms require regular monitoring once deployed since currents, wind and waves can move and/or twist them. Damage to the fabric can also result as the boom grounds and chafes in the intertidal zone. Their deployment in ice-infested waters is questionable. The water in the lower chambers might freeze and the fabric of many models could be damaged when ice pieces puncture the boom.

5.4 Mechanical Recovery (A) (B) (C)

The objective of mechanical recovery is to collect contained and concentrated oil and to transfer the oil to temporary storage for subsequent disposal. Three basic types of skimmers are used to recover oil:

- (A) **advancing systems**
- (B) **stationary skimmers**
- (C) **vacuum units**

There are a wide variety of oil collection principles. Some oil recovery mechanisms are unique to either the advancing or stationary skimmer groups, whereas others can be configured to operate in either mode:

Advancing Skimmers

- advancing weir
- zero relative velocity rope mop
- oleophilic lifting belt
- oleophilic brush
- submersion plane/belt
- paddle/belt

Stationary Skimmers

- simple weir
- self-leveling weir
- screw auger weir
- oleophilic drum
- oleophilic disc
- oleophilic rope mop
- oleophilic brush
- hydrodynamic

Vacuum systems can include purpose-built units but usually refer to either a conventional vacuum truck or air conveyor.

Operational factors such as oil viscosity, oil thickness, debris and temperature all play an important role in the selection of skimmers. At temperatures below freezing, most skimmers are difficult to operate. Ice forms in pumps and hoses, motors are difficult to start, and pickup mechanisms, e.g., belts, brushes and rope mops, can freeze if water is recovered. Brittle failure of metals and plastics also can occur at extreme cold temperatures. The addition of steam, hot water at high pressure, heating elements and heated enclosures are sometimes considered for skimmers used in cold conditions.

Tables 5 - 6 and 5 - 7 provide details for specific types of skimmers.

5.4.1 Advancing Skimming

It might be necessary to intercept uncontained slicks in open water or to attempt to recover oil in moving water. In both cases, an advancing skimmer of some type is required. Advancing skimmers can be either self-propelled, towed or pushed by another vessel.

The six advancing skimmer types are shown in Figure 5 - 20. Advancing skimmers are usually relatively large and often are used together with booms to divert oil into the path of the skimmer. For the most part, they are limited to application in low concentrations (less than 30% ice cover) of small ice pieces (generally less than 1 m across), if deployed at all in ice.

Some advancing skimmers are designed to be deployed as a Vessel of Opportunity Skimming System (VOSS), taking advantage of an existing vessel to reduce the cost of procuring and maintaining a dedicated spill recovery vessel.

Table 5 - 6 shows each basic advancing skimmer and its general applicability to the recovery of light, medium and heavy oils in various sea states and operational conditions, including debris and ice. Generally, rope mop, belt and brush systems can process ice; however, this depends on the specific machine design. For example, brush skimmers that utilize a boom connected to a side arm to concentrate oil for collection are less effective in broken ice than simple brush devices.

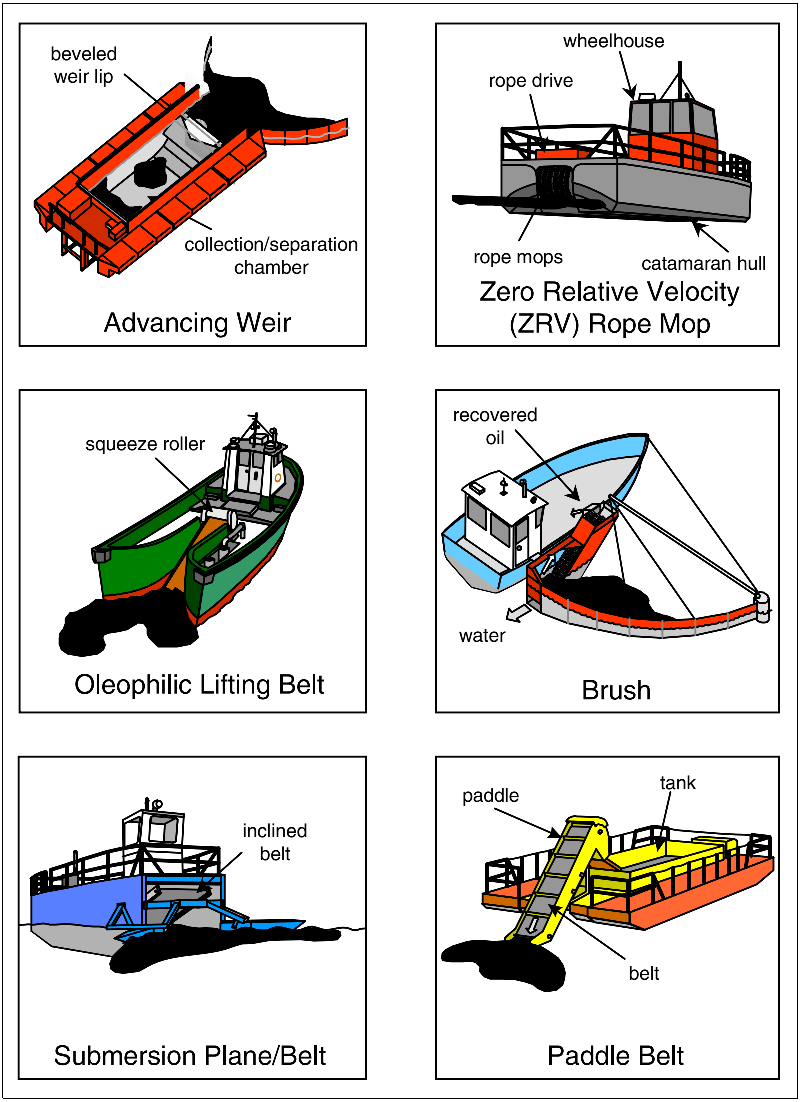


Figure 5 - 20 Advancing skimmer types

Table 5 - 6 Advancing skimmers

			Skimmer Type					
			advancing weir	zrv rope mop	sorbent lifting belt	brush	submersion plane/belt	paddle belt
Operating Environment	open water		◒	○	○	◒	●	●
	protected water		○	○	○	○	◒	●
	calm water		○	○	○	○	○	○
	high current (<2 kts)		○	○	◒	◒	◒	◒
	shallow water (<1 ft)		●	●	●	◒	◒	○
	debris (including ice)		●	○	○	○	●	◒
Oil Viscosity	light		○	◒	●	●	◒	◒
	medium		○	○	○	○	○	○
	heavy		●	◒	○	○	◒	○
Skimmer Characteristics	oil/water pickup % *		◒	○	◒	○	◒	◒
	recovery rate		◒	◒	◒	◒	◒	◒
	ease of deployment	open water	◒	○	○	○	●	◒
		in ice	●	◒	○	◒	○	●
available as VOSS (Vessel of Opportunity Skimming System)					✓	✓		✓
available with integral storage			✓	✓	✓	✓	✓	✓

* oil/water pickup % = % oil in recovered product   ○ good   ◒ fair   ● poor   ✓ yes

5

5.4.2 Stationary Skimming

Spills that have been contained by a boom, a berm or in a trench on solid ice can be skimmed and pumped into storage containers (Figure 5 - 21). Where subsurface oil has collected in slots cut into the ice, various portable skimmers can be used to collect and transfer the oil to storage containers.

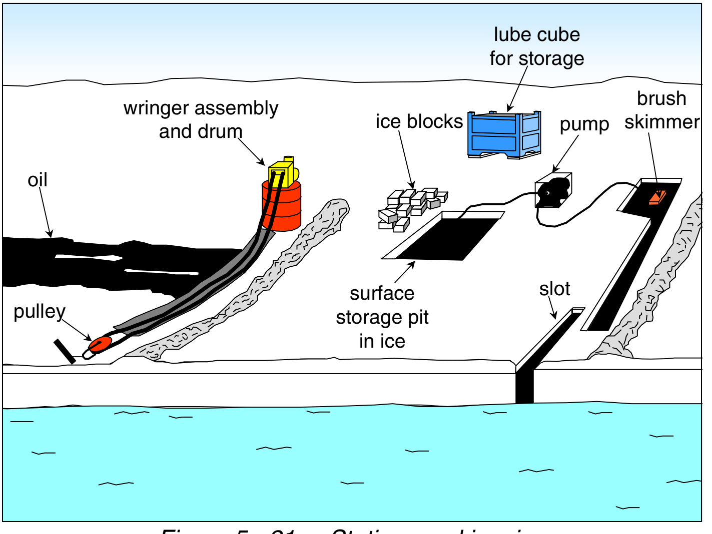


Figure 5 - 21 Stationary skimming

Small, portable brush, disc, drum or weir skimmers can be used, depending on the oil type and thickness. Portable rope mop skimmers can be deployed between holes cut in the ice to recover oil trapped beneath the ice. Pumps, hydraulic power packs and/or generators may be required to operate portable skimmers. The eight basic stationary skimmer types are shown in Figure 5 - 22.

Table 5 - 7 lists each stationary skimmer type and its general applicability to the recovery of light, medium and heavy oils in various sea states and operational conditions, including ice. With the exception of weir devices, such skimmers can process small ice pieces, but are usually placed in open-water areas or between floes where oil collects to ensure that good contact with slicks is made and that recovery proceeds.

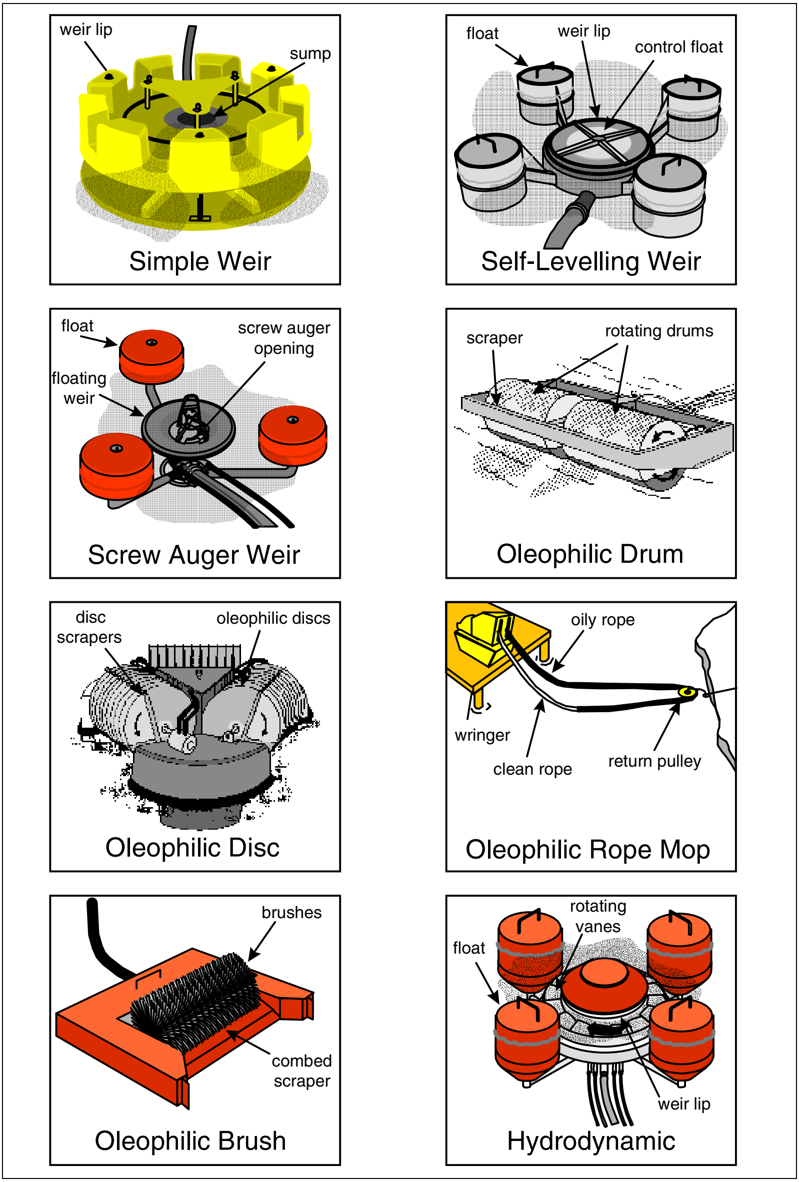


Figure 5 - 22   Stationary skimmer types

Each skimmer has operating functions, e.g., disc speed, weir height, that must be optimized for the conditions in which the device is used.

Table 5 - 7 Stationary skimmers

			Skimmer Type							
			simple weir	self-levelling weir	screw auger weir	oleophilic drum	oleophilic disc	oleophilic rope mop	oleophilic brush	hydrodynamic
Operating Environment	open water		●	●	●	◒	◒	○	◒	◒
	protected water		◒	●	●	○	○	○	○	○
	calm water		○	○	○	○	○	○	○	○
	high current (<2 kts)		●	●	◒	●	●	◒	◒	◒
	shallow water (<1 ft)		○	◒	●	◒	◒	○	◒	◒
	debris (including ice)		●	●	◒	●	●	○	○	●
Oil Viscosity	light		○	○	○	◒	◒	◒	●	○
	medium		○	○	○	○	○	○	○	○
	heavy		●	●	◒	◒	●	◒	○	◒
Skimmer Characteristics	oil/water pickup % *		●	●	◒	◒	◒	○	○	◒
	recovery rate		◒	●	●	◒	◒	●	◒	◒
	ease of deployment	open water	○	○	◒	○	○	◒	○	◒
		in ice	◒	◒	●	○	◒	◒	○	●
available with integral storage						✓	✓	✓	✓	

* oil/water pickup % = % oil in recovered product ○ good ◒ fair ● poor ✓ yes

5

5.4.3 Vacuum Systems

Vacuum systems provide a quick and effective method for recovering large volumes of oil. Vacuum systems are capable of handling a wide range of fluid viscosities and a variety of small debris. Their gentle pickup action also minimizes oil/water emulsification, thus reducing the need for decanting collected water.

Vacuum Truck

Vacuum trucks (Figure 5 - 23) are effective when access to pooled oil is possible, but they are large, heavy, expensive and limited to lifting fluids to heights of 10 m or less.

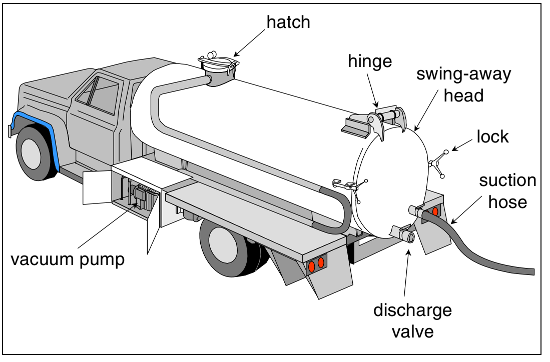


Figure 5 - 23   Vacuum truck

Vacuum trucks pick up a high ratio of water to oil when used on thin slicks, and air intake can disrupt the high vacuum levels required as suction is lost. They are commonly used to recover oil in ice but sometimes lose suction when lines freeze and ice pieces clog the hose inlet.

Air Conveyor

Air conveyors employ a cyclone, filters and a blower or pump to collect pooled oil. Normally, optimum results are achieved using lower blower speeds (below 1500 rpm) on thin slicks, whereas higher speeds (above 1500 rpm) should be used on thicker slicks. Also, water pickup can be minimized by keeping the opening of the pickup hose approximately 10 cm from the surface. The length of pickup hose should be minimized to reduce handling problems.

In cold temperatures, ice can block suction lines, particularly at the inlet and at connections. Freezing sometimes occurs when water is recovered. Blockages also result from mixtures of viscous oil and small ice pieces that cannot flow through a hose.

5.5 In-situ Burning (A) (B) (C)

The objective of in-situ burning is to remove oil in one step, i.e., without collection and disposal. In-situ burning is a treatment method that can be used for oil on open water, on ice and in broken ice.

A	**burning oil on water contained in booms**
B	**burning oil on ice**
C	**burning oil in broken ice**

5.5.1 Burning Oil On Water Contained in Booms

A

Oil on water can be burned if the thickness is greater than 2 or 3 mm. Typically, slicks must be contained and concentrated to achieve this thickness on open water using fire-resistant booms.

Towing or drifting vessels may be able to hold fire-resistant boom in position to capture oil when currents at the spill source are low enough to allow containment (less than 0.4 m/s or 0.7 knots).

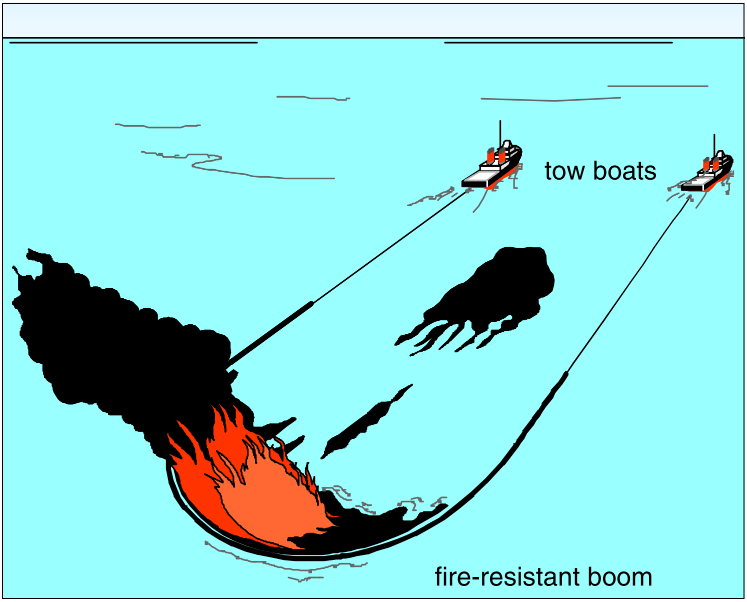


Figure 5 - 24   Open water containment/burning

If the initial area or flow rate of the spill source is too great to be contained or if the currents exceed 0.4 m/s (0.7 knots), it may be necessary to move the vessels and fire-resistant boom to a new location farther downstream.

Two or more towed U-boom configurations can be positioned near the spill source while burning oil when drifting with the current.

5

Fire-Resistant Booms

Fire-resistant booms can be used for the containment, diversion or exclusion of spilled oil. Typically, booms that are heavily and strongly constructed are difficult to handle but are durable and can survive burning in an offshore marine environment for long periods. Other boom types are lighter and easier to handle and deploy but are not as durable. Most fire-resistant booms, except for stainless steel models, incorporate mineral-based fabric and ceramics in their structure.

Like conventional booms, fire-resistant booms have limited effectiveness in broken ice due to deployment difficulties.

Igniters

A good ignition system is characterized by the following features:

- provides a reliable source of heat that rapidly vaporizes a slick without forcing oil away

- is simple in design, safe and easy to use, has a long shelf-life and minimal transportation requirements

For obvious safety reasons, aircraft pilots prefer to work with ignition systems that do not require lighting fuses within aircraft and releasing the igniter by hand from an open window or door.

Two types of ignition systems are commercially available: Igniters used from a vessel or from shore and igniters for use from helicopters.

One device, the Heli-Torch®, has received wide acceptance, because it can be slung from a helicopter and provides a good source for igniting multiple burns, e.g., oil in melt pools on ice. Also, the device is remotely-operated and is relatively safe to use.

Hand-held igniters and other devices, such as propane torches, pose a slightly higher risk and are more logistically complex to store, transport and use on oil than the Heli-Torch®. However, igniters that can be manually deployed are more practical in remote communities or other situations where a helicopter is not immediately available.

5.5.2 Burning Oil on Ice

B

On Solid Ice

On continuous, solid ice, oil tends to accumulate in natural depressions and cracks in the ice. Snow and ice berms can be used to contain the oil. If safe to do so, burning is often the most practical and effective method of removing concentrations of oil in ice.

Backhoes, bulldozers and graders can be used to build piles or cones (Figure 5 - 25) of oil contaminated snow. By adding a suitable combustion promoter, e.g., diesel, the contained oil can be ignited and burned. Compacted snow berms surrounding the cones prevent the spreading of oil in the melt water that forms during the burn.

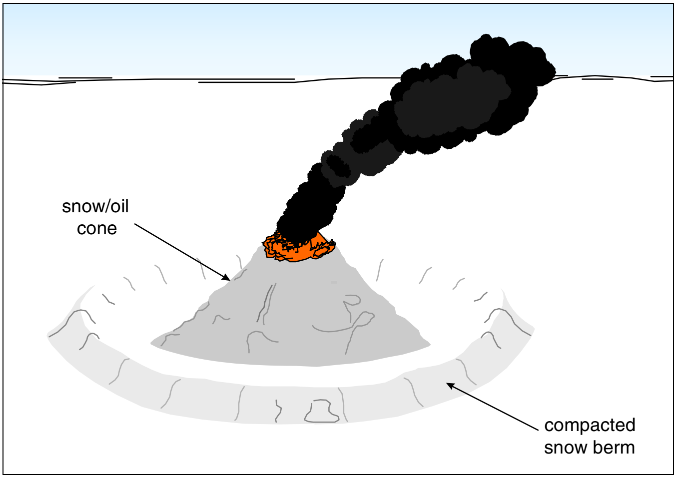


Figure 5 - 25   Burning snow cone

Melt Pools

Oil spilled under continuous sea ice will spread and fill the rough spaces on the underside. If ice is still forming, the oil will become encapsulated in the ice. In spring, the oil will rise up through brine channels and pool on the surface where it can be burned.

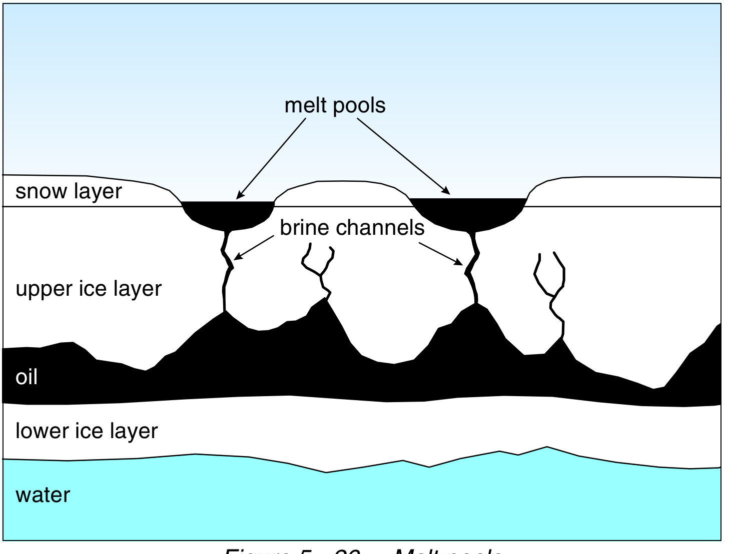


Figure 5 - 26   Melt pools

Because melt pools quickly appear and may only exist for several days before they join together, or the ice melts and decays, burning oil contained in melt pools must be carried out relatively quickly.

Even if operations are quickly mounted, the logistics of using in-situ burning techniques on a large spill to remove oil from melt pools can be daunting. A very large number of separate, small pools (thousands) can form over a wide area, as ice floes containing the pools move under the influence of the wind. The result is many moving targets, i.e., pools containing oil, that have a relatively brief life span. Additionally, any released oil can spread quickly into thin, unburnable layers as the melt pools grow and join together, and the floes melt. Smaller spills are much easier to burn.

5.5.3 Burning Oil In Broken Ice

In broken ice, oil can be transported by wind and currents around and under larger ice forms, and can accumulate between tightly-packed ice fields. The ice serves as a natural barrier against which the oil concentrates. If slicks form in layers more than 2 - 3 mm thick, in-situ burning is possible.

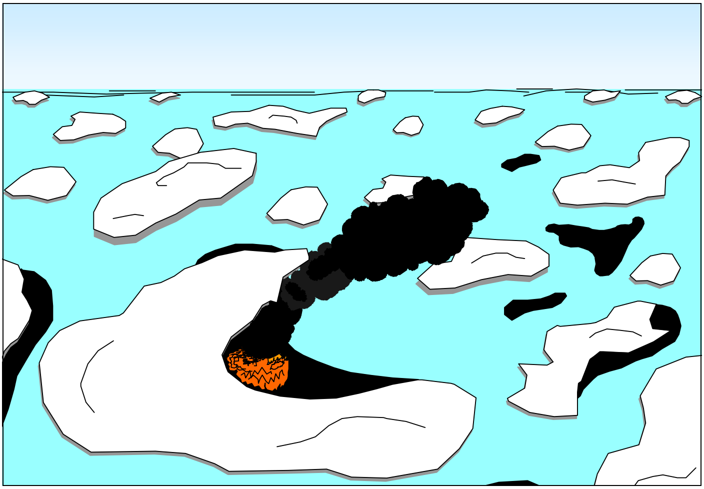


Figure 5 - 27   Burning in open water/ice embayments

Air-deployable igniters may be deployed from helicopters to initiate a burn. As with any in-situ burn, a minimum oil thickness of several millimetres is required for ignition and sustained combustion.

Where possible and applicable, a helicopter-slung ignition unit is preferred for safety and logistical reasons.

5.6 Chemical Dispersion

The objective of chemical dispersion is to promote the formation of oil droplets in order to accelerate the natural dispersion and biodegradation of spilled oil. Dispersants often can be applied to control offshore slicks or oil that accumulates in coastal areas that have significant tidal or flushing action. Dispersant use requires consideration of the following factors:

oil properties	To be dispersed, oil must have a viscosity less than 10 000 cSt, a pour point below ambient temperature, and contain light petroleum fractions.
Environmental concerns	Dispersants should be used to reduce impacts; the proximity of resources, toxic effects, weather, and sea conditions require assessment.
application mode	Dispersants are usually applied from vessels, fixed-wing aircraft, and helicopters at optimum speeds, delivery rates, and droplet size.
spray equipment	Spray arms, pumps, fire monitors, metering systems, nozzles and rigging must be used in a well-designed and integrated system.

When used appropriately, dispersants should result in the distribution of oil into the water column, and thereby reduce the amount of oil that might otherwise enter bays and estuaries or reach shore and affect sensitive habitats. Application decisions are usually based on estimating minimum effective dosages to minimize possible impacts.

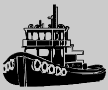
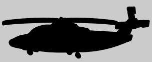
Dispersants must be applied as early in the spill as possible because weathering significantly increases the viscosity of many oils. Dispersants are effective on oils with a viscosity of less than 2 000 cSt. For oils up to 10 000 cSt viscosity, dispersants will still be effective but higher dosages may be required, depending on wave energy. At 10 000 to 20 000 cSt, dispersion becomes very difficult because the dispersant may not penetrate the oil. The viscosity limits that determine dispersant effectiveness are not well documented. Many viscous oils have been successfully dispersed in laboratory tests.

In broken ice, there might not be sufficient mixing energy to disperse treated slicks, and the flushing action can be relatively low.

Application Method

Dispersants can be applied from work/tug boats, single-engine aircraft, helicopters, multi-engine aircraft or any combination of these platforms. The limitations of wind, sea state and wave height are shown in Table 5 - 8 for each basic deployment mode. Note that in extreme weather and sea conditions, it is unlikely that dispersants would be applied to a spill.

Table 5 - 8 Comparison of dispersant application platforms

Application Method	Weather Limitations	Advantages	Disadvantages
 **work/tug boats**	• 10 - 35 km/h winds • 0.3 - 3 m waves	✓ good control ✓ mixes water	✗ limited to small spills ✗ small swath width
 **single-engine airplane**	• 30 - 35 km/h winds • 2 - 3 m waves	✓ relatively inexpensive ✓ can land on field	✗ limited to smaller spills ✗ uses dispersant only (neat)
 **medium-size helicopter**	• 30 - 50 km/h winds • 2 - 5 m waves	✓ highly maneouverable ✓ lands almost anywhere	✗ relatively expensive ✗ uses dispersant only (neat)
 **large, multi-engine airplane**	• 50 - 60 km/h winds • 5 - 7 m waves	✓ high payload ✓ high coverage rate	✗ very expensive ✗ requires runway ✗ uses dispersant only (neat)

Regardless of the method used, communication between spotter aircraft and deployment vessels is essential to ensure that dispersants are applied efficiently and effectively.

A water-level vantage point does not provide a sufficient overview of the areal extent, configuration, and distribution of oil slicks compared to an aerial observation platform.

5

5.6.1 Vessel Dispersant Application

Various vessels, such as workboats, tugboats, and barges, can be used to apply dispersants, but they are effective only on small spills due to their relatively slow speed and small swath width.

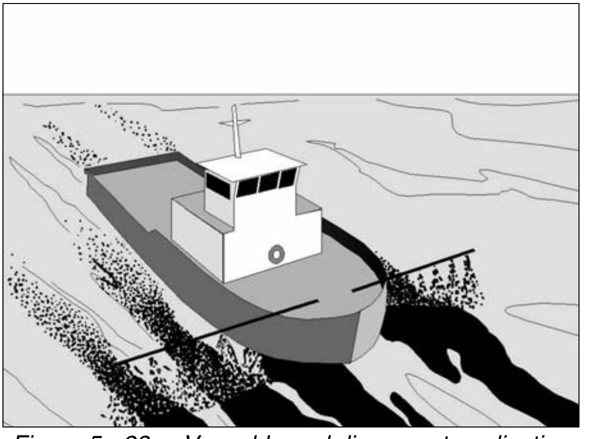


Figure 5 - 28 Vessel-based dispersant application

Other vessel-related considerations are:

- Spray arms should be positioned as near to the bow of a vessel as possible to avoid interference with the bow wave.
- Spray boom length should be limited to ensure that the end of the boom does not contact the water when the vessel rolls.
- Nozzles should be sized and positioned to give a uniform spray of droplets instead of a fog or mist.
- Dispersant should be sprayed so that it strikes the water in a flat line perpendicular to the direction of travel of a vessel at typical boat speeds of 4 - 19 km/h (2 - 10 knots).
- A fire monitor fitted with a wire mesh bag on the nozzle can apply a dispersant/water mixture at a rate of up to four times that of a standard spray boom (400 - 100 L/min or 100 - 300 US g/min). Fire monitors, which are readily available, should be elevated from 30 to 40° and should be aimed downwind.

5.6.2 Aerial Dispersant Application

Dispersants can be applied to large spills with fixed-wing aircraft equipped for aerial spraying or with helicopters equipped with an underslung bucket. Typically, aerial application should begin at the outer, leading edges of the thicker parts of the slick.

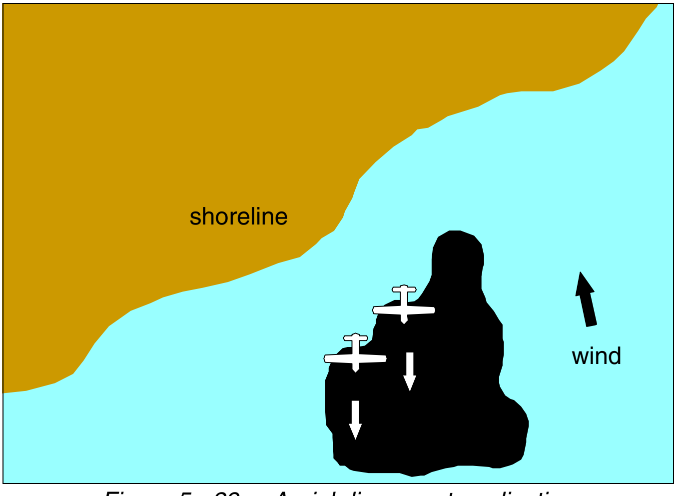


Figure 5 - 29 Aerial dispersant application

Except for large spills, cross-wind application is not recommended, because much of the dispersant will miss the slicks.

Crews must be experienced in low-altitude flying.

Helicopter Systems

Helicopters fitted with underslung buckets are used to apply dispersants. Deployment specifics, e.g., air speed and bucket altitude, depend on the type of helicopter, bucket, and dispersant used. Helicopters must be equipped with radar altimeters.

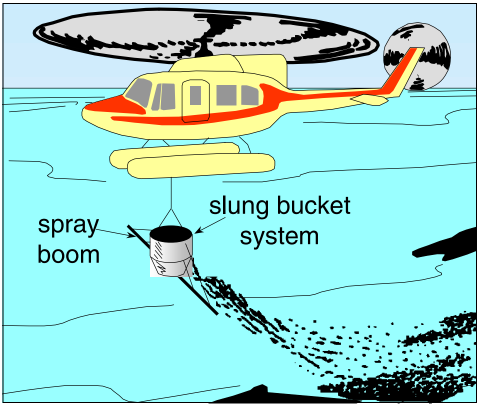


Figure 5 - 30   Helicopter-based system

Dispersant applied at a speed of 112 km/h (60 knots) and an altitude of 15 m (50 ft) results in a swath width of 21 m (70 ft) and an application rate of 32 L/hectare (3.5 US gal/acre).

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Reducing the air speed to 56 km/h (30 knots) and the bucket altitude to 8 m (25 ft) results in a 15 m (51 ft) swath width and an application rate of 127 L/hectare (14 US gal/acre). Maintaining this minimum speed optimizes effectiveness and minimizes rotor downwash. Hovering should be avoided. Upwind application is recommended at a maximum speed of 150 km/h (80 knots).

Fixed-wing Systems

A wide range of fixed-wing aircraft can be used to apply dispersants. These include a number of smaller aircraft normally used for agricultural spraying.

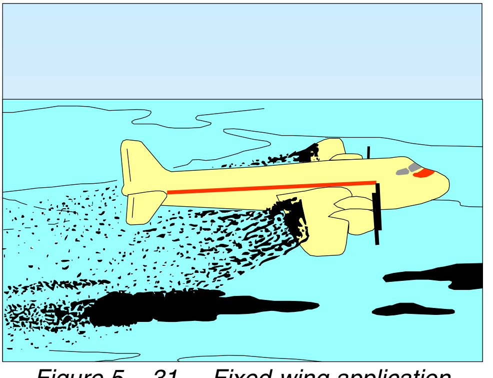

Figure 5 - 31   Fixed-wing application

The nozzles typically used on these types of aircraft are designed to produce a fine spray that is not suitable for dispersant application. If these aircraft are used, the existing nozzles should be replaced with larger ones.

5.7 Shoreline Treatment

The objective of shoreline treatment is to accelerate the recovery of the oiled areas. The treatment or cleanup techniques selected to meet this objective should be compatible with the character of the shore zone and with the oiling conditions (type and volume of oil) as described in Section 4.11.

This section provides practical information on 20 shoreline response techniques. They are grouped on the basis of five primary treatment methods as shown below.

natural recovery	Section 5.7.1
physical methods	
• **washing**	Section 5.7.2
• **removal**	Section 5.7.3
• **in-situ treatment**	Section 5.7.4
chemical/biological	Section 5.7.5

Table 5 - 9 lists the 20 response techniques or tools. The numbers used in this table for the 20 techniques are applied throughout this Field Guide for ease of reference. All treatment options, except for natural recovery, involve some form of intrusion on the ecological character of the shoreline type that is being treated or cleaned. Table 5 - 9 summarizes the relative level of impact that each technique or tool may have for the shoreline types used in these guidelines, irrespective of the type or volume of oil spilled. Snow and ice-covered shorelines are not included in the table as they would be protected from oiling by snow and ice.

Each shoreline treatment option is defined separately, although in practice, two or more techniques usually are selected in combination to achieve the treatment objective.

Methods that rely on pumping water or the operation of motorized equipment can be adversely affected by cold weather. Difficulties in starting motors, freezing of water lines, and other interferences from ice and cold temperatures can impede shoreline treatment.

Table 5 - 9 *Summary of the relative potential impact of response techniques in the absence of oil (modified from API/NOAA, 1994)*

	bedrock	man-made solid	sand beaches	mixed sediment beaches	pebble/cobble beaches	boulder beaches	sand flats	mud flats	salt marshes	peat	low-lying indundated tundra	tundra cliffs
1 natural recovery	–	–	–	–	–	–	–	–	–	–	–	–
2 flooding	○	○	○	◒	○	○	○	○	○	○	○	○
3 low-pressure, cold wash	○	○	◒	◒	◒	○	●	●	○	○	○	○
4 low-pressure, warm/hot wash	◒	○	●	◒	◒	◒	●	●	●	●	●	○
5 high-pressure, cold wash	○	○	●	●	●	◒	●	●	●	●	●	●
6 high-pressure, warm/hot wash	◒	○	●	●	●	◒	●	●	●	●	●	●
7 steam cleaning	◒	○	●	●	●	●	●	●	●	●	●	●
8 sandblasting	●	◒	–	●	●	●	–	–	–	–	–	–
9 manual removal	○	○	○	○	○	○	◒	●	●	●	●	○
10 vacuums	○	○	○	○	○	○	◒	◒	◒	○	○	○
11 mechanical removal	–	–	◒	◒	◒	◒	◒	●	●	◒	●	◒
12 vegetation cutting	◒	○	–	–	–	◒	–	●	●	–	●	–
13 passive sorbents	○	○	○	○	○	○	○	◒	◒	○	○	○
14 mixing	–	–	◒	◒	◒	–	◒	●	●	●	●	○
15 sediment relocation	–	–	◒	◒	◒	–	●	●	●	●	●	○
16 burning	○	○	◒	◒	◒	◒	●	●	◒	●	●	–
17 dispersants	○	○	○	○	○	○	–	–	●	●	●	○
18 shoreline cleaners	○	○	○	○	○	○	–	–	◒	–	–	○
19 solidifiers	–	–	○	○	○	○	◒	◒	◒	○	○	○
20 bioremediation	○	○	○	○	○	○	○	○	○	●	○	○

○ good (low potential impact) ◒ fair (medium potential impact) ● poor (high potential impact)

5.7.1 Natural Recovery 1

Optimum Use

All shoreline types that are affected by small amounts of non-persistent oil can naturally recover, even in Arctic conditions, given appropriate circumstances.

The objective of natural recovery is to allow a site to recover without intervention or intrusion.

Description

Evaluation of this option requires field observations of the oiling conditions and of the resources at risk, to assess the likely consequences of allowing the oil to weather naturally. In some circumstances, it may be appropriate to monitor the site to ensure that the assessment is accurate or that conditions do not change.

Applications

The natural recovery option may result from an evaluation which makes the determination that:

- the treatment or cleaning of stranded oil may cause more damage than leaving the environment to recover naturally
- typical response techniques cannot accelerate natural recovery or are not practical
- safety considerations could place response personnel in danger either from the oil or from environmental conditions (adverse weather, difficult access, etc.)

Other factors that may be involved in the evaluation include an analysis of the resources at risk, the type and amount of oil and the location of the site. For example, a determination could be made that a small amount of non-persistent oil, spilled at a remote location may weather and degrade without any threat to the local environment, human health or to wildlife and the segment should be left to recover naturally.

Natural recovery can be applicable on any spill incident and for any type of coastal environment or shoreline type. Natural recovery is more applicable for:

- small rather than large amounts of oil
- non-persistent rather than persistent oil
- exposed shorelines, rather than sheltered or low wave-energy environments
- remote or inaccessible areas

The trade-off (or Net Environmental Benefit - see also Section 7.5) analysis for natural recovery considers:

1 the estimated rate of natural recovery

2 possible benefits of a response to accelerate recovery

3 possible delays to recovery caused by response activities

5

Constraints/Limitations on Natural Recovery

Natural recovery may not be appropriate if important ecological resources or human activities/resources are threatened.

The potential for stranded oil to be remobilized and to contaminate or re-oil adjacent resources or clean sections of shore must be determined. If there is a threat to adjacent resources or areas, this may preclude natural recovery as an option.

5.7.2 Physical Techniques - Washing

The objective of washing is to remove oil from the shore using water and to recover the oil for disposal. Each washing or flushing technique requires a number of separate operational steps that usually include washing, containment and recovery or collection of displaced oil for disposal.

These techniques involve washing the oil:

1. onto the adjacent water where it can be contained by booms and collected by skimmers
2. toward a collection area, such as a lined sump or trench, for removal by a vacuum system or skimmer

The washing or steam cleaning techniques (3) through (7) are sometimes referred to as spot washing when applied to small sections of shoreline.

The variables that distinguish one particular washing technique from another are pressure and temperature (Table 5 - 10). Generally, the equipment used for these techniques is not manufactured specifically for spill response but is available commercially for other purposes.

Table 5 - 10   Summary of washing technique ranges

Technique	Pressure Range		Temperature Range (°C)
	psi	bars	
(2) **flooding (deluge)**	<20	<1.5	ambient water
(3) **low-pressure, cold wash**	<50	<3	ambient water
(4) **low-pressure, warm/hot wash**	<50	<3	30 - 100
(5) **high-pressure, cold wash**	50-1000	4 - 70	ambient water
(5) **pressure washing**	>1000	>70	ambient water
(6) **high-pressure, warm/hot**	50-1000	4 - 70	30 - 100
(7) **steam cleaning**	50-1000	4 - 70	200
(8) **sandblasting**	~ 50	~ 4	n/a

The seven basic techniques in this group are summarized in Table 5 - 11 in terms of the objective of each technique, the preferred or recommended application and relevant shoreline types and oil characteristics.

Table 5 - 11   Summary of washing techniques applications

Technique	Objective	Optimum Use
2 **flooding**	flood a site so that mobile or remobilized oil is lifted and carried downslope to a collection area	• most shoreline types • light to medium oils
3 **low-pressure, cold-water wash**	wash or flush oils toward a collection area using normal temperature sea, lake or river water at low pressure	• impermeable shorelines and marshes • light to medium oils
4 **low-pressure, warm or hot-water wash**	wash and flush oils at low pressure, using heated water, toward a collection area	• impermeable shorelines • light to medium oils
5 **high-pressure, cold-water wash**	wash or flush oils toward a collection area using normal temperature sea, lake or river water at high pressure	• impermeable shorelines • medium to heavy oils
6 **high-pressure, warm or hot-water wash**	wash and flush oils at high pressure, using heated water, toward a collection area	• impermeable shorelines • medium to heavy oils
7 **steam cleaning**	remove stains or dislodge thin layers of viscous oil from hard surfaces	• impermeable man-made structures • stains or heavy, weathered oils
8 **sand blasting**	remove stains or dislodge thin layers of viscous oil from hard surfaces	• impermeable man-made structures • stains or heavy, weathered oils

In flooding (2), water can be pumped onto the shoreline:

- directly from a hose without the use of a nozzle
- through a pipe or hose (header) perforated (0.25 to 0.5 cm holes) at intervals and placed along the upper shoreline parallel to the water line

Usually, the header hose is placed on the beach above the oiled area (Figure 5 - 32). Flooding (2) and low-pressure washing techniques (3) (4) generally are not intrusive in terms of ecological effects, as most organisms are left in place. This method frequently is appropriate for oiled marshes or vegetated shores (Table 5 - 9).

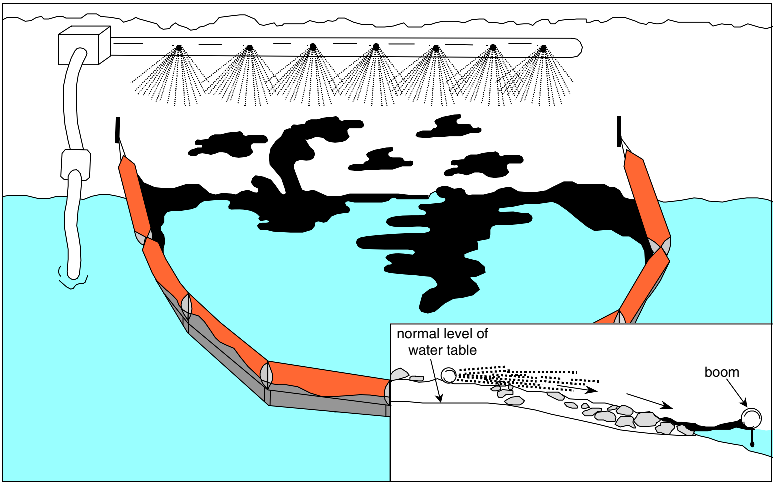

Figure 5 - 32   Flooding technique

Inset shows how the water table in the beach is raised to the surface so that the oil then washes downslope on the surface to the water line.

Low-pressure, cold-water washing (3) can be practical and effective on most impermeable shoreline types and on some permeable shores (beaches) or marshes. Effectiveness decreases as oil viscosity increases and as depth of oil penetration increases on cobble or boulder beaches. Washing techniques have limited application on sand beaches or mixed-sediment beaches and probably are not appropriate on sand or mud flats. Washing techniques can be used in conjunction with flooding to prevent oil from being redeposited downslope.

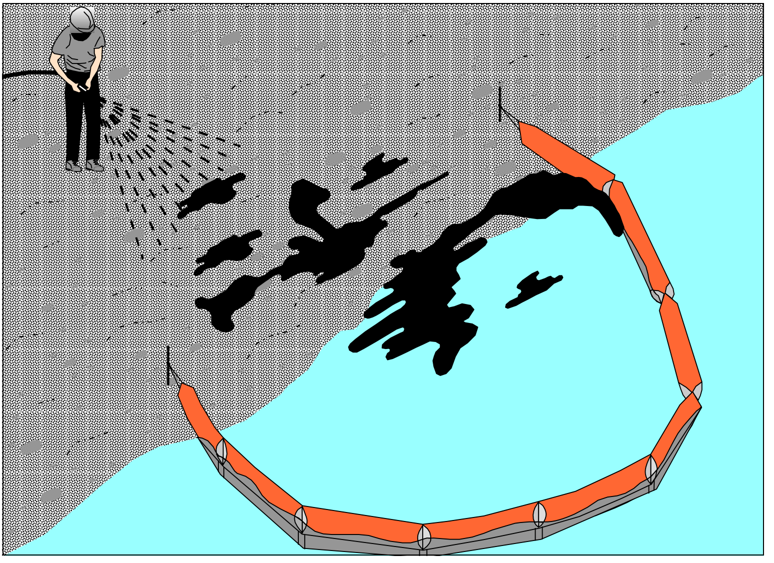

Figure 5 - 33   Low-pressure washing

Constraints/Limitations

Washing oil and/or sediments downslope into the lower intertidal zones that have attached plant or animal communities should be avoided, particularly if the flora or fauna were not initially oiled. On ocean shores, such impacts 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.

The mobilized or flushed oil and oiled sediment should be contained and collected for disposal (Figures 5 - 32 and 5 - 33). Otherwise, the technique only disperses the oil and does not clean the shoreline. On marine coasts, only sea water should be used since fresh water can harm intertidal plants and animals.

High-pressure (5) (6) water can dislodge or may damage attached healthy organisms. High-pressure action could emulsify the oil, if emulsification has not occurred already. Very high-pressure washing, steam cleaning (7) and sand blasting (8) are very intrusive in terms of ecological effects and may remove all organisms, leaving a clean and pristine but barren surface.

5.7.3 Physical Techniques - Removal

The objective of this group of physical techniques or tools is to remove the oil or oiled materials (sediments, debris and vegetation) from the shore zone for disposal.

9	**manual removal**
10	**vacuum systems**
11	**mechanical removal**
12	**vegetation cutting**
13	**passive sorbents**

With the exception of sorbent materials and several beach cleaners, all of the equipment necessary to implement these techniques is used for non-spill-related activities and is available commercially. Mechanical techniques essentially use equipment designed for earth-moving or construction projects, although a few commercial devices have been fabricated specifically for spill cleanup applications. Most sorbents referred to in this section are manufactured specifically for use on oil spills.

In selecting the appropriate technique, important factors to be considered include the size of the area, the type and amount of oil, access and the shoreline type. Efficiency and cost also may be 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 multiple-step transfer systems, such as a grader that side casts material for collection by a front-end loader or an elevating scraper.

The five basic techniques in this group are summarized in Table 5 - 12 in terms of the objective of each technique, the preferred or recommended application and the relevant shoreline types and oil character.

Table 5 - 12   Summary of physical removal techniques

Technique	Objective	Optimum Use
9 **manual removal**	remove oil or oiled materials (including oiled sediments) with manual labour and hand tools	• any shoreline type • small amounts of surface oil
10 **vacuum systems**	remove oil by suction from areas where it has pooled or collected in sumps	• light to medium, non-volatile, pooled or collected oil
11 **mechanical removal**	remove oil and oiled materials using mechanical equipment	• most fine to coarse-sediment beaches • large volumes of medium, heavy or solid oil
12 **vegetation cutting**	remove oiled stems to prevent remobilization of the oil or contact by animals and birds, or to accelerate the recovery of the plants	• marshes, vegetated shorelines • where remobilization of oil will affect other resources
13 **passive sorbents**	place sorbents in a fixed location(s) so that they pick up oil by contact	• any shoreline type • light to heavy, non-solid, non-volatile oils

Table 5 - 13 identifies the relative resource requirements, cleanup rates and amounts of waste generated by the different removal techniques, and indicates whether they are a single or multiple-step transfer system.

Table 5 - 13 Summary of efficiency factors for physical removal techniques

Technique or Device	Resource Requirements	Relative Cleanup Rate	Single or Multiple-Step	Waste Generation
9 **manual removal**	labour-intensive	slow	multiple	minimal
10 **vacuum systems**	labour-intensive	slow	multiple	moderate
11 **grader/ scraper**	minimal labour support	very rapid	single/multiple	moderate
11 **front-end loader**	minimal labour support	rapid	single	high
11 **bulldozer**	minimal labour support	rapid	multiple	very high
11 **backhoe**	minimal labour support	medium	single	high
11 **dragline/ clamshell**	minimal labour support	medium	single	high
11 **beach cleaners**	minimal labour support	slow-medium	varied	low
12 **vegetation cutting**	labour-intensive	slow	multiple	can be high
13 **passive sorbents**	labour intensive if used extensively with large amounts of oil	slow	multiple	can be high if frequent change-outs required

Manual removal 9 involves cleanup teams picking up oil, oiled sediments or oily debris with gloved hands, rakes, forks, trowels, shovels, sorbent materials or buckets (Figure 5 - 34). This technique is most applicable for:

- small amounts of viscous oil, e.g., asphalt pavement
- surface or near-surface oil
- areas either inaccessible to vehicles or in which vehicles cannot operate

Manual removal may include scraping or wiping with sorbent materials, or sieving if the oil has come ashore as tar balls. Workers wear personal protective equipment that includes splash suits or rain gear, boots and gloves.

Oiled materials can be 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 what can be carried by one person easily and safely. To avoid spillage, containers should not be overfilled or dragged.

Manual removal is labour intensive and slow for large oiled areas. This method is significantly slower than mechanical removal but generates less waste (Table 5 - 13), and the waste materials (tar balls, oiled sediment, oiled debris, etc.) can be segregated easily during cleanup.

The use of square shovels is more efficient for sand beaches, whereas pointed shovels work better on mixed-sediment or pebble/cobble beaches.

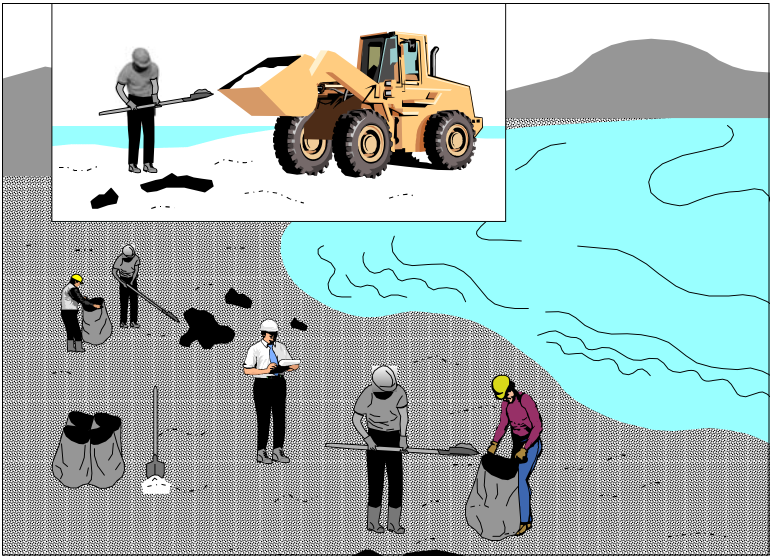

Figure 5 - 34   Manual removal; inset illustrates shoveling oiled material directly into front-end loader to reduce a transfer step

Vacuum systems (10) are used primarily where oil is pooled in natural depressions and hollows, or where it has been herded into collection areas such as lined pits or trenches (sumps) (Figure 5 - 35). This technique can be used in combination with flooding (3) or washing techniques to float and collect oil. A dual-head wash and vacuum system can be used in locations that are difficult to access, such as between boulders.

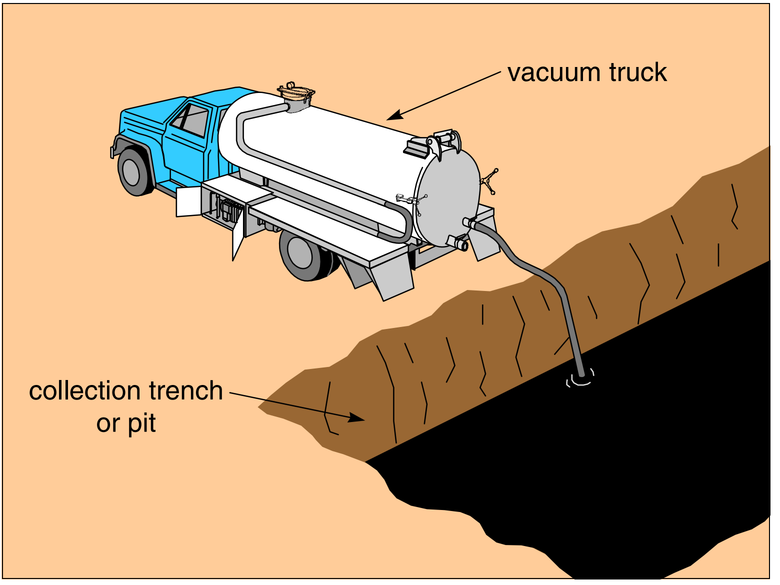

Figure 5 - 35   Vacuum pump removing oil from a collection trench or sump

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Mechanical removal 11 can involve a range of devices to remove oil and oiled surface and subsurface materials from shorelines. Mechanical removal is more rapid than manual removal but generates larger quantities of waste. The method of operation varies considerably depending on the type of equipment that is available (Tables 5 - 14 and 5 - 15) and its ability to operate on a particular section of shore. The efficiency of each type of equipment, in terms of the rate of cleaning that can be achieved and the amount of waste that is generated, is shown in Table 5 - 13.

Some equipment, e.g., elevating scrapers, loaders, backhoes or vacuum trucks, can remove and transfer material directly to a truck or temporary storage area in a single step (Figures 5 - 36, 5 - 37 and 5 - 38). Other equipment (graders and bulldozers) are less efficient and require two steps or more to move or side cast material that must then be picked up by other types of equipment (scrapers, loaders or backhoes) for transfer (Figures 5 - 39 and 5 - 40).

Table 5 - 14 Typical earth-moving equipment

Device	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 can be used to remove 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 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 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 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

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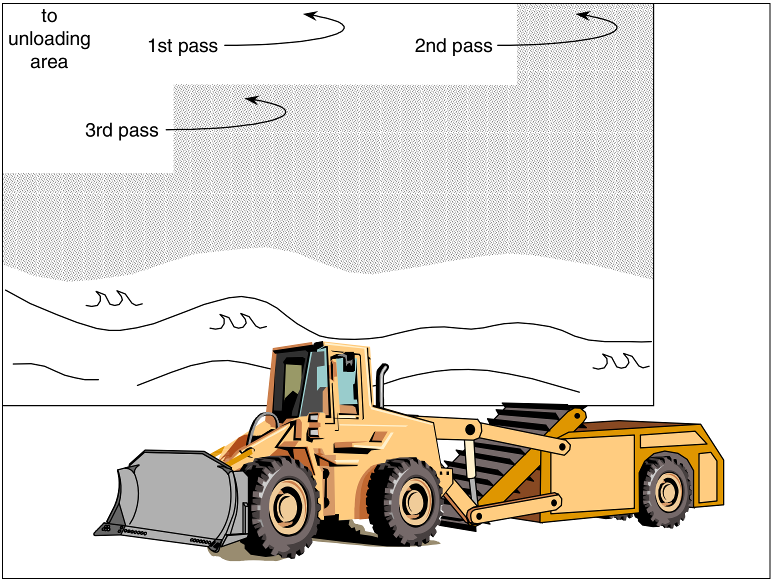

Figure 5 - 36 Direct mechanical removal with elevating scraper

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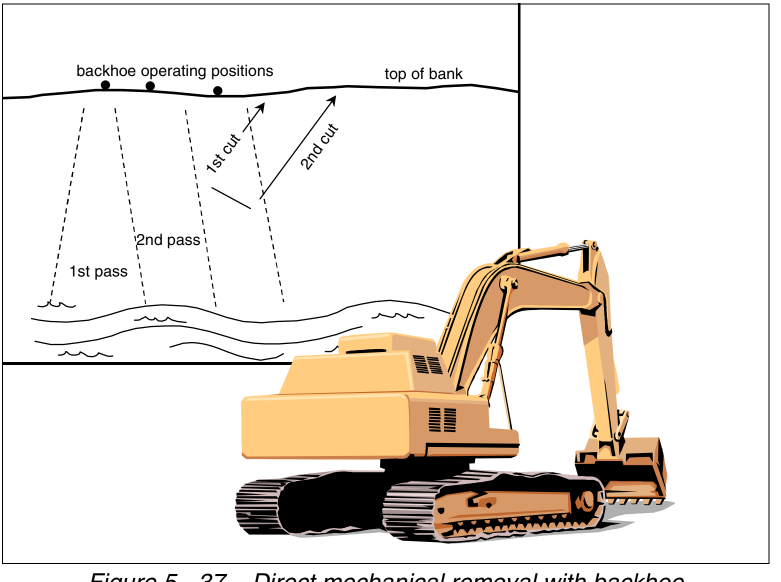

Figure 5 - 37 Direct mechanical removal with backhoe

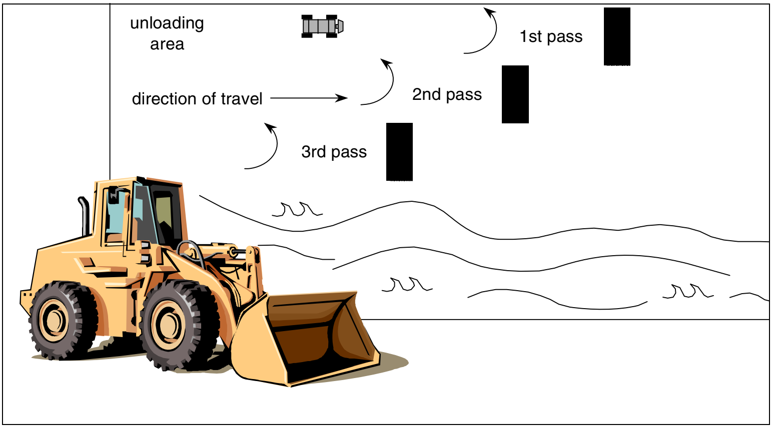

Figure 5 - 38   Direct mechanical removal with front-end loader

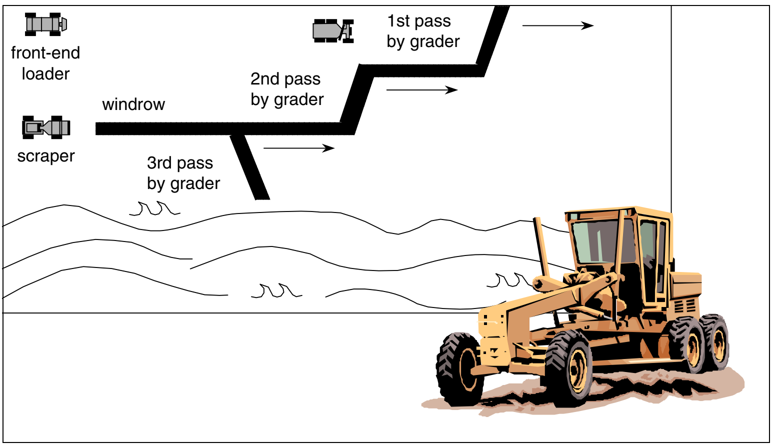

Figure 5 - 39   Two-stage removal with grader supported by loader and/or scraper

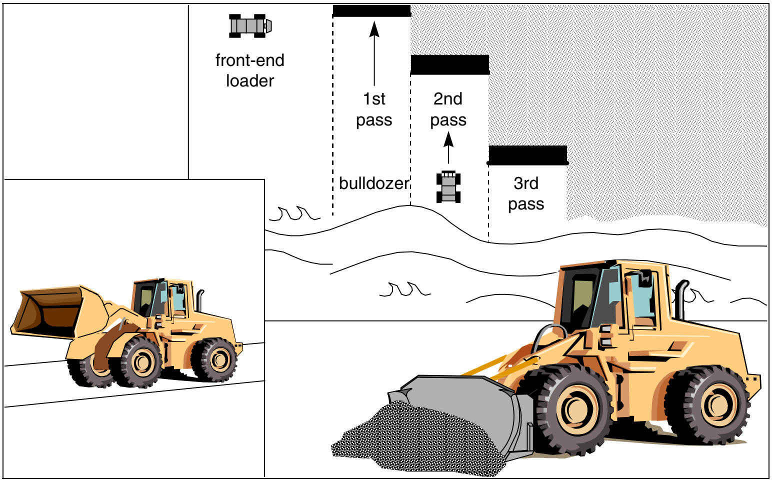

Figure 5 - 40 Two-stage removal with bulldozer supported by front-end loader

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Mechanical removal can be used on all but bedrock or solid man-made shoreline types. The bearing capacity of the sediments and the slope of the shore zone, as well as the performance characteristics of the individual equipment, govern the applicability of different types of machines.

Each type of commercially-available, earth-moving equipment has different operational requirements and different applications (Table 5 - 14). The most important variable is the bearing capacity, which controls the ability of a piece of equipment to travel on a shore type without becoming immobilized. Mechanical equipment has limited applicability on sand or mud flats due to poor bearing capacity. Traction for wheeled equipment on soft sediments (low bearing capacity) can be improved by reducing tire pressures. Tracked equipment may be able to operate where wheeled vehicles cannot, but is not a preferred option, as tracks disturb sediments to a much greater degree than tires.

- Scrapers and graders can operate only on hard and relatively flat surfaces and are capable of moving only a thin cut (approximately 10 cm) of surface material.
- Loaders, bulldozers and backhoes can operate in a wider range of conditions and are designed to dig and move large volumes of material.

- Backhoes, draglines and clamshells use an extending arm or crane so that they may be operated from a barge or a backshore area and can reach to pick up material.

- Beach cleaning machines operate in a number of different ways (Table 5 - 15). Mobile equipment operates on a beach, e.g., Figure 5 - 41, whereas other equipment operates off-site (adjacent) to treat oiled sediment so that cleaned material may be replaced on the beach.

- Vacuum trucks remove pooled oil or oil collected in lined sumps.

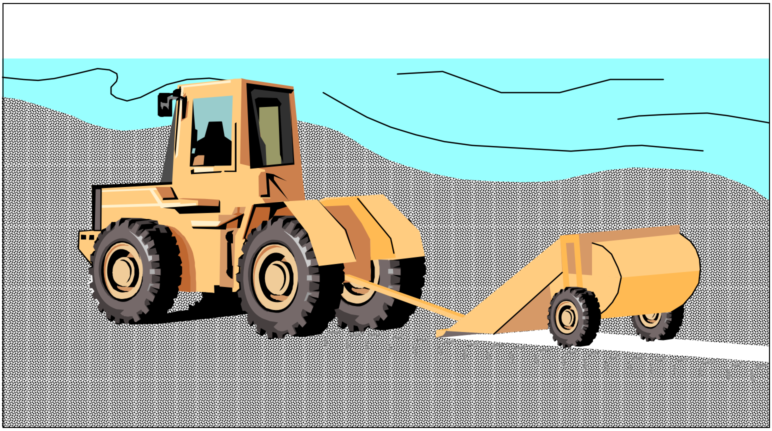


Figure 5 - 41   Mobile beach cleaning machine (after ITOPF, 1975)

Direct removal can only be carried out by elevating scrapers, front-end loaders, backhoes, draglines, clamshells or vacuum trucks. Graders and bulldozers move material that then is removed by other types of machines.

In almost all instances, test runs or trials with experienced operators will determine the exact application of particular types of machines. The applicability of one type of machine may vary locally due to changes in sediment type and beach slope, both across shore, i.e., between the upper intertidal zone and the supra-tidal zone, as well as along the shore.

Table 5 - 15   Beach cleaning machines

Device	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 vacuum units	vacuum systems that have 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 low throughput
off-site sorters	oiled materials are removed from the beach, sorted or sieved, and the clean material is replaced; oily wastes are disposed	can handle most sizes of sediments but only weathered oil types; usually low through-put
off-site washers or treaters	oiled materials are removed from the beach, treated, and the treated materials are replaced or disposed	can handle most sizes of sediments and oil types; usually low throughput

The graphics presented in Figures 5 - 36 to 5 - 41 are intended as a guide. Operators usually can provide suggestions or improvisations to meet the cleanup objectives for a particular section of beach.

Vegetation cutting 12 is a labour-intensive technique used in marshes or on attached plants, such as seaweed. It is applicable only where the continued presence of oil may pose a contact threat to animals and birds that use the area, or where mobile oil or oiled plants could be released to impact adjacent healthy organisms. If oiled stems are cut, avoid disturbance of the root systems as this will delay recovery of the plants.

Sorbent materials are placed in the shore zone to collect oil as slicks come ashore (protection mode) or in the oiled area after slicks have been stranded (cleanup mode). Commercially available sorbents can be supplied as pads, rugs, blankets, rolls, sweeps, pillows or booms. Locally available materials may be appropriate on occasion, e.g., straw or peat, but usually such natural products are less effective and efficient than commercial sorbents.

The sorbent booms or sweeps usually are deployed in a fixed position using stakes and/or anchors. They can be deployed in a line or in parallel lines to form a floating barrier that moves with the tide at the water's edge. Alternatively, individual sorbents may 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 approach is not always feasible, depending on whether the sorbent supply is limited and whether the spill location is remote.

Constraints/Limitations for Physical Removal

Foot traffic and vehicles can have adverse impacts by breaking or crushing vegetation, or by trampling and pushing oil into subsurface sediments. When large numbers of personnel are required to meet the cleanup objectives, excessive foot traffic can impact vegetated areas such as backshore dunes, or can disturb adjacent resources such as nesting birds.

Care should be exercised, since oiled or wet bedrock and pebbles/cobbles can be very slippery, leading to trips, slips and falls. For safety reasons, vacuum systems are not applicable for volatile oils; nor are they applicable for oils that cannot be pumped.

Sorbents can quickly reach their pickup capacity when in contact with large amounts of oil. Frequent replacement is necessary, even for relatively small amounts of oil. This is a labour-intensive activity that can generate large amounts of waste on a daily basis.

5.7.4 Physical Techniques - In-situ Treatment

The objective of this group of physical, on-site treatment techniques is to alter the character of the oil or change the location of the oil with respect to the intertidal zone to promote or increase weathering and natural degradation.

14	**mixing**
15	**sediment relocation**
16	**burning**

5

A key feature of this group of techniques is that essentially no oiled materials that require transfer and disposal are generated or recovered.

Dispersants, nutrient enhancement or bioremediation are separate forms of in-situ treatment that are discussed under the category of Chemical/Biological Response Techniques (Section 5.7.5).

The three basic techniques in this group are summarized in Table 5 - 16 with respect to the objective of the techniques and the preferred or recommended application, and in terms of shoreline types and oil character.

Table 5 - 16   Summary of physical in-situ techniques

Technique	Objective	Optimum Use
14 **mixing**	expose or breakup surface and/or sub-surface oil to accelerate evaporation and other natural degradation processes	• sand or coarse-sediment beaches • small amounts, medium to heavy oils • buried oil
15 **sediment relocation**	accelerate natural degradation by moving oil and oiled materials to areas with higher levels of physical (wave) energy	• sand or coarse-sediment beaches • exposed shorelines • buried oil stranded above the normal limit of wave action
16 **burning**	remove or reduce the amount of oil by burning it on site	• logs, debris • large amounts of oil

Evaluation of the appropriateness of in-situ treatment involves consideration of the consequences of not removing the oil. In particular, an assessment should be made of the anticipated change in oil weathering or natural removal rates that will be brought about by the treatment.

The advantages of mixing and sediment relocation are that no material is removed from the beach, and standard agriculture or earth-moving equipment can be used. The technique can be used for the underwater agitation of oiled sediments in shallow areas. The oil that is freed can be contained by booms and recovered using skimmers or sorbents.

In mixing 14, the oiled surface or subsurface sediments are excavated, exposed or mixed in place without being moved to another part of the beach. This technique is also known as “tilling” or “aeration”.

In sediment relocation [15], earth-moving equipment is used to move oil or oiled sediments from the surface or subsurface areas, where there is protection from natural physical abrasion and weathering processes, to locations such as the active intertidal zone where these processes are more active. Equipment such as farm-type machinery, e.g., disc systems, harrows, ploughs, rakes or tines, can be used to rework and expose subsurface oiled sediments. Earth-moving equipment, such as front-end loaders, graders or bulldozers, can be used to move oiled material to another location. These techniques are also called “surf washing”.

Mixing and sediment relocation are particularly useful:

- where oiled sediments are located above the limit of normal wave action, i.e., if a beach were oiled during a storm surge or a period of higher tide levels

- where oil or oiled sediments have been buried or oil has penetrated to a level below the normal or seasonal wave-active zone

- for polishing where other cleanup or treatment activities have removed most of the oil or oiled sediment and only light oiling, i.e., stains, remain

- immediately prior to expected storm events or periods of high wave-energy levels

Burning [16] can be used if oil is pooled or has been concentrated in sumps, trenches or other types of containers. Oil on a beach usually will not sustain combustion by itself. This technique is used primarily where combustible materials, such as logs or debris, have been oiled and can be collected and burned. Burning can also be used where vegetation, such as that found in a wetland, has been heavily oiled.

Constraints/Limitations

The objective of mixing and sediment relocation is to expose the oil to degradation. Burying the oil must be avoided as it would delay physical breakdown or weathering. These techniques may affect biological populations and are not appropriate if large amounts of oil might be released that could 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 biological communities in the lower intertidal zone.

Burning of heavily oiled marsh vegetation when soils are dry can have a major impact on the ecosystem, as the root systems can be destroyed. Wet soils protect the root systems from heat damage so that recovery from burning is more rapid.

Generation of smoke may be an undesirable side effect, although a smoke plume is not a health or safety issue provided that standard precautions are observed. Burning generally will require a permit from local authorities, especially if carried out on a large scale.

5.7.5 Chemical/Biological Response Techniques

The objective of this group of techniques is to alter the oil to enhance collection or to accelerate natural weathering processes. This group of methods includes:

17	**dispersants**
18	**shoreline cleaners**
19	**solidifiers and visco-elastic agents**
20	**nutrient enrichment/bioremediation**

5

Nutrient enrichment and bioremediation use products developed for other, non-spill related, applications. All of the other techniques involve commercially-available agents or materials designed specifically for oil spill response.

The four basic techniques in this group are summarized in Table 5 - 17 according to the objective of the techniques, the preferred or recommended application and shoreline types and oil characteristics.

Only dispersant application and bioremediation are stand-alone techniques. Other methods require an additional removal component.

The use of chemicals often is controlled by governments and appropriate approval and/or permission usually is required.

Selection of treatment agents involves an evaluation of the trade-offs associated with:

1. addition of another substance that could have side effects on the ecosystem
2. moving oil from the shore into the water column

Table 5 - 17 Summary of chemical and biological techniques

Technique	Objective	Optimum Use
17 **dispersants**	create fine oil droplets that are dispersed into the adjacent waters where they then are naturally weathered and degraded	• light to medium, fresh oils
18 **shoreline cleaners**	remove and recover oil using a cleansing agent that lifts the oil from the substrate	• coarse-sediment beaches • non-solid oils • as a pretreatment with collection methods
19 **solidifiers and visco-elastic agents**	alter the viscosity of oil to enhance recovery and collection.	• sand or mixed-sediment beaches • medium oils
20 **nutrient enrichment/ bioremediation**	accelerate natural biodegradation processes by the addition of nutrients (fertilizers containing nitrogen and phosphorus)	• all shorelines • small amounts of residual oil

Dispersants [17] or shoreline cleaners [18] can be applied directly to an oiled area and left to work, or can be used as a pre-soak prior to flooding or washing. In some cases, effectiveness is a function of mixing, and the agent and oil may have to be mixed if mixing is not accomplished by wave action.

Dispersants are most effective with low viscosity and fresh oils. They are less effective on medium crude and high-viscosity oils.

Some shoreline cleaners are used in conjunction with 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. They are more effective on medium to heavy oils and least appropriate for light oils (Figure 5 - 42).

Solidifying agents [19] are also known as elastomizers, gelling agents or spill recovery enhancers. Solidifiers alter the oil from a liquid to a solid to make recovery easier or to prevent remobilization or spreading of the oil. The visco-elastic agents or elasticity modifiers alter the elasticity of oil. Solidifiers and visco-elastic agents are not applicable on beach sediments with large pore spaces (cobble or boulder), as oil may penetrate into the subsurface sediments and become difficult to remove. Solidifiers and visco-elastic agents are more appropriate for light and medium oils (Figure 5 - 42). The effectiveness or applicability of solidifiers and visco-elastic agents in cold climates has not been tested. If these techniques are considered to be potentially appropriate, small-scale field tests can assess the feasibility and practicality of these agents.

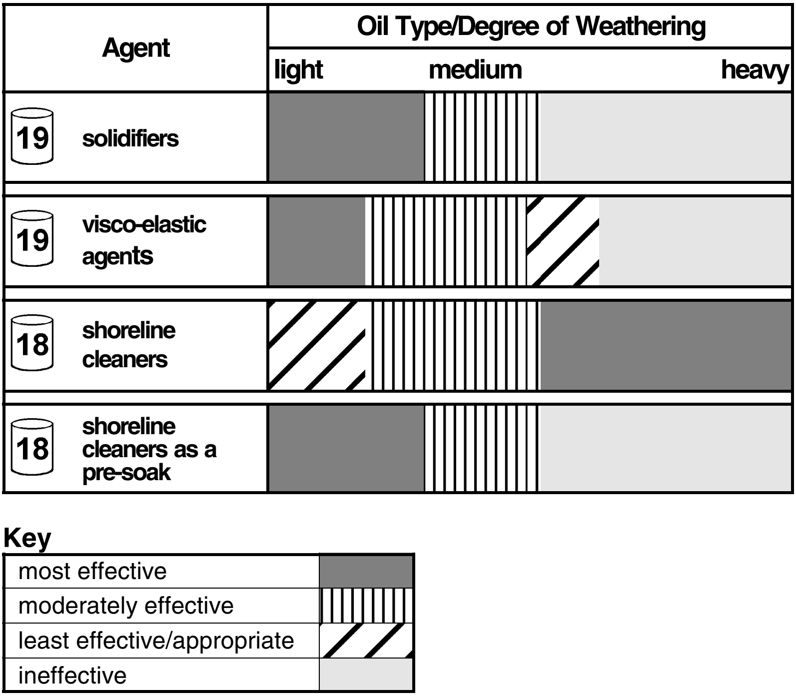


Figure 5 - 42 *Potential application of treatment agent by oil type (after Walker, et al., 1993)*

Bioremediation 20 usually involves naturally-occurring micro-organisms (bacteria) that use oxygen to convert hydrocarbons into water and carbon dioxide. This process usually occurs at the oil/water interface and is limited by oxygen, nutrient availability and by the exposed surface area of the oil. If these three factors can be increased, then the rate of biodegradation can be accelerated.

Fertilizers can be obtained in solid or liquid form. Solid fertilizers, such as pellets, can be broadcast using seed spreaders that are commonly used on lawns or fields. On contact with water, the fertilizer slowly dissolves and releases water-soluble nutrients over time. Liquid fertilizers can be sprayed onto a shoreline using various commercially-available types of equipment, such as paint sprayers or back packs.

This technique is applicable for use where there is light oiling or on residual oil (polishing) after other techniques have been used to remove mobile or bulk oil from the shoreline.

Applications may be repeated periodically (weeks or months as appropriate) to continue the supply of nutrients.

Fertilizers may be used alone on a shore to degrade residual surface and/or subsurface oil, but the process is more effective if combined with mixing or other methods of breaking the oil into smaller particles. This mixing action significantly increases the surface area available to the micro-organisms.

Constraints/Limitations

Various agents and brands of chemicals have been developed for different environmental conditions. Some have been formulated for freshwater, for colder temperatures or for high-viscosity, emulsified or weathered oils.

Detergents and dispersants function by using opposite mechanisms so that, generally, a good detergent (surface washing agent) is a poor dispersant and a good dispersant is a poor detergent. Once a dispersant has been applied, oil will not stick to the substrate, sorbents or certain types of skimmer surfaces, e.g., discs. However, some shoreline cleaners can be used together with mechanical recovery.

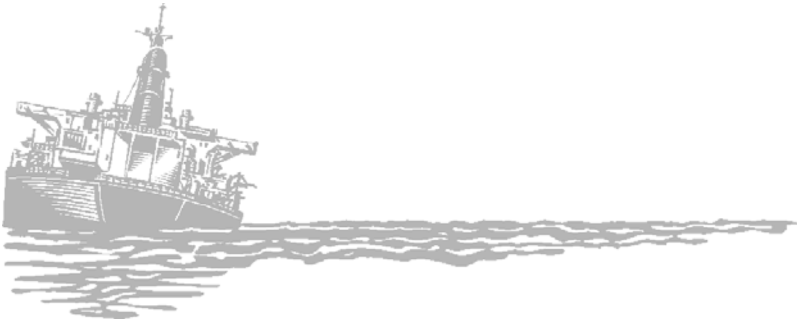
The effectiveness of the solidifying or visco-elastic agent is a function of the cure time and the contact area. Unless mixed correctly, the application can produce a conglomeration of solid, liquid and semi-solid oil. Effectiveness also decreases for emulsified, weathered, thick or heavy oil, due to the difficulty associated with mixing the agent and the oil. These techniques also are not applicable where there is oiled vegetation, as the solidified oil may incorporate or smother healthy plants and animals.

Bioremediation is an effective but relatively slow process compared to other response options. The rate of biodegradation decreases with lower temperatures so that nutrient enrichment is more effective during warmer summer months.

Part B

Technical Support Information

6 Spill Behaviour and Tracking



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6.1 Weathering and Behaviour of Spilled Oil

In order to devise practical response strategies, it is important to understand the behaviour and fate of oil on water or in ice and the residence time of oil that is stranded on a shore.

Weathering is the combination of physical and chemical processes that change the properties of the oil after a spill has occurred and the oil has been exposed to environmental degradation (Figure 6 - 1).

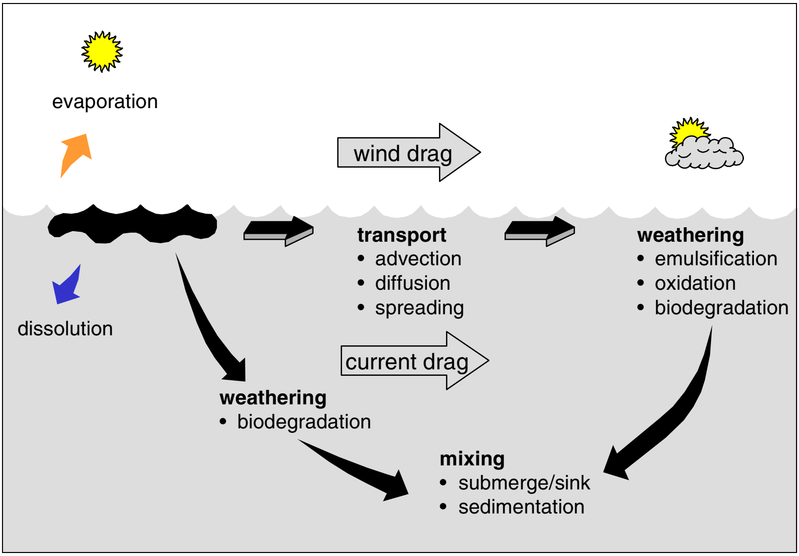

Figure 6 - 1 Oil weathering

Natural processes that occur initially and that are important for response operations are:

- dispersion
- emulsification
- evaporation
- spreading
- sinking or sedimentation

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Processes that are predominant in the later stages of weathering, and that usually determine the ultimate fate of the spilled oil, include:

- biodegradation
- oxidation

The rate of weathering depends on:

- oil type (physical properties, such as viscosity and pour point; chemical properties, such as wax content)
- the amount of spilled oil
- the proportion of the surface area of the oil that is exposed
- wave, current, ice and weather (temperature and wind) conditions
- the location of the oil (on the water surface or submerged; on, in, or under ice; on a shoreline or buried in shore sediments)

Non-persistent oils, such as gasoline, aviation fuel and diesel, usually weather rapidly, provided that they are exposed to the air, i.e., they are not buried or covered. These refined oils contain only light fractions and weather primarily through evaporation. The evaporation rates increase as the temperature rises and as wind speed increases. In calm conditions, between 5% and 20% of diesel fuel will evaporate in 2 days on warm water (0° to 5°C) and in 4 or 5 days on very cold water (-20° to 0°C).

Persistent oils weather and break down more slowly. If emulsification occurs, an increase in the volume of the oil results as water and oil mix. The physical properties of the oil also change, which in turn can affect the choice of response options that will be successful, i.e., skimming, in-situ burning and dispersion.

6.1.1 Oil on Water

The behaviour of oil on water and in ice depends on the relative densities of the oil and the water. Oil that is less dense than water will float on the surface and is subject to weathering. Oil that is more dense than water will submerge and is subject only to dissolution, which is usually a minor weathering process. Submerged oil will degrade slowly. Floating oil with almost the same density as sea water may submerge if the oil meets less dense, freshwater.

6.1.2 Oil in Ice

Buoyant oil under ice will migrate to the underside of a floating ice sheet, which typically has an uneven surface. A current of 0.4 m/s is usually required to move oil along the underside of the ice. Oil will tend to migrate to pockets on the underside (see ❶ below) unless lateral movement is stopped by ice ridges or keels ❷.

Ice forms by freezing at the ice-water interface. Oil at that interface can become frozen into the ice sheet. As the ice melts on the upper surface and continues to form on the underside, oil will move up through the ice sheet ❸ and eventually appear on the upper surface. The primary mechanism by which oil migrates upwards is through brine channels or cracks in the ice ❹.

If the oil finds a break in the ice sheet, such as a lead or a seal hole, it will flow into the open water ❺ and may spill over onto the surface of the ice. Oil in broken ice will tend to collect in leads, unless lateral movement is prevented on the underside of an ice floe. During freeze-up, new ice can form on the underside of a slick.

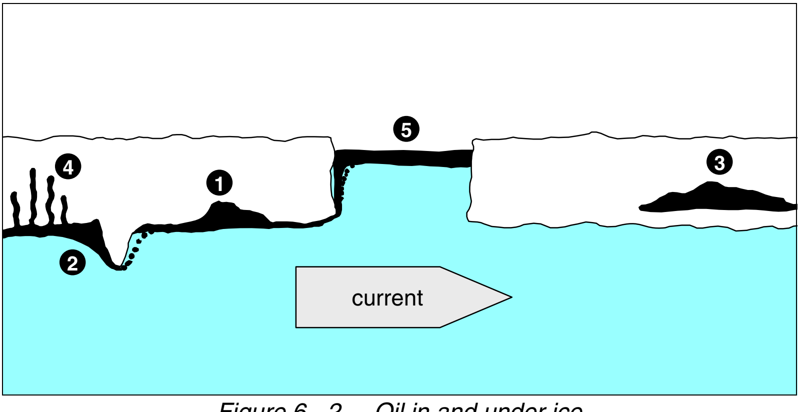

Figure 6 - 2 Oil in and under ice

6.1.3 Stranded Oil

On a shore, the penetration of oil into sediments is a function of the size of the shore materials and the oil viscosity. Only light oils, such as gasoline and diesel, can penetrate sands, whereas all but the most viscous oils can easily penetrate a pebble/cobble shore. Oil on the surface of a shore is subject to weathering and the physical action of winds and waves, whereas oil that has penetrated the sediments or that has been buried is largely protected from most weathering processes and will degrade slowly, taking decades in some cases.

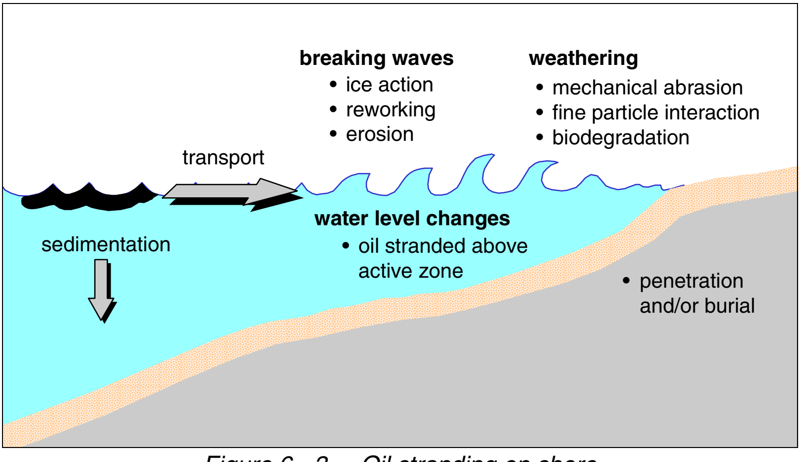

Figure 6 - 3 Oil stranding on shore

Oil that is stranded on beaches can be reworked and the oil-sediment mixture refloated. If the oil-sediment mixture is more dense than the water, it will be deposited in the nearshore zone.

In cold temperature conditions, the oil may be frozen within ice as an ice foot forms, or it may be splashed onto the ice surface.

6.2 The Movement of Spilled Oil

Oil on water spreads and disperses, in part, due to the effects of winds and currents. Because water is denser than air, the surface water currents have a much greater drag effect on the transport and spreading of the oil. Oil will move at the same speed as the surface water current and at about 3% or 1/30 of the surface wind speed. If the wind and current are moving in the same direction, then there is an additive effect. If the current and wind are moving in different directions, then the net effect is a combination of the two forces (Figure 6 - 4).

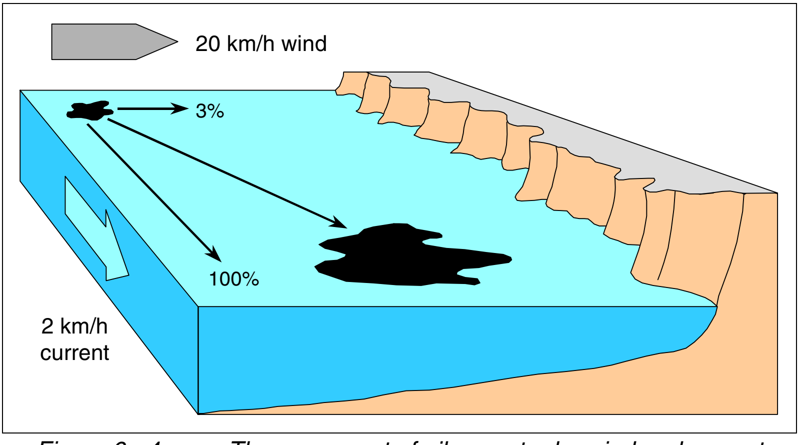

Figure 6 - 4 The movement of oil on water by wind and current (adapted from ITOPF, 1987)

In a river in which the water flow is always in one direction, surface transport is a relatively straightforward process. The effect of the current is to move the oil downstream; the wind acts to push the oil toward one of the banks. However, in some coastal rivers, tidal influences can cause “upriver” currents during the flood stage; these currents must be addressed when planning spill response operations. Although the general direction of river flow is downstream, current patterns usually vary within the channel so that oil may be carried more quickly or more slowly in different sections and may collect in low-flow areas.

Transport is generally more complex on open-water seas or lakes. Currents usually vary from one location to another, even over small geographic areas. At sea, currents may also vary at any one location due to tidal changes.

Oil in broken ice will move at the same speed as the drifting ice. Wind effects are greater on ice than on oil alone, with the result that oil in drifting ice usually moves faster than on open water for the same wind conditions.

Ice jams form in many northern rivers during breakup. This results in overbank flooding and under these conditions, spilled oil could be spread over what are normally land environments.

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6.3 Detection, Surveillance and Tracking

The purpose of surveillance is to locate slicks and determine their direction of movement. For oil on the surface in open water, tracking slicks can be carried out by a variety of methods that include:

- optical: visual observations, still or video camera
- optical: infrared camera or IR/UV system
- laser fluorosensor
- microwave radiometer or radar
- satellite images

Surveillance and tracking operations involve systematic flight patterns to ensure that all possible areas are searched in a complete and repeatable manner. These methods do not work for oil in or on ice. Low light-level video cameras or laser-fluorosensors may provide useful data for these conditions.

Visual observations and the interpretation of optical or remote sensing data require special knowledge and are best left to experienced responders. The identification of oil in broken ice is usually simple from aircraft because of the strong colour contrast.

Detection and tracking are very difficult, and often impossible, if the oil is more dense than the water, i.e., submerged below the surface.

Similarly, detection and tracking of oil under ice is difficult and may require the use of divers or remotely-operated underwater vehicles (ROVs) with cameras.

Oil on water or in ice can be described and recorded with reference to a standard set of terms (in part after Allen and Dale, 1997).

oiled area (km^2)	<0.1 0.1-1.0 1-10 10-100 100-1000 >1000
percent cover	ratio of oil-covered water to unoiled water in that area, expressed as a percent
oil thickness	(see Table 6 - 1)
slick character	tar balls - patchy - windrows - continuous

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Table 6 - 1 Slick thickness and approximate volume (adapted from ITOPF, 1987)

Oil Appearance	Approximate Thickness (mm)	Approximate Volume (m^3/km^2)
silver/gray	0.0001	0.1
rainbow	0.0003	0.3
black - dark brown - orange “mousse”	greater than 0.1	more than 100

In describing the spilled oil on open seas, rivers or lakes, or in broken ice, it usually is necessary to divide the area into different slicks and to describe each slick area separately.

6.4 Trajectory Analysis

The purpose of trajectory analysis is to estimate the spill path for the development of control and protection strategies. On open water at sea, a simple analysis of the speed and direction of the wind and current may be all that is required for an estimate of the movement of oil on open water (Figure 6 - 4). Trajectory models can provide more sophisticated estimates if suitable wind and current data are available.

Spill trajectories usually are easier to estimate in lakes since currents generally are not a significant factor. Wind speed and direction are the prevailing factors influencing slick movement in these situations.

In a river, currents are the primary force influencing slick movement and usually (except as noted) move downstream. Wind is the primary factor that determines the side of the river to which oil moves. Maximum surface current data are used to estimate the time of arrival of the leading edge of a slick at downstream control points. Rivers in Arctic regions have a distinct seasonal character (Figure 6 - 5) with lower ❶ flow conditions during winter months, a sharp rise and higher ❷ flows during spring melt and breakup, and a gradual lowering ❸ of discharge during summer months.

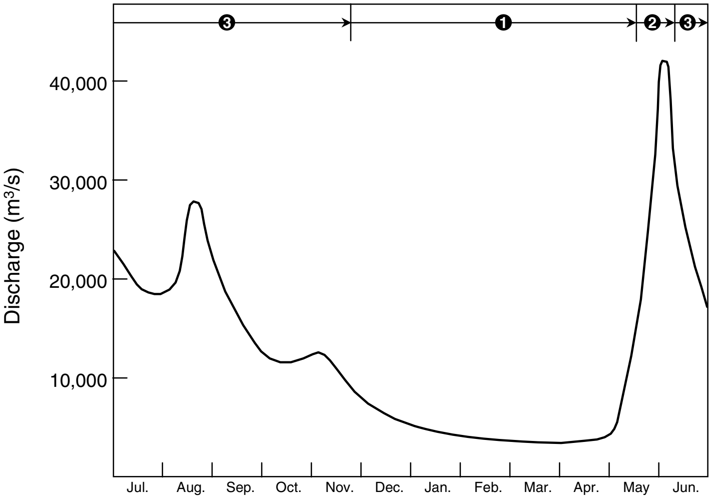


Figure 6 - 5 Typical seasonal variation in river discharge, Mackenzie River, Canada

Oil in broken ice moves in the same direction and at the same speed as ice. Wind has a strong effect on the movement of broken ice and has little additional effect on oil, except in wide leads. In open-water leads, the wind drives the oil toward one side of the lead.

Estimating the movement of submerged oil requires knowledge of subsurface water currents. Often, subsurface currents move at a different speed or in a different direction than surface currents, e.g., in estuaries and tidal inlets. The transport of oil under ice requires data on the relative movements of the ice and the under-ice waters. In both situations, it may be necessary to measure those currents to obtain meaningful estimates.

In all attempts at trajectory analyses or trajectory modelling, one should assume a worse-case situation. Uncertainty related to wind, weather, sea or current conditions must be considered in the evaluation of the potential spill trajectory.

6.5 Sampling

Spill response often involves the collection of samples for the following reasons (Swedish Coast Guard, 1993):

health and safety	Substances may be flammable or toxic.
legal liability	Comparison of sample analyses from the spill site and the suspected source.
economic liability	Analyses are the basis for compensation claims against the polluter.
spill response planning	Physical property data can assist in the selection of response equipment.
short-term environmental protection	Oil properties can indicate acute or damaging effects.
long-term environmental protection	Assessments of oil can allow the development of environmental restoration strategies for longer periods.
information service	Clarification can be provided on the spill source, oil properties and impacts.
disposal	Oil volume and properties dictate appropriate, safe disposal methods.

6.6 Documentation and Description of Stranded Oil

Defining stranded oil conditions is critical for properly planning shoreline treatment operations.

Techniques have been developed for the systematic documentation of oil on ocean shores, lake shores and river banks (Owens and Sergy, 1994). The method of documentation described in this section has been adopted by the governments of Canada (Environment Canada), the United States (National Oceanographic and Atmospheric Administration) and the European Commission.

The method involves the subdivision of the shore into segments and descriptions of the location, character and amount of oil, using a set of standard terms and definitions. The key elements of the description are the oil width and surface oil cover (distribution).

oil width	The width is the average width of the oiled area or band in the shoreline segment. If multiple bands or areas occur across a shore, width represents the sum of their widths.

wide	more than 6 m
medium	3 to 6 m
narrow	0.5 to 3 m
very narrow	less than 0.5 m

oil distribution	The oil distribution is the percent of the surface within a band or area covered by oil. In the event of multiple bands, distribution refers to the term that best represents the oil conditions for the segment.

continuous	91 to 100%
broken	51 to 90%
patchy	11 to 50%
sporadic	1 to 10%
trace	less than 1%

Surface oil distribution can be difficult to estimate without experience or practice. Examples of the percent surface coverage of oil are shown in Figure 6 - 6. The width and distribution can be combined to provided a simple summary of surface oil cover as shown in Table 6 - 2. These data can be collected from low-altitude, low-speed aircraft or by ground surveys.

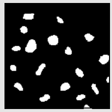
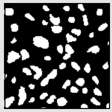
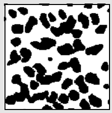
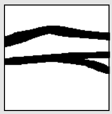
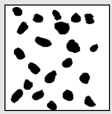
Range	Examples			
continuous (91 - 100%)	95%			
broken (51 - 90%)	70%			
patchy (11 - 50%)	30%			
sporadic (1 - 10%)	5%			

Figure 6 - 6 Examples of percent surface oil cover

Table 6 - 2 Surface oil cover matrix

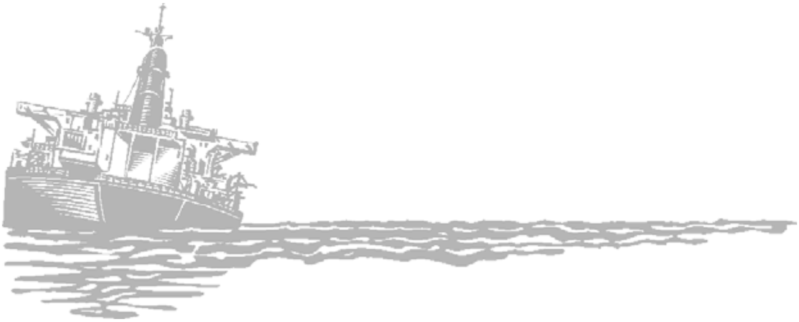
		Width of Oiled Area			
		wide (>6 m)	**medium (3 - 6 m)**	**narrow (0.5 - 3 m)**	**very narrow (<0.5 m)**
Oil Distribution	**continuous (91 – 100%)**	heavy	heavy	moderate	light
	broken (51 – 90%)	heavy	heavy	moderate	light
	patchy (11 – 50%)	moderate	moderate	light	very light
	sporadic (1 – 10%)	light	light	very light	very light
	trace (<1%)	very light	very light	very light	very light

Ground surveys also can document the actual amount of stranded oil in terms of oil thickness using:

oil thickness	Oil thickness is the average or dominant oil thickness within a band or area.
pooled or thick oil	generally consists of fresh oil or mousse accumulations more than 1.0 cm thick
cover	1.0 cm to 0.1 cm thick
coat	0.1 cm to 0.01 cm thick coating; can be scratched off with fingernail on coarse sediments or bedrock
stain	less than 0.01 cm; cannot be scratched off easily on coarse sediments/bedrock
film	transparent or translucent film or sheen

Oil that has penetrated coarse sediments, or that has been buried by mobile beach materials, can be detected and documented only by digging pits or trenches.

7 Notification and Spill Response Decision Process



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7.1 Introduction

Effective spill response, in any situation, requires two separate and distinct actions:

1. An initial ***notification*** step must be taken to inform others who might be involved.
2. A ***decision process*** must be implemented that sets immediate and long-term objectives for the overall response operation and for individual actions within that operation.

7.2 Notification

Notification of appropriate government agencies is the top priority and a legal requirement in most countries. All individuals associated with the exploration, production, transfer and transportation of oil should be aware of the correct notification procedures.

Unless the volume released is very small (a few barrels or less) and unless immediate action will safely contain the oil at source, the first action upon discovering an oil spill is to notify a responsible individual, e.g., person-in-charge, and/or others who would be involved in response operations.

In most cases, the first person to be notified is a supervisor. The supervisor then will set in motion a notification sequence that could include:

- a spill response team(s)
- local government agencies
- national government agencies, in some cases
- agencies in neighbouring countries
- the general public and local agencies and groups

7.3 Decision Process

The management of a spill response operation involves a decision process that allows for operational activities to be developed according to a set of specified goals. The ultimate goal of a response is to mitigate the effects of spilled oil. Response should be carried out within an organized approach that allows for ongoing evaluation of, and modifications (if needed) to, the plan of action.

Management by objectives is achieved through the application of a decision process that follows a logical sequence of steps:

1. Gather information and assess the situation.
2. Define response objective(s).
3. Develop strategies to meet the objectives.
4. Select appropriate technique(s), method(s) or tactics to implement the strategy.
5. Evaluate the practicality, feasibility and safety of the strategies and methods or tactics in view of the environmental conditions and the nature of the spill.
6. Prepare an action or response plan.
7. Obtain appropriate approvals, permission or permits.
8. Implement the field response operations plan.

This decision process should be applied to the entire spill response area and, within that area, to specific operational units on water, river reaches or shoreline segments. The approach is applicable equally to small and large spills.

Response objectives, strategies and methods will change from area to area and, in rivers or on the coast, downstream or alongshore, depending on the variability of the resources at risk (sensitivity), the risk of oiling (vulnerability) and the ice conditions or shore type.

The following two pages provide examples of the types of activities or actions that may be associated with the decision process.

Step 1	***Gather and assess information and data.*** • Define the regional distribution of the oil on water and on shorelines, e.g., surveillance, tracking and aerial videotape survey. • Extract data from sensitivity maps and resource databases. • Obtain local knowledge. • Estimate the spill path, resources at risk and persistence of the oil. • Identify safety, environmental, ecological and cultural constraints.
Step 2	***Define objectives.*** • Set regional response objectives. • Define regional priorities. • Identify acceptable recovery or treatment levels. • Establish local (site) response objectives and priorities.
Step 3	***Develop strategies.*** • Develop regional response strategies to meet the objectives and priorities. • Establish local response strategies to meet local response objectives.
Step 4	***Select response options.*** • Define acceptable and available methods and tactics to achieve the response objectives and strategies.

Step 5	***Evaluate operational feasibility and safety.*** • Identify environmental (physical), ecological, safety and logistical constraints that might affect the proposed operations. • Evaluate the Net Environmental Benefit of the proposed actions. • Evaluate the practicality and ability of the proposed operations and procedures to achieve the local response objectives and strategies. • Evaluate the need to redefine an objective or strategy if the original proposed actions cannot be conducted in a safe or effective manner (feedback loop).
Step 6	***Prepare operational plans.*** • Develop a long-range regional response plan. • Prepare individual (site or group) response plans.
Step 7	***Obtain approvals and permits.*** • Obtain approval of response plans from person in charge or command team. • Obtain permission for access to private property. • Secure other permits, e.g., disposal, incineration of materials.
Step 8	***Conduct response.*** • Implement strategies developed in the response plans for water- and land-based operations.

7

7.4 Response Objectives

Once information has been gathered on the nature of a spill and on the distribution of the spilled oil, the decision process, in all cases, should begin with a set of general objectives that include:

- ✓ Protect the life and health of responders and the public.
- ✓ Stop the discharge at the source.
- ✓ Avoid causing more damage in responding to the spill than the oil would cause alone.
- ✓ Use available resources in a safe, efficient and effective manner.
- ✓ Always consider local interests in the development of strategies and priorities.
- ✓ Minimize environmental damage and protect property from the spilled oil.
- ✓ Minimize the generation and handling of waste materials.

The different geographic components of a response operation should have specific objectives, set by the management team, so that planners and operations teams have clearly defined goals.

At Source

The operations objectives of response actions at the source of a spill can include one or more of the following four statements:

1. Allow the oil to weather naturally.
2. Contain and recover the oil.
3. Burn the oil.
4. Chemically disperse the oil.

On Water or in Ice

The operational objectives of response actions away from the source, either at sea, on a lake, on a river or in ice can include one or more of the following four statements:

1 Allow the oil to weather naturally.

2 Intercept, control, contain and recover the oil.

3 Burn the oil.

4 Chemically disperse the oil.

In both ice and ice-free conditions, all four objectives may be applied in different locations to different parts of a spill at the same time.

Protection

The objective of response actions for the protection of a specific resource or resources at risk from the spilled oil can include only one of the following two statements:

1 Prevent contact between the oil and the resource(s) at risk.

2 Minimize contact between the oil and the resource(s) at risk.

Shoreline Treatment

The objective of response actions for the treatment of a specific section of river bank or a shoreline segment can include only one of the following three statements:

1 Allow the oiled area to recover naturally.

2 Restore the oiled area to its pre-spill condition.

3 Accelerate the natural recovery of the oiled area.

7

7.5 Feasibility and Net Environmental Benefit

Two other important steps in the decision process outlined above, before a course of action is approved or finalized, are the evaluation of the practicality and effectiveness (or feasibility) of the planned activities and the likely environmental effects of proposed actions (the Net Environmental Benefit).

The evaluation of feasibility includes an assessment of the potential of proposed actions to achieve the objectives defined in the decision process. If the stated objectives cannot be achieved, then the objectives should be re-evaluated. This process could lead to the selection of alternative strategies and response actions.

Because much of the Arctic is remote, two additional key elements of the operational assessment are safety and practicality. If the objectives can be met, but if such actions either could jeopardize the safety of response personnel or would require a disproportionate use of available resources, then the objectives should be re-evaluated.

The decision process for establishing response and protection priorities must include local knowledge and input from local inhabitants. The potential effects of the spill, and also those of response operations on subsistence and other economic activities, are part of the overall assessment. Local knowledge also is used in the assessment of environmental concerns or issues, as there frequently exists a strong connection between the environment and subsistence or economic activities.

The practicality of spill response operations can include questions such as:

- *Is this a remote area, i.e., is overnight accommodation required away from the primary staging area?*
- *Can vessels navigate through ice?*
- *Does the oil present a safety hazard for responders, the public or wildlife?*
- *Is there direct access to the shore from the back shore?*
- *Is a back shore cliff or high relief present?*

- *Is there a suitable staging area nearby?*
- *Is the shore zone suitable for machinery?*
- *What wastes will be generated and can they be managed without interrupting recovery or treatment?*
- *Are ecological resources present that might be adversely affected by response activities?*
- *Are cultural resources present that might be adversely affected by response activities?*

The Arctic is a fragile ecological environment in which small changes to a habitat or to subsistence activities often can have large, and sometimes irreversible, effects. Response plans, therefore, should be evaluated in the context of the consequences of the proposed action on the ecology and the economic activities of an area. This component of the evaluation is recognized as a formal process and involves an attempt to forecast the natural recovery rate and the consequences of proposed treatment actions on recovery. The process is generally called the ***Net Environmental Benefit*** analysis (Baker, 1995). The key question in this analysis is:

- *Will the proposed action(s) accelerate or delay natural recovery?*

Recent studies of response actions on bedrock shores and in salt marshes have shown that, in most cases, treatment or cleanup did not promote ecological recovery (Sell *et al.*, 1995). If the proposed actions likely would delay, rather than accelerate, the rate of recovery then alternative action or no action should be considered.

All spill response activities involve some form of intrusion or change to the natural system. The risk of changing the natural ecosystem as a result of response activities is greater for shorelines or land as compared to on-water activities.

This concept of net benefit can be taken to a second level in the analysis, to ensure that recovery is not delayed, by asking the question:

- *At what point in the treatment will further actions or attempts to remove additional oil change from a positive benefit to a negative effect?*

Environmental recovery may be accelerated if only the easily removable oil is cleaned up or treated and the residue is left to weather naturally. Usually it takes more effort and it is more intrusive to take away or treat oil residue than it is to take away the bulk oil.

8 Coastal Character of the Arctic Regions and the Adjacent Areas Affected by Ice

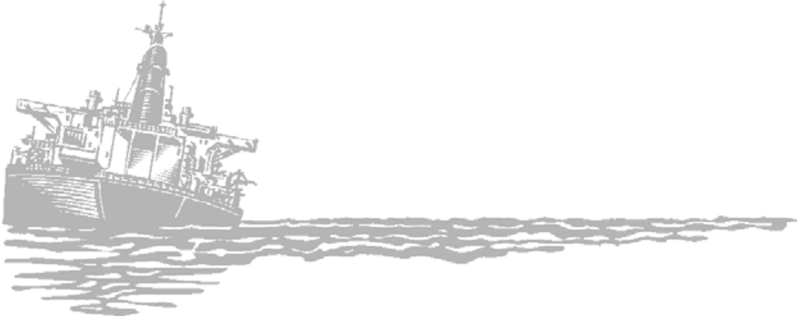

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Table of Contents

8

8.1 Introduction

The boundaries of the Arctic Region defined by the AEPS member countries are described in Section 2.2. The EPPR Working Group requested that this section on the geography of the region include the Baltic Sea and eastern Canada regions. By outlining the physical features of the coasts of this region, an awareness is provided for each country of the geographic character and environmental conditions of neighbouring countries.

Interior continental regions are affected by ice each year. Waters in this region experience lower winter temperatures than the coastal margins and include the shores of the inland Great Lakes (42° North) and the northern Caspian Sea (40° North), as well as many rivers and streams located in these latitudes.

The winter air masses that move westward across the continents from the interior carry cold air to the eastern continental margins, whereas warmer air moving west across the oceans, combined with northerly moving coastal warm-water currents, cause milder winter climates on the western margins of the continents. As a result, typically, ice extends farther south on the eastern coasts of continents than on the western margins. Winter ice in Asia forms as far south as 43° North at Vladivostok and some years, in North America, on the beaches of Cape Cod at 41° 50' North. By contrast on west-facing coasts, the most southerly ice effects occur at 57° North on the Alaskan coast and the west coast of Svalbard may be ice-free year-round to 78° North.

The regional surface water current pattern and the general drift directions for the Arctic Ocean are shown in Figure 8 - 1 and Figure 8 - 2, respectively.

Seven regions have been delineated in this section to characterize the shore types and processes of the coasts for which this Field Guide was prepared. Subdivisions within each of these regions are described in a summary table that focuses on:

- coastal character
- wave exposure
- ice season
- tidal range

The response strategy for oiled shorelines (Section 4.11) is based on 14 shore types, for which colour photographs are presented in Section 8.9.

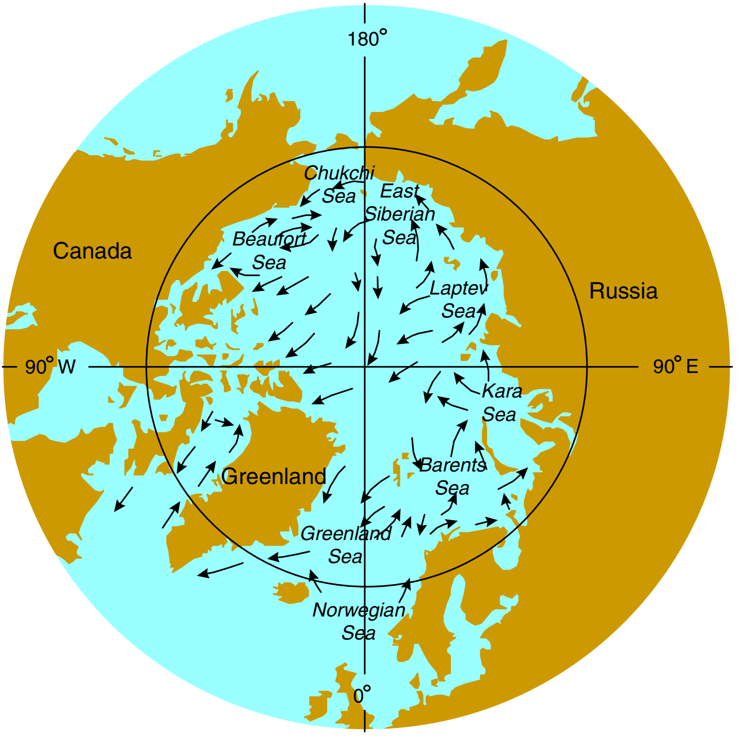

Figure 8 - 1 Surface currents of the Arctic Ocean

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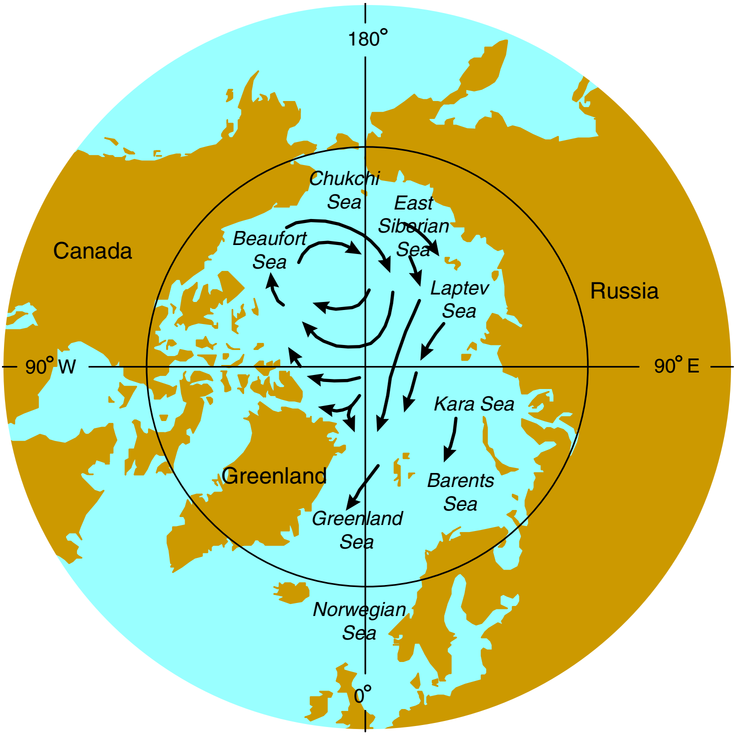

Figure 8 - 2 Ice drift in the Arctic Ocean

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8.2 Baltic Sea

The Baltic Sea is a large trough that was eroded by the ice sheets of the last Ice Age and then invaded by the sea after the retreat of the ice. The coast generally has low relief, but sediments, and therefore beaches, are scarce in the eroded northern sections. In contrast, beaches are plentiful where the ice deposited material in the southern areas. The only access to the ocean is through the narrow channels of the Danish archipelago and between Denmark and Sweden. The coastline is heavily populated with more than 50 million people in adjacent countries.

Wave-energy levels are limited by the relatively short fetch areas within the Baltic. Tides are not a significant feature of the coastal zone and the range everywhere is less than 0.1 m. Salinity is low in the range of 0.1 - 0.3 $^{o}/_{oo}$. The ice-free season in most areas is May through December and is somewhat shorter in the north and longer on the most southerly coasts. Ice conditions are quite variable in the south, depending on the severity of the winter weather.

The Baltic Sea has been divided into four regions as shown below. Each region is described in terms of coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

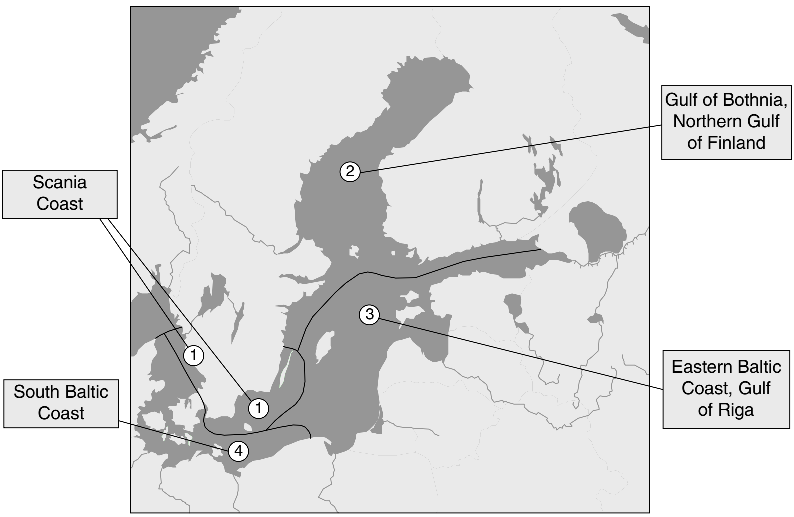
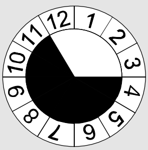
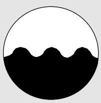
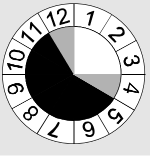
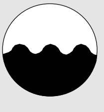


Figure 8 - 3 Baltic Sea

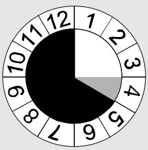
Zone ① Scania Coast

Coastal Zone Character	• low relief, but thick sediments that often form eroding cliffs • areas with archipelagos and islands
lowland/coastal plain	
Shoreline Types	
bedrock shores sand beaches pebble/cobble beaches	
Ice Season	• ice-free April to November
	
Tidal Range	• less than 0.1 m
	

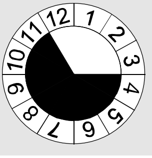
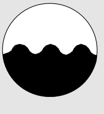
Zone ② Gulf of Bothnia, Northern Gulf of Finland

Coastal Zone Character	
lowland/coastal plain	• low coastal relief • sediments not abundant • many archipelagos and islands • one section of high coastal relief (300 m)
Shoreline Types	
bedrock shores	
Ice Season	• ice-free period usually May to December in northern areas and April to November in the Stockholm area
	
Tidal Range	• less than 0.1 m
	

Zone ③ **Eastern Baltic Coast, Gulf of Riga**

Coastal Zone Character	• lowland coastal plain with abundant sediments • barrier beaches, lagoons and marshes, with a delta at the mouth of the Daugava River
lowland/coastal plain delta barrier islands/beaches	
Shoreline Types	
sand beaches mixed-sediment beaches marshes	
Ice Season	• ice-free period usually May to December in northern areas and April to December farther south
	
Tidal Range	• less than 0.1 m
	

Zone ④ South Baltic Coast

Coastal Zone Character	
lowland/coastal plain deltas barrier islands/beaches	• lowland coastal plain with abundant sediments • some cliffed sections and barrier beaches, lagoons and marshes • Oder and Wisla Rivers drain the north German Plain
Shoreline Types	
bedrock shores sand beaches mixed-sediment beaches marshes	
Ice Season	• coastal area is ice-free usually April to November
	
Tidal Range	• less than 0.1 m
	

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8.3 Canada

The coasts of Canada that are affected by ice extend over a large geographic area, from 53° to 140° West and between 43° and 83° North.

Hudson Bay and Foxe Basin form a large inland sea that is connected to the Atlantic Ocean through Hudson Strait. North of the mainland of Canada, the Queen Elizabeth Islands are a large archipelago system with few large bodies of open water during summer months. The coastal zone is characterized by high relief and fiords in the east, from Newfoundland to Ellesmere Island, with lowland coasts in the west on the Arctic Ocean coast and in Hudson Bay.

Beaches are common through the central and western Arctic, and the Beaufort Sea coast is a lowland tundra environment with extensive barrier beaches and lagoons. The Mackenzie River has a major delta system. In the east, coastal sediment supply is limited, due to high relief and resistant bedrock, and only the southern Gulf of St. Lawrence has well-developed beaches.

The permanent polar pack remains close to the Beaufort Sea coast during summer months, and in some years the open-water areas are only tens of kilometres in length. The ice-free season decreases to the north, and the northwest Queen Elizabeth Islands Archipelago and northern Ellesmere often have no open-water season. The majority of the central Archipelago and Hudson Bay have less than 3 months that are ice-free and the open-water season exceeds 6 months only south of Labrador. The Gulf of St. Lawrence has ice 3 to 4 months each year. Ice forms in the Bay of Fundy in most winters for a few weeks and in some years in sheltered bays on the outer coast as far south as Cape Cod and northern Nantucket Sound in the United States (41° 50' North). Tidal ranges are generally low, less than 2 m, except for the Hudson Strait (8 m), Foxe Basin (5 m), Ungava Bay (15 m) region and the St. Lawrence estuary (5 m). Wind surges are important during the open-water season on the Beaufort Sea coasts, due to the low angle backshore and nearshore slopes.

The area of Canada that is covered by this Guide has been divided into 10 regions as shown below. Each region is described in terms of coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

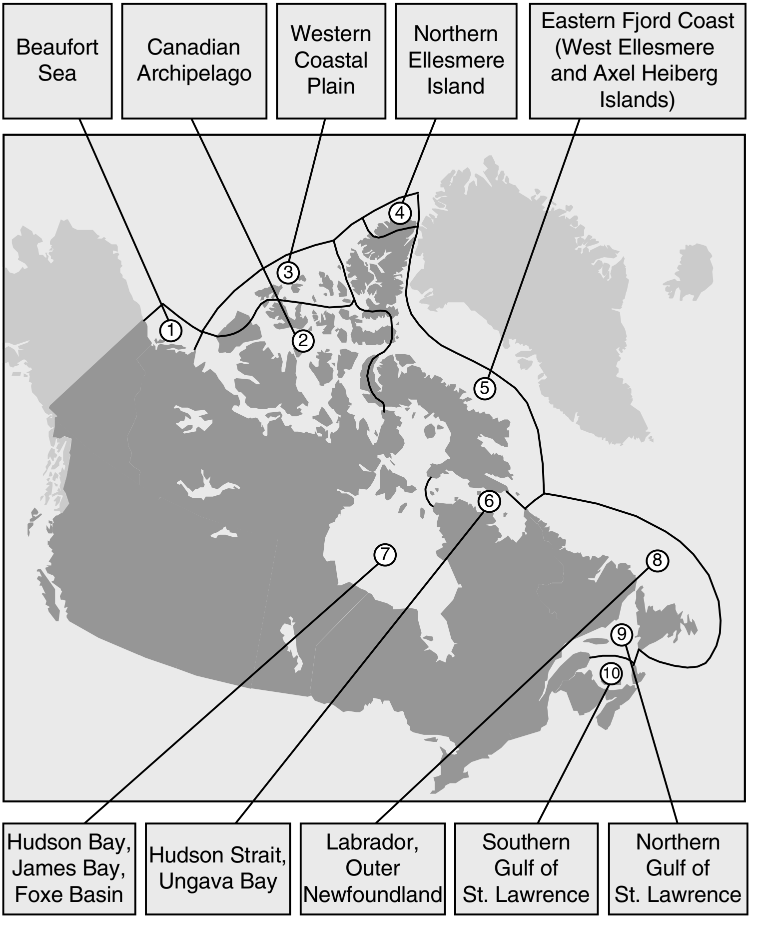


Figure 8 - 4 Canada

Zone ① Beaufort Sea

Coastal Zone Character

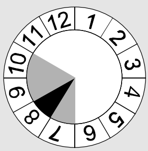
lowland or coastal plain
delta
barrier islands/beaches
tundra coast

Shoreline Types

sand beaches
peat shores
low tundra shores
tundra cliff shores

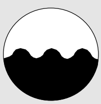
- low tundra plain
- barrier beaches and sand barrier islands with lagoons and inundated lowland tundra, and sections of rapidly eroding tundra cliffs
- Mackenzie River has a very large delta

Ice Season



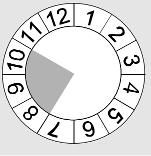
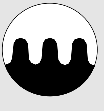
- permanent polar pack stays close to shore all year so limited areas for wave generation
- 1 - 4 months open water (August to October) season

Tidal Range



- less than 0.5 m

Zone ② Canadian Archipelago

Coastal Zone Character	
upland or mountains lowland or coastal plain	• upland coast in most areas, with steep cliffs and talus slopes • relief decreases from east to west • mixed-sediment beaches generally narrow except in low-lying areas
Shoreline Types	
bedrock shores sand beaches mixed-sediment beaches	
Ice Season	• ice-free 0 - 3 months • open-water areas small due to size of the channels between the islands
	
Tidal Range	• 1.0 - 2.0 m
	

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Zone ③ Western Coastal Plain

Coastal Zone Character

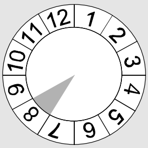
lowland or coastal plain
deltas
barrier islands/beaches

- lowland coast with narrow beaches, except in southwest Banks Island which has sand barrier beaches
- many deltas, braided streams and raised beaches

Shoreline Types

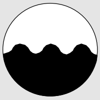
bedrock shores
sand beaches
mixed-sediment beaches
pebble/cobble beaches

Ice Season



- permanent polar pack stays close to shore all year so limited areas for wave generation (max. fetch less than 100 km)
- ice-free period usually less than 1 month and some years no open water

Tidal Range



- less than 1.0 m

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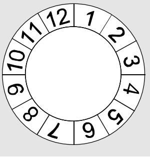
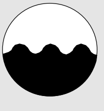
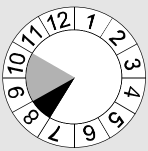
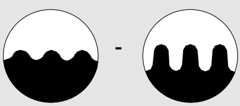
Zone ④ Northern Ellesmere Island

Coastal Zone Character fiord coast ice shelf **Shoreline Types** bedrock shores ice shores	• high-relief, ice shelf coast • occasional rock cliffs with a few beaches • usually permanent ice foot
Ice Season	• rarely ice free
Tidal Range	• less than 1.0 m





Zone ⑤ Eastern Fiord Coast (includes West Ellesmere Island and Axel Heiberg Island)

Coastal Zone Character	• high-relief fiord coasts with tide-water glaciers in northern areas • beaches generally narrow or absent • deltas or intertidal flats at heads of fiord
upland or mountains fiord coast ice shelf deltas	
Shoreline Types	
bedrock shores ice shores mixed-sediment beaches sand flats	
Ice Season	• ice-free less than 1 month in north to 3 months in south
	
Tidal Range	• 0.5 - 3.0 m
	

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Zone ⑥ Hudson Strait, Ungava Bay

Coastal Zone Character

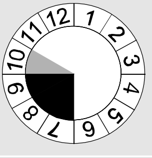
upland or mountains
fiord coast
deltas
tidal flats

- high-relief fiord coast with few beaches
- small fiord-head deltas, often with boulder-strewn platforms
- wide tidal flats in Ungava Bay

Shoreline Types

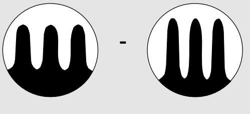
bedrock shores
mixed-sediment beaches
pebble/cobble beaches
boulder beaches
sand flats
mud flats

Ice Season



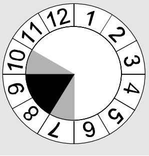
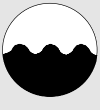
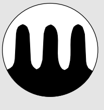
- ice-free 3 - 4 months
- exposed eastern areas subject to occasional storm-wave action

Tidal Range



- 3.0 - 8.0 m
- Ungava Bay to 15 m

Zone ⑦ Hudson Bay, James Bay, Foxe Basin

Coastal Zone Character	• low muskeg coast and wide tidal flats in southwest Hudson Bay • elsewhere, lowland coasts with narrow pebble/cobble beaches and mud flats common
lowland or coastal plain tidal flats	
Shoreline Types	
bedrock shores mixed-sediment beaches pebble/cobble beaches boulder beaches sand flats mud flats marshes	
Ice Season	• sheltered inland sea • ice-free 2 - 4 months
	
Tidal Range	• 0.5 - 4.0 m • Foxe Basin to 5 m
 - 	

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Zone ⑧ Labrador, Outer Newfoundland

Coastal Zone Character

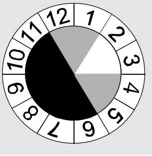
upland or mountains
fiord coast
deltas

- high-relief, fiord coastline
- beaches absent or narrow pebble/cobble beaches, with small fiord-head deltas

Shoreline Types

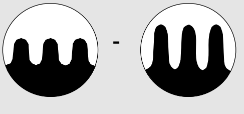
bedrock shores
pebble/cobble beaches
boulder beaches
sand flats

Ice Season



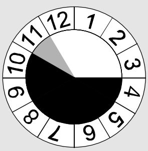
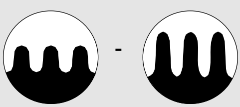
- exposed storm-wave coasts with sheltered bay environments
- ice-free 6 - 10 months, increasing to 11 - 12 months in south Newfoundland

Tidal Range

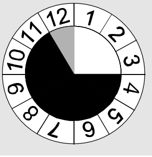
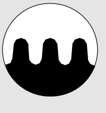


- 1.0 m increasing to 8 m in the north

Zone ⑨ Northern Gulf of St. Lawrence

Coastal Zone Character	
upland or mountains fiord coast lowland or coastal plain tidal flats	• relief decreases east to west • fiords in western Newfoundland and elsewhere lowlands with few beaches • wide mud tidal flats and marshes in St. Lawrence estuary
Shoreline Types	
bedrock shores mixed-sediment beaches mud flats marsh	
Ice Season	• enclosed sea, fetch up to 700 km energy levels increase NW to SE • ice-free 7 - 8 months (April to November)
	
Tidal Range	• 1.0 - 2.0 m • St. Lawrence Estuary to 5 m
	

Zone ⑩ Southern Gulf of St. Lawrence

Coastal Zone Character	
lowland or coastal plain barrier islands/beaches	• generally low relief • mixed-sediment beaches in upland areas, sand beaches and barrier islands with lagoons in lowland areas
Shoreline Types	
bedrock shores sand beaches mixed-sediment beaches sand flats marsh	
Ice Season	• enclosed sea, fetch distances up to 500 km • energy levels increase W to E • ice-free 8 - 9 months (April to December)
	
Tidal Range	• 1.0 - 2.0 m
	

8

8.4 Greenland

The coasts of Greenland are uniformly high relief, with deeply indented fiords and few beaches. The Greenland ice sheet reaches the coastal zone in the form of calving glaciers. Ice shelves may be present along the North coast of Greenland and increase in frequency northwards. In Northern Baffin Bay, the Inland Ice margin reaches the sea along most of Melville Bay. The southern section of the Baffin Bay coast, around and to the south of Disko Island, has areas of lower relief and skerries (an archipelago of small, bedrock islands). Elsewhere, fiords dominate the coastal character.

Where present, the sediments are coarse-grained (pebble to boulder size) and form pocket beaches. Sandy beaches are found in Eastern Disko and along Jameson Land in East Greenland.

Consolidated multi-year ice dominates the north and east coast (north of 70°N - 72°N) of Greenland but in some years the drift ice opens and navigation is possible from late July until late September. Multi-year ice of Arctic Ocean origin is normally present on the Southeast coast of Greenland from early winter until late summer. The Denmark Strait is free of ice a few weeks from mid-August until late September but the Cape Farewell area is normally free of sea ice from early August until late December. The Davis Strait coast is free of sea ice most of the year but to the north, first year ice occurs from late December until May or early June. The southern parts of the region are affected by multi-year ice (from the Greenland East coast) in the spring months (April - June). Only in severe winters, first-year ice occurs in southeastern Davis Strait; however, locally-formed ice in bays or fiords occurs each winter. The coastal sea ice in Baffin Bay breaks up for about 5 months (July - November) in the south, 1 - 2 months (August - September) in northeastern sections, and 3 - 4 months (June - September) in the northwestern areas.

Greenland has been divided into four regions as shown below. Each region is described in terms of its coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

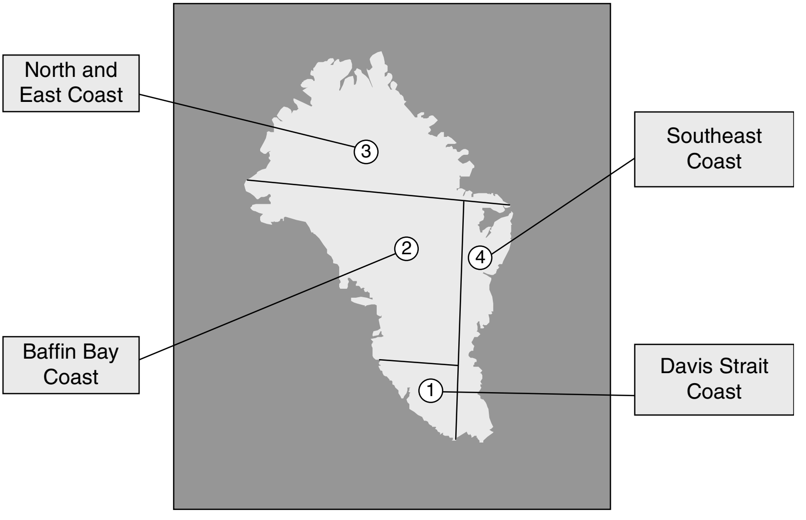


Figure 8 - 5 Greenland

Zone ① Davis Strait Coast

Coastal Zone Character

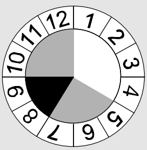
fiord coast

- high-relief coast with cliffs and fiords and calving glaciers
- few beaches, coarse material where present

Shoreline Types

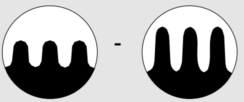
bedrock shores
ice shores
pebble/cobble beaches

Ice Season



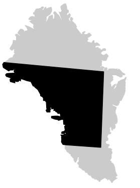
- in the north, free of sea ice about 6 months (May/June - December)
- in the south, only sea ice in short periods in late winter (February - March)
- some years multi-year ice in the south in April - June
- first-year ice (thickness normally less than 1.0 metre)

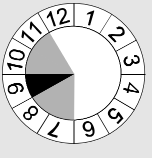
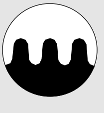
Tidal Range



- 2.7 - 4.8 m

Zone ② Baffin Bay Coast



Coastal Zone Character	• high-relief coast with cliffs and fiords • numerous calving glaciers particularly in Melville Bay • sand beaches on Disko and Nuussavaq
fiord coast	
Shoreline Types	
bedrock shores ice shores	
Ice Season	• in the northwest, free of sea ice 3 - 4 months (June - September), the northeast about 2 months (mid-August to mid-October), and in the south 5 - 6 months (June - November) • first-year ice (thickness 1 - 1.5 metres), to the northwest first-year ice mixed with multi-year ice
	
Tidal Range	• 2.0 - 2.8 m
	

Zone ③ North and East Coast

Coastal Zone Character

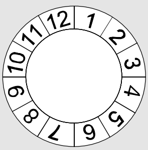
fiord coast
ice shelf

- high-relief coast with cliffs and fiords
- the ice shelf forms the coast in many sections
- numerous glacier outlets with floating ice shelves

Shoreline Types

bedrock shores
mixed-sediment beaches
ice shores

Ice Season



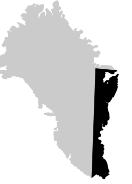
- no ice-free season
- multi-year ice (thickness 3 - 4 metres)
- navigational possible some years on the east coast in August and September

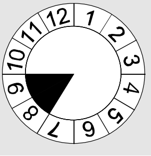
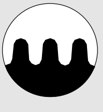
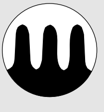
Tidal Range

- less than 2.8 m

8

Zone ④ Southeast Coast



Coastal Zone Character	
fiord coast	• high-relief coast with cliffs and fiords • calving glaciers
Shoreline Types	
bedrock shores ice shores mixed-sediment beaches pebble/cobble beaches	
Ice Season	• in the south, free of sea ice August - December, in the north only a few weeks in August - September • multi-year ice (thickness 2 - 3 metres)
	
Tidal Range	• 1.5 m increasing to 3.3 m in the SW
 - 	

8.5 Iceland

The Icelandic coast is considered within the Arctic Region of the AEPS, even though the coastal zone typically does not have coastal sea ice or shore-fast ice.

Coastal relief is generally low, except in the northwest peninsula where cliff heights exceed 600 m in places and on the fiord coasts of the north and central east coasts. Bedrock outcrops dominate the coastal zone, except in the south and the strandflat coasts, which typically have low relief with cliffed headlands or shallow nearshore waters with numerous bedrock shoals and low islands (skerries). The strandflats also are characterized by large pocket beaches and backshore salt and freshwater marshes. The south coast is very different and is characterized by over 300 km of almost continuous barrier beaches. This coast is supplied annually by large volumes of sand from the glacial streams of the Vatnajökull and Myrdalsjökull ice fields. These extensive barrier beaches are constantly changing at rates on the order of 1 metre/year, and up to 10 metres/year, in places.

The south and southwest coasts are characterized by high-energy storm waves in winter months as low pressure systems move from southwest to northeast across this part of the North Atlantic Ocean. The tidal range is generally less than 2 m except in the western embayments of Beidafjördur and Faxaflói where spring tides can reach 5 m. Sea ice is not common, but ice from the Denmark Strait can drift along the north and northwest coasts and is a factor for shipping during most springs in the Horn area. Shore-fast ice does not form in the coastal zone, but ice can form in sheltered bays and lagoons, particularly where fresh water is present, and swash and spray can freeze on the shore zone.

Iceland is located on the Mid-Atlantic Ridge and is an active volcanic region. Eruptions on land and offshore cause shoreline and bathymetric changes. The most dramatic changes occur on the south coast when inland sub-glacial eruptions cause a “jökulhlaup” (or *glacier burst*) that carries large volumes of sand to the coastal zone. These events can result in shoreline progradation of several kilometres over relatively short time intervals (days to weeks).

Iceland has been divided into six regions, as shown below. Each region is described in terms of its coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

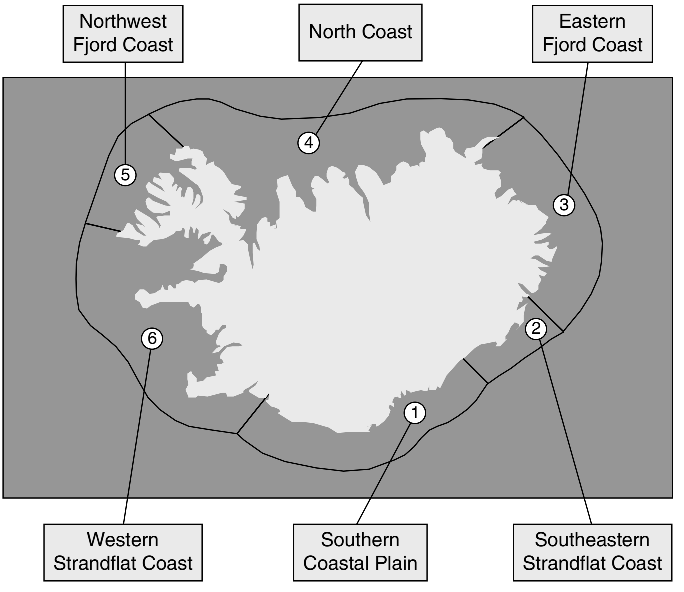


Figure 8 - 6 Iceland

Zone ① Southern Coastal Plain

Coastal Zone Character

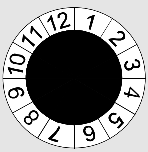
barrier islands
lowland/coastal plain

Shoreline Types

sand beaches
mixed-sediment beaches

- sediment-rich barrier spits and islands of predominantly sand sediments fed by glacial streams; beaches are subject to shoreline changes that occur due to sudden, volcanic-related sediment inputs from the inland ice fields or to spring meltwater processes (“glacier bursts”)
- the western boundary of the sand-dominated coast is the Thjörsá River
- strong alongshore movement of sediments by wave action
- wave action lowest and stream/river runoff highest in spring and summer

Ice Season



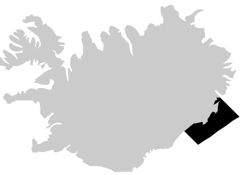
- open water all year

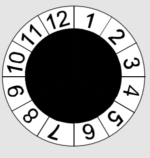
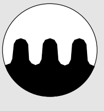
Tidal Range

- 1.0 - 3.0 m

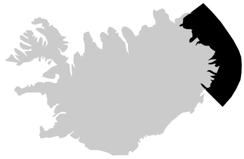
8

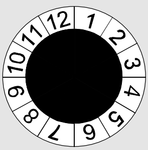
Zone ② **Southeastern Strandflat Coast**



Coastal Zone Character	• alternating bedrock headlands and pocket barrier beaches • beaches cut by tidal inlets and backed by tidal flats and salt marshes
lowland/coastal plain deltas barrier islands	
Shoreline Types	
bedrock shores mud flats salt marshes	
Ice Season	• open water all year; but some drift ice in exceptional years
	
Tidal Range	• 1.0 - 3.0 m
	

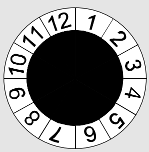
Zone ③ Eastern Fiord Coast



Coastal Zone Character	• high-relief fiord coast
upland or mountains fiord coast	
Shoreline Types	
bedrock shores	
Ice Season	• open water on outer coast with some local ice in sheltered bays and fiords • occasional drift ice originating from the Denmark Strait
	
Tidal Range	• 1.0 - 3.0 m
	

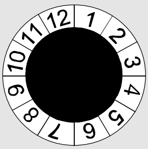
8

Zone ④ North Coast

Coastal Zone Character	• high-relief coast with cliffs and some fiords (Hrútfjördur and Eyjafjördur) • broad beach systems at Hérardsflói, Axarfjördur, Skagafjördur and Húnaflói
upland or mountains fiord coast	
Shoreline Types	
bedrock shores mixed beaches	
Ice Season	• open water on outer coast with some drift ice in the coastal waters and local ice in sheltered bays and fiords
	
Tidal Range	• 1.0 - 3.0 m
	

8

Zone ⑤ Northwest Fiord Coast

Coastal Zone Character	
upland or mountains fiord coast	• high-relief coast with cliffs and fiords • cliff heights up to 600 m
Shoreline Types	
bedrock shores pebble/cobble beaches	
Ice Season	• open water on outer coast with some local ice in sheltered bays and fiords • drift ice from the Denmark Strait can affect shipping in late winter and spring; in some years, the area around Horn is not passable due to ice congestion
	
Tidal Range	• 1.0 - 3.0 m
	

Zone ⑥ Western Strandflat Coast

Coastal Zone Character

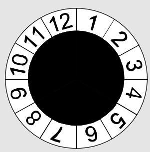
upland or mountains
lowland/coastal plain
barrier islands

- high-relief coast with cliffs and fiords
- two major volcanic headlands separate Beidafjördur and Faxaflói
- embayments have many bedrock islands, shoals, and skerries
- extensive sand barrier beaches in northern Faxaflói
- coarse-sediment beaches on headlands

Shoreline Types

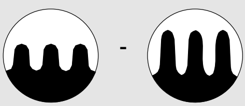
bedrock shores
sand beaches
pebble/cobble beaches

Ice Season



- open water on outer coast with some local ice in sheltered bays and fiords

Tidal Range



- generally less than 2 m but up to 5 m in Beidafjördur and Faxaflói

8

8.6 Arctic Norway

The coasts of Norway that are north of the Arctic Circle include the islands of Svalbard, Bjønøya and Jan Mayen Island. With the exception of Bjønøya, the coastal character is predominantly associated with high relief and the effects of glaciation. Glacial ice sheets cover much of Svalbard and calving glaciers are common in many fiords. The northern mainland coast has a complex coastline of steep-sided fiords and few sections with beaches. Jan Mayen and Bjønøya are predominantly lowlands with an almost continuous cliffed coast and narrow fringing beaches in some sections.

Wave-energy levels are high on all exposed outer coasts. The mainland of Norway and Jan Mayen Island have ice-free coasts and nearshore waters. The warm Gulf Stream waters keep much of the Norwegian Sea ice-free year-round and there is a large annual variation in the location of the edge of the polar pack ice. The ice reaches a maximum southward (75° N) and westward (10° E) extension in March and is at a minimum in August. Coastal and sea ice may remain on the north and east coasts of Svalbard in some years, whereas the outer, exposed southwest coasts occasionally are ice-free year-round. Similarly, on Bjønøya, which is near the edge of the seasonal pack ice limit, the outer, west-facing coast may have open water all year but the eastern coast usually is ice-bound from October through May. The coasts and waters of the fiords of Svalbard have ice usually from November or December through to June or July.

The tidal range on the mainland coast is between 2 and 4 m, and is less than 2 m on Svalbard, Bjønøya and Jan Mayen Island.

Arctic Norway has been divided into six regions, as shown below. Each region is described in terms of coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

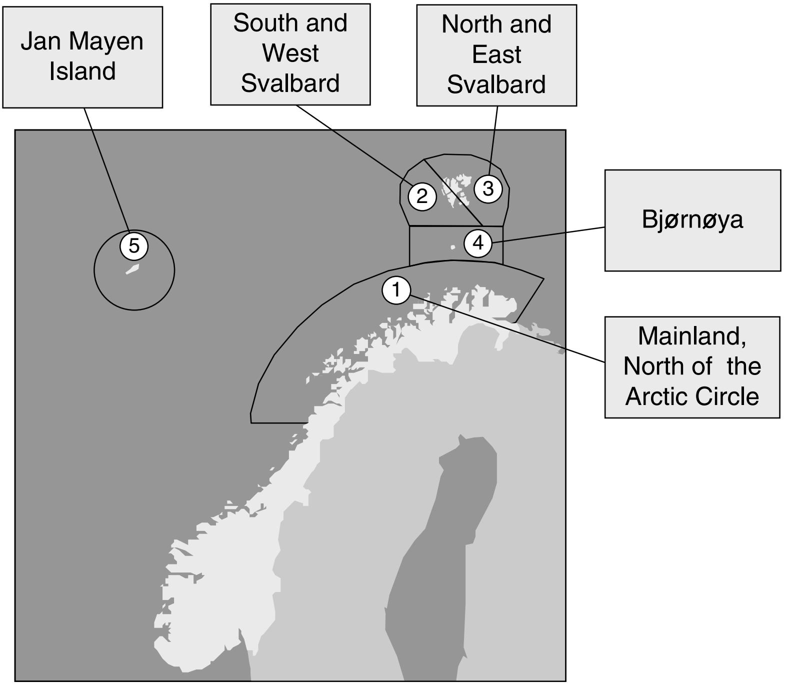
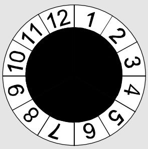


Figure 8 - 7 Norway

Zone ① Mainland, north of the Arctic Circle

Coastal Zone Character	• upland cliffed coasts with many steep-sided fiords and a complex coastline • coarse-grained beaches in some sections
upland or mountains fiord coast	
Shoreline Types	
bedrock shores mixed-sediment beaches pebble/cobble beaches	
Ice Season	• exposed to the Atlantic Ocean, unlimited fetch • outer coast has open water all year
	
Tidal Range	• 1.0 - 4.0 m
	

8

Zone ② **South and West Svalbard**

Coastal Zone Character

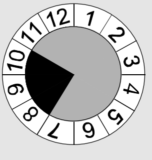
upland or mountains
fiord coast
ice shelf

- upland cliffed coasts with calving glaciers present in fiords
- extensive coarse-grained beaches in some sections

Shoreline Types

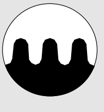
bedrock shores
ice shores
mixed-sediment beaches
pebble/cobble beaches

Ice Season



- exposed to the Atlantic Ocean, unlimited fetch
- outer coast usually has open water all year but may have coastal ice from October through May
- sheltered fiord coasts have open water 4 - 5 months (mid July to early December)

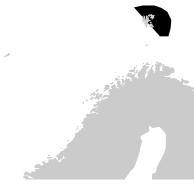
Tidal Range

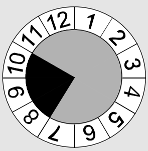
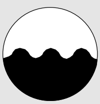


- 1.0 - 2.0 m

8

Zone ③ North and East Svalbard



Coastal Zone Character	
upland or mountains fiord coast ice shelf	• high-relief fiord coast with calving glaciers and ice shelves
Shoreline Types	
bedrock shores ice shores mixed-sediment beaches pebble/cobble beaches	
Ice Season	• low wave-energy northern coasts are ice-locked all year • southern sections open usually in August and September, and at times into October
	
Tidal Range	• less than 1.0 m
	

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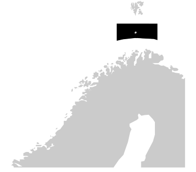
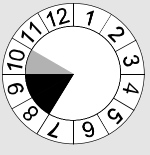
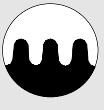
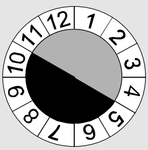
Zone ④ Bjønøya



Coastal Zone Character	• lowland cliffed coasts • narrow coarse-grained beaches in some sections
lowland or coastal plain	
Shoreline Types	
bedrock shores mixed-sediment beaches	
Ice Season	• exposed to the Atlantic Ocean, unlimited fetch • near the edge of the polar pack during winter - outer west-facing coast usually has open water all year • the eastern coast may be ice-bound from October through May
	
Tidal Range	• 1.0 - 2.0 m
	

Zone ⑤ Jan Mayen Island

Coastal Zone Character	• lowland cliffed coast with narrow coarse-grained beaches in some sections
upland or mountains	
Shoreline Types	
bedrock shores mixed-sediment beaches	
Ice Season	• exposed to the Atlantic Ocean, unlimited fetch • outer coast has open water all year
	
Tidal Range	• 1.0 - 1.5 m
	

8.7 Russia

The northern coasts of Russia that border the Arctic Ocean and the Bering Sea that are affected by ice extend over a large geographic area, from 40° East to 175° West and between 63° and 83° North. The mainland coast is generally low lying, with an interruption to the general trend where the Ural Mountains extend into Novaya Zemlya. Many sections of the lowland coast have tundra cliffs which have documented erosion rates on the order of 5 to 10 m/year. The offshore islands in the western half of the region have ice caps and glaciers that carve at the coast. The continental land mass is drained by several large rivers (the Northern Dvina, Pechora, Ob, Enisey, Lena, and Kolyma Rivers). On the Bering Sea coast, the coastal zone is predominantly bedrock controlled uplands, with only a few long sections of lowlands associated with large embayments. The form of the coastline is provided by the northeast-southwest trend of the Koryaksk and Kolyma Ranges in the north and the volcanic line of the Kamchatka Peninsula.

Wave-energy levels are low throughout the region as fetch distances are limited by the permanent polar pack and by generally calm wind conditions during the open-water season. In some years, the polar pack may not move north of the Taimyr Peninsular, effectively cutting off the Northeast Passage except to icebreakers. The northern shores of the offshore islands border the polar pack and may not have a coastal ice-free season in many years. The northern Kola peninsula is ice-free all year, due to the effects of the warm current that carries warm air northward along the Scandinavian coast, but ice is present in the White Sea from December through May. The Bering Strait coasts usually are ice-free during August and September. Freeze-up begins in the coastal zone of the Bering Sea in October and in western and northern Sea of Okhotsk in November. By December, ice extends to northern Sakhalin Island and most of the Kamchatka Peninsula.

The tidal range on the Arctic Ocean coast is low, usually less than 1 m, except for one part of the eastern White Sea, in the Mezen Gulf, where the range reaches 10 m. Wind-generated surges are important during the open-water season on the Barents, Laptev and Chukchi Sea coasts, due to the low angle backshore and nearshore slopes.

In the eastern Arctic, on the Bering Sea Coast, tide ranges generally are less than 3 m, and in the Gulf of Shelekov the tide ranges reach 10 m at the head of the Gulf of Penzinsk.

The areas of Russia covered by this Guide have been divided into eleven regions as shown below. Each region is described in terms of coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

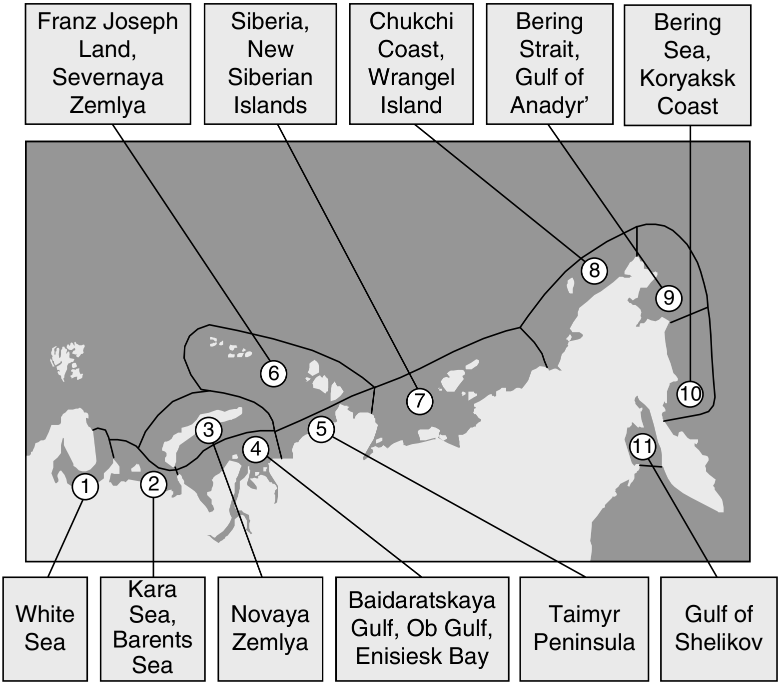
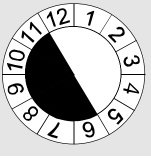
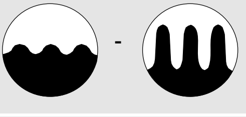


Figure 8 - 8 Russia

Zone ① White Sea

Coastal Zone Character	
lowland or coastal plain deltas barrier islands/beaches tidal flats tundra coast	• northern area (south Kola Peninsula) is a resistant lowland coast with many islands and few beaches • the south coast is a sedimentary plain with beaches and deltas, e.g., Onega and Northern Dvina Rivers, and wide mud tidal flats, eroding tundra cliffs (retreat rates up to 5 m/yr), sand barrier beaches, and marshes in eastern areas (Mezen Gulf)
Shoreline Types	
bedrock shores sand beaches mixed-sediment beaches mud flats marshes tundra cliff shores	
Ice Season	• restricted fetch area • ice-free June through November
	
Tidal Range	• less than 1.0 m in the White Sea • 7.0 m at the entrance increasing up to 10.0 m in Mezen Gulf
	

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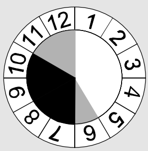
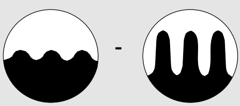
Zone ② Kara Sea, Barents Sea

Coastal Zone Character	
lowland or coastal plain delta barrier islands/beaches tundra coast	• low coastal plain with tundra cliffs, sand barrier beaches, spits and backshore marshes • tundra cliff erosion rates are 7 - 8 m/yr. • large delta at the mouth of the Pechora River
Shoreline Types	
sand beaches marshes low tundra shores tundra cliff shores	
Ice Season	• open water usually 4 months (July to October) in eastern sections, increasing westerly to 7 months at the entrance to the White Sea (June to December)
	
Tidal Range	• generally less than 1.0 m, increasing to 2.0 m in the strait between Vaigach Island and the mainland
	

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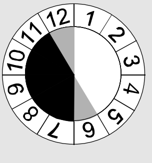
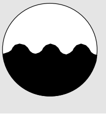
Zone ③ Novaya Zemlya

Coastal Zone Character	
upland or mountains fiord coast ice shelf	• upland cliffed fiord coasts (extension of the Ural Mountains) with calving glaciers present in northern areas
Shoreline Types	
bedrock shores ice shores mixed-sediment beaches pebble/cobble beaches	
Ice Season	• southwest sections usually have open water in June, the northeast in July and the east coast in August • the east coast freezes up in November and the west in December
	
Tidal Range	• less than 1.0 m
	

Zone ④

Baidaratskaya Gulf, Ob Gulf, Enisiesk Bay

Coastal Zone Character

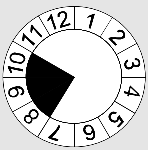
fiord coast
barrier islands/beaches
tundra coast

- low coast of tundra cliffs (annual retreat rates on the order of 5 - 10 m/yr), sand barrier beaches, lagoons and marshes
- two large river estuaries (Ob and Enisey)

Shoreline Types

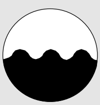
bedrock shores
ice shores
sand beaches
pebble/cobble beaches
low tundra shores
tundra cliff shores

Ice Season



- open-water usually 3 months (August to October), decreasing near river mouths due to fresh-water influx

Tidal Range



- less than 1.0 m

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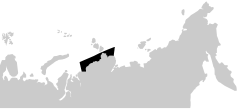
Zone ⑤ Taimyr Peninsula



Coastal Zone Character

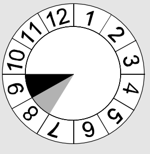
uplands or mountains

- upland cliffed coast with bedrock outcrops and many small islands
- mixed or coarse sediments where beaches are present

Shoreline Types

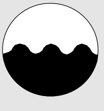
bedrock shores
mixed-sediment beaches
pebble/cobble beaches

Ice Season



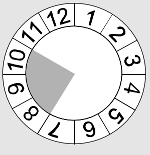
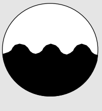
- open-water period can be 1 month (September) and sometimes 2 months (August to September), but may not have open water some years due to proximity of polar pack ice

Tidal Range

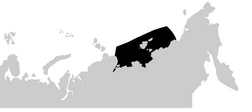


- less than 1.0 m

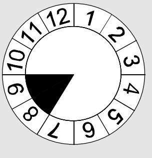
Zone ⑥ Franz Joseph Land, Severnaya Zemlya

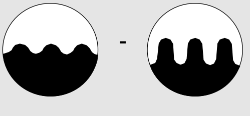
Coastal Zone Character	• high-relief coast with calving glaciers
uplands or mountains fiord coast ice shelf	
Shoreline Types	
bedrock shores ice shores mixed-sediment beaches pebble/cobble beaches	
Ice Season	• low wave-energy northern coasts are ice-locked all year; southern sections open usually in August and September, and at times into October
	
Tidal Range	• less than 1.0 m
	

Zone ⑦ **Siberia, New Siberian Islands**



Coastal Zone Character	
lowland or coastal plain fiord coast delta barrier islands/beaches tidal flats tundra coast	• low coastal plain with eroding tundra cliffs, mud flats and barrier beaches • large eroding delta at the mouth of the Lena River • New Siberian Islands have bedrock outcrops and tundra cliffs (erosion rates up to 15 m/yr in places) • shallow nearshore waters
Shoreline Types	
bedrock shores sand beaches mud flats low tundra shores tundra cliff shores	
Ice Season	• low wave-energy coast • permanent polar pack ice stays close to shore all year, so limited areas for wave generation • 2 months (August to September) open-water season
Tidal Range	• less than 0.5 m • wind surges are common and can flood inland several kilometres • up to 3.0 m at the head of the Khatanga estuary





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Zone ⑧ Chukchi Coast, Wrangel Island

Coastal Zone Character

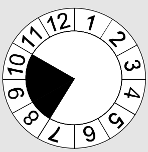
fiord coast
barrier islands/beaches
delta
tundra coast

Shoreline Types

bedrock shores
sand beaches
mixed-sediment beaches
mud flats
low tundra shores
tundra cliff shores

- narrow coastal plain with interior uplands
- mixed coast of bedrock headlands, tundra cliffs and sand-gravel barrier beaches with lagoons in low-lying areas, particularly east of Wrangel Island
- large delta at the mouth of the Kolyma River

Ice Season



- permanent polar pack ice stays close to shore all year, so limited areas for wave generation maximum 3 months (August to October) open-water season
- Wrangel often has no open-water season

Tidal Range

- less than 0.1 m

8

Zone ⑨ Bering Strait, Gulf of Anadyr’

Coastal Zone Character

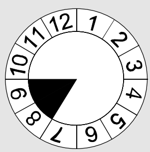
fiord coast
barrier islands/beaches
tundra coast

- alternating bedrock and lowland eroding tundra cliff coast
- fiords on southeast Chukchi Peninsula
- many coarse-grained barriers and spits in the Gulf of Anadyr’

Shoreline Types

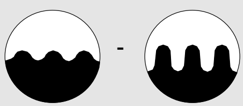
bedrock shores
ice shores
sand beaches
pebble/cobble beaches
low tundra shores
tundra cliff shores

Ice Season



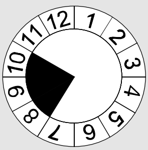
- high-energy coast during the 2-month open-water season (August to September)

Tidal Range



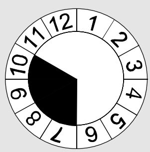
- 0.25 m increasing to 3 m at the head of the Gulf

Zone ⑩ Bering Sea, Koryaksk Coast

Coastal Zone Character	• upland region with small fiords and coarse-grained bay-mouth barriers
uplands or mountains fiord coast barrier islands/beaches	
Shoreline Types	
bedrock shores ice shores pebble/cobble beaches	
Ice Season	• high-energy coast during the 3-month open-water season (August to October)
	
Tidal Range	• 1.0 - 2.0 m
	

8

Zone (11) Gulf of Shelikov

Coastal Zone Character	• wide tidal flats
lowland or coastal plain tidal flats	
Shoreline Types	
sand flats mud flats	
Ice Season	• 4-month open-water season (July to October)
	
Tidal Range	• 6 m increasing to 10 m in the north
	

8

8.8 United States of America (Alaska)

Ice affects the shores of Alaska as far south as Bristol Bay and the northern Aleutian Islands in the Bering Sea and also those of Cook Inlet and Prince William Sound on the northern Gulf of Alaska coast. The regional coastal trends are east-west, due to the orientation of the Brooks Range. These mountain trends have produced a series of three large embayments on the Bering Sea coast: Bristol Bay, Norton Sound, and Kotzebue Sound. The Aleutian chain is an island arc that stretches nearly 2 000 km into the north Pacific.

Beaches are common throughout the region as sediment is supplied by the coastal erosion of glacial deposits and by the many large rivers that reach the coast (Colville, Kobuk, Yukon, Kuskokwim and Susitna). The coasts of the Beaufort and Chukchi Seas are lowland tundra environments, with extensive barrier beaches and lagoons.

The permanent polar pack remains close to the Beaufort Sea coast during summer months, and in some years, the open-water areas are only a few kilometres in length. Open-water fetch distances increase rapidly into the Chukchi and northern Bering Seas and the ice-free season usually is greater than 6 months south of Norton Sound. The Bering Sea has high-energy coasts during the open-water season due to the effects of storm-generated waves. Cook Inlet is an anomaly on the southern Alaska coast and has ice for up to 5 months each year, whereas the adjacent waters of Prince William Sound, at the same latitude, are ice-free all year. The tidal range is low in all northern coastal areas, increasing to 7 m at the head of Bristol Bay to over 11 m at the head of Cook Inlet. Winter conditions in Cook Inlet are difficult from an operational viewpoint, due to the combination of strong tidal currents and the presence of pack ice. Wind surges are a significant phenomenon during the open-water season on the Beaufort and Chukchi Sea coasts, due to the low angle backshore and nearshore slopes.

The area of Alaska that is covered by this Guide has been divided into six regions as shown below. Each region is described in terms of coastal zone character, shoreline type, wave exposure and ice season, and tidal range.

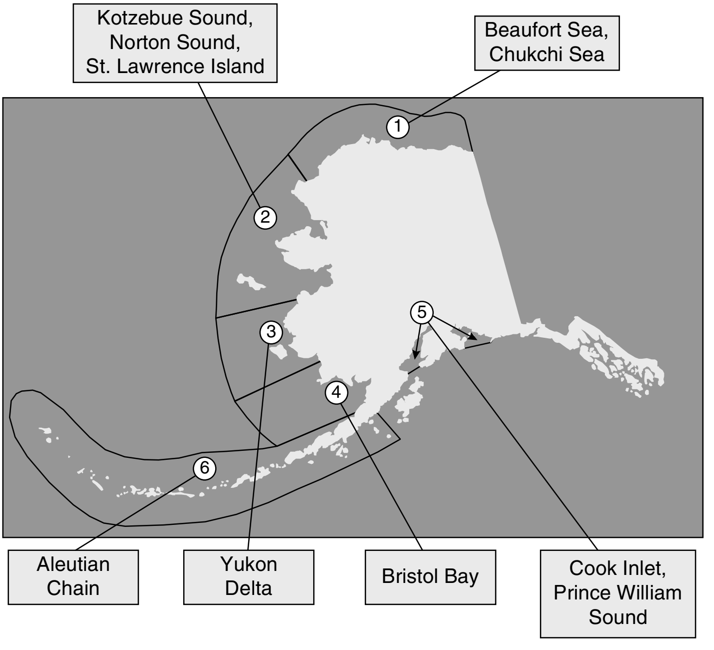


Figure 8 - 9 Arctic Alaska

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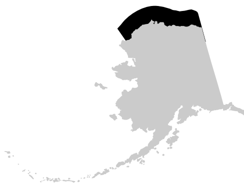
Zone ① Beaufort Sea, Chukchi Sea



Coastal Zone Character

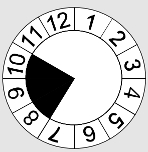
lowland/coastal plain
deltas
barrier islands/beaches
tundra coast

Shoreline Types

sand beaches
peat shores
low tundra shores
tundra cliff shores

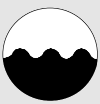
- low tundra plain
- barrier beaches and barrier islands with lagoons and inundated lowland tundra, and sections of rapidly eroding tundra cliffs
- Colville and Canning Rivers have large deltas: smaller deltas common elsewhere

Ice Season



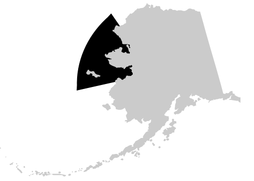
- permanent polar pack ice stays close to shore all year so limited areas for wave generation
- 3 months open-water season (August to October)

Tidal Range



- less than 0.25 m

Zone ② Kotzebue Sound, Norton Sound, St. Lawrence Island



Coastal Zone Character

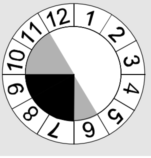
upland or mountains
lowland/coastal plain
barrier islands/beaches

Shoreline Types

bedrock shores
sand beaches
mixed-sediment beaches

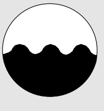
- mixed coasts with upland and mountainous relief at headlands and lowland beaches in embayments
- extensive sand barrier beaches in Kotzebue Sound and on the St. Lawrence Island
- St. Matthew and Diomede Islands predominantly bedrock cliffs and narrow beaches

Ice Season



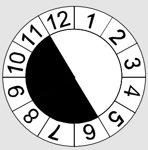
- open water for 3 months (July to September) in northern areas, increasing south to 6 months (June to November) in Norton Sound and the St. Lawrence Islands

Tidal Range



- 0.5 - 1.0 m

Zone ③ Yukon Delta

Coastal Zone Character	
lowland/coastal plain delta tidal flats tundra coast	• large lobate delta with numerous (12) channels, marshes, and islands and extensive mud flats • lowland tundra
Shoreline Types	
mixed-sediment beaches sand flats mud flats marshes low tundra shores tundra cliff shores	
Ice Season	• open water for 6 months (June to November)
	
Tidal Range	• 1.0 - 1.5 m
	

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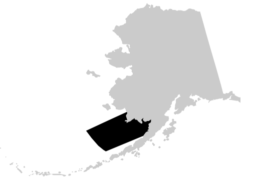
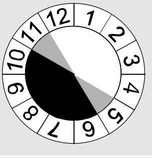
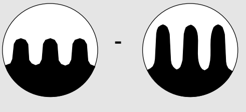
Zone ④ Bristol Bay



Coastal Zone Character	• lowland coastal plain with extensive mud flats • the Pribilof Islands are predominantly bedrock cliffs with narrow beaches
lowland/coastal plain tidal flats	
Shoreline Types	
mixed-sediment beaches sand flats mud flats	
Ice Season	• high wave-energy coast during the 5 to 7 month open-water season (maximum May to November) • the Pribilof Islands are near the southern ice limit; occasional sea ice in March or April
	
Tidal Range	• 3 - 7 m
	

Zone ⑤ Cook Inlet, Prince William Sound

Coastal Zone Character

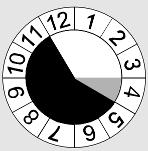
upland or mountains
fiord coast
tidal flats
ice shelf

Shoreline Types

bedrock shores
pebble/cobble beaches
sand flats
mud flats
marshes

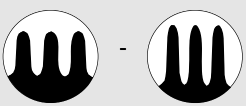
- beaches predominantly coarse-grained sediments
- Cook Inlet is a funnel-shaped estuary with extensive mud tidal flats and marshes
- Prince William Sound has a fiord coast with calving glaciers in some sections

Ice Season



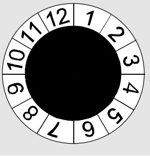
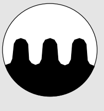
- Cook Inlet and Prince William Sound have sheltered wave environments
- Cook Inlet has strong tidal currents, and shore-zone fast ice and pack ice for 4 - 5 months (November to April)
- Prince William Sound is ice-free

Tidal Range



- 3 - 11 m

Zone ⑥ Aleutian Chain

Coastal Zone Character upland or mountains **Shoreline Types** bedrock shores pebble/cobble beaches	• volcanic island chain • high relief with cliff coasts and bedrock outcrops on most islands • beaches are rare and usually coarse sediment
Ice Season 	• high wave-energy coasts all year • ice-free coasts at the southern limit of the maximum ice extent
Tidal Range 	• strong tidal currents in many channels • 1.0 - 2.0 m

8

8.9 Photographs of Shore Types of the Arctic Region

The 14 shore types described in Section 5.11 are illustrated with colour photographs.

Shoreline Type	Figure(s)
bedrock	8 - 10
man-made solid structures	8 - 11
ice or ice-covered shores	8 - 12, 8 - 13
sand beaches	8 - 14
mixed-sediment beaches	8 - 15
pebble/cobble beaches	8 - 16
boulder beaches	8 - 17
sand flats	8 - 18
mud flats	8 - 19
salt marshes	8 - 20
peat shores	8 - 21
inundated low-lying tundra shores	8 - 22
tundra cliff shores	8 - 23, 8 - 24
shorelines with snow	8 - 25

Figures 8 - 26 to 8 - 29 depict shorelines in winter conditions. Figures 8 - 30 to 8 - 32 illustrate oil in snow and ice.

Figure 8 - 10 Bedrock coast, Labrador, Canada

Figure 8 - 11 Man-made solid structure: dock of pilings and sheet metal, Prudhoe Bay, Alaska

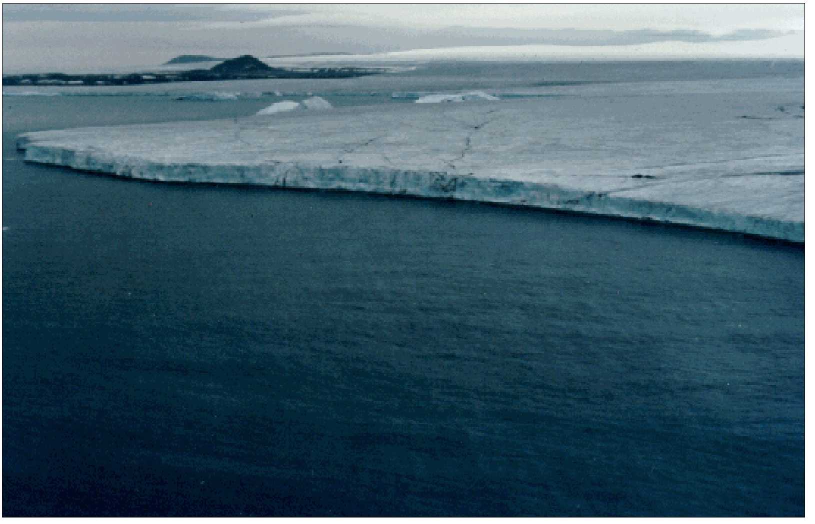


Figure 8 - 12 Ice shelf, southwest Devon Island, Canada

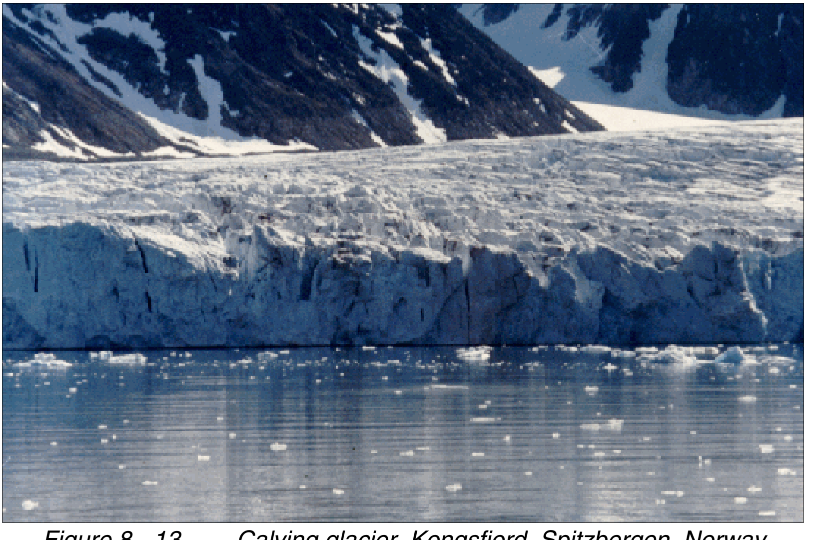


Figure 8 - 13 Calving glacier, Kongsfjord, Spitzbergen, Norway

Figure 8 - 14 *Sand beach, Sakhalin Island, Sea of Okhotsk, Russia*

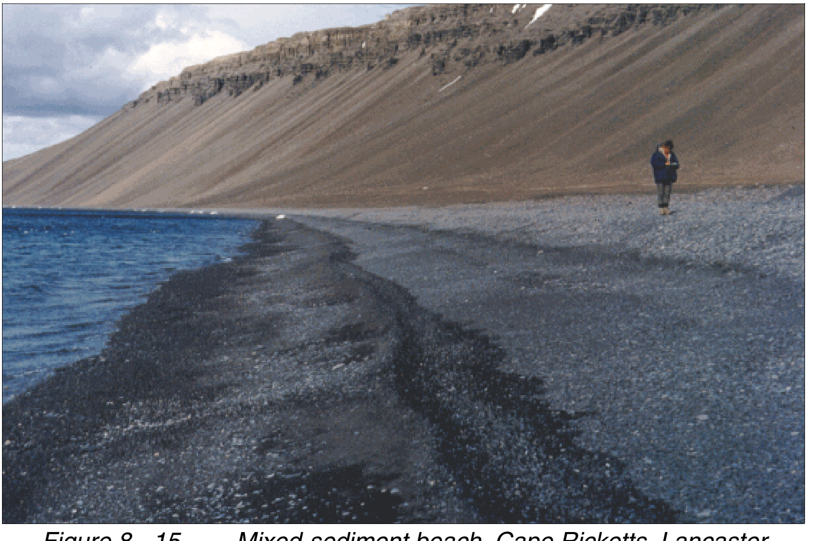


Figure 8 - 15 *Mixed-sediment beach, Cape Ricketts, Lancaster Sound, Canada*

Figure 8 - 16 Pebble beach, Ny Ålesund, Spitzbergen, Norway

Figure 8 - 17 Boulder beach, Cartwright, Labrador, Canada

Figure 8 - 18 Sand-mud tidal flat with boulder barricade, Cartwright, Labrador, Canada

Figure 8 - 19 Mud flat with drying cracks on river bank, Kupigruak Channel, Colville River, Alaska

Figure 8 - 20 *Salt marsh with stranded ice floe and broken surface due to ice action tearing clumps and patches of marsh grass, St. Lawrence River, Quebec, Canada*

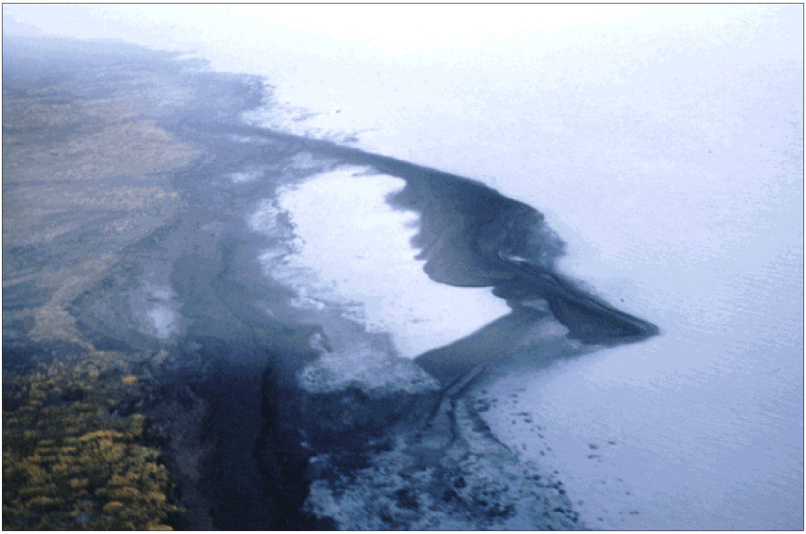


Figure 8 - 21 *Peat shore, Foggy Island Bay, Beaufort Sea, Alaska*

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Figure 8 - 22 *Inundated, low-lying tundra near Ikpikpuk River, Beaufort Sea, Alaska*

Figure 8 - 23 *Ice-rich tundra cliff, Point Brower, Beaufort Sea, Alaska*

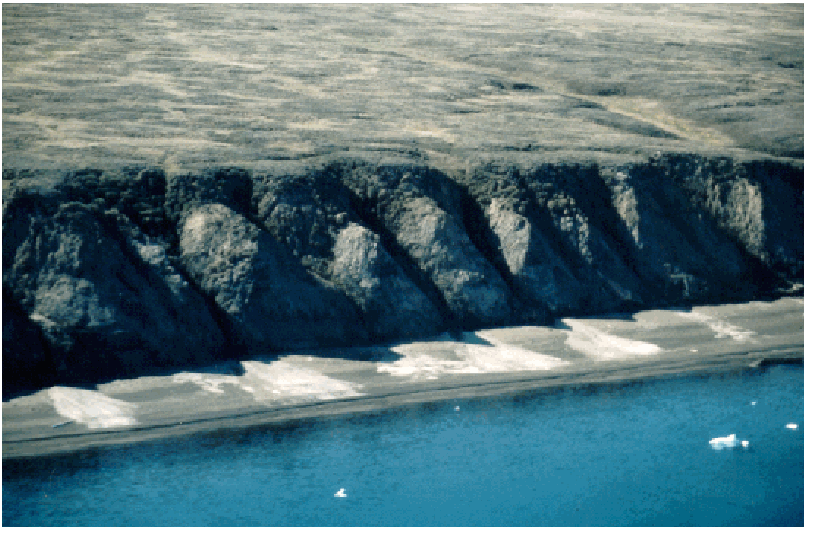


Figure 8 - 24 Ice-poor tundra cliff, Peard Bay, Chukchi Sea, Alaska

Figure 8 - 25 Winter shoreline, tundra cliff at Peard Bay, Alaska (same location as 8 - 24)

Figure 8 - 26 Shore zone covered with snow, Prince William Sound, Alaska

Figure 8 - 27 Ice foot forming on a sand beach, Gulf of St. Lawrence, Canada

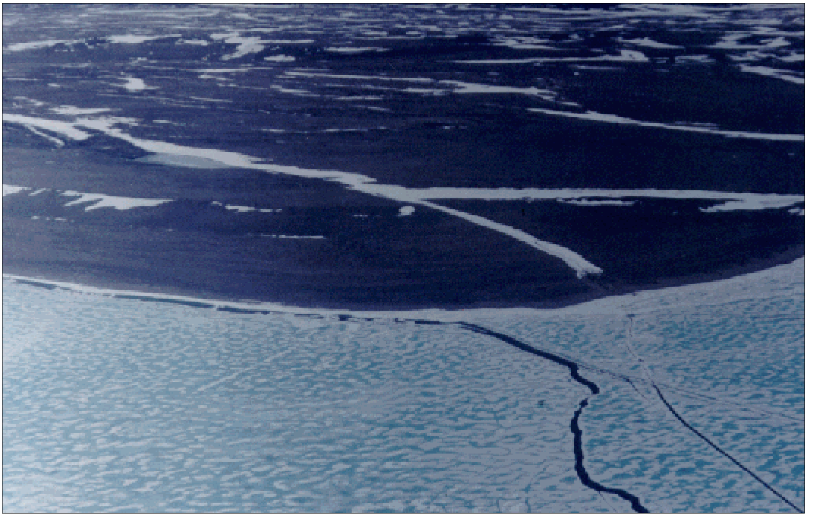


Figure 8 - 28 *Leads that often develop in solid ice where pooled oil can be burned or skimmed*

Figure 8 - 29 *The ice-free, lee-side of an artificial island in dynamic, broken ice where the mechanical recovery of oil may be possible*

8

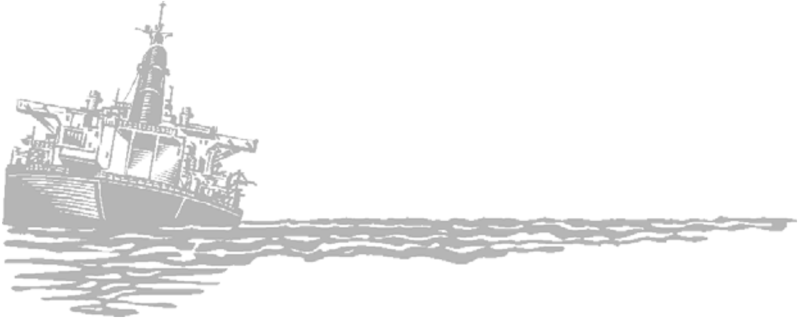
Figure 8 - 30 Oil widely distributed in small ice forms near shore; no countermeasures approach is practical

Figure 8 - 31 In-situ burning of pooled oil in an ice lead, Kolva River, Komi Republic, Russia

Figure 8 - 32 Globules and droplets of oil adhering to a chunk of ice; recovery of the oil is difficult

8

9 References and Bibliography



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Legend

Countermeasures Methods

A	mobile floating barriers	B	stationary barriers
C	subsurface barriers	D	berms
E	trenches or slots	F	diversion booming

A	advancing skimmers	B	stationary skimmers	C	vacuum systems
A	burning oil on water contained in booms	B	burning oil on ice	C	burning oil in broken ice

A	vessel dispersant application	B	aerial dispersant application

Shoreline Treatment Methods

1	natural recovery	2	flooding
3	low-pressure, cold-water wash	4	low-pressure, warm- or hot-water wash
5	high-pressure, cold-water wash	6	high-pressure, warm- or hot-water wash
7	steam cleaning	8	sandblasting
9	manual removal	10	vacuum systems
11	mechanical removal	12	vegetation cutting
13	passive sorbents	14	mixing
15	sediment relocation	16	burning
17	dispersants	18	shoreline cleaners
19	solidifiers and visco-elastic agents	20	nutrient enrichment/bioremediation

Countermeasures Methods

○	good/recommended	◒	fair/conditionally recommended	●	poor/not recommended

Arctic Region Map Courtesy of US Central Intelligence Agency
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