



EMERGENCY PREVENTION,
PREPAREDNESS AND RESPONSE

FIELD GUIDE FOR OIL SPILL RESPONSE IN ARCTIC WATERS

(SECOND EDITION, 2017)



ARCTIC COUNCIL

ISBN 978-82-93600-29-9 (digital, PDF)

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Suggested citation

EPPR, 2017, Field Guide for Oil Spill Response in Arctic Waters (Second Edition, 2017). 443 pp.

The revised second edition was funded by the Oil Spill Recovery Institute, Prince William Sound Science Center in Cordova, Alaska, as a project of EPPR.

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This EPPR project was led by the United States, with contributions for Arctic States, Permanent Participants, and Arctic Council Working Groups.

Published by

Arctic Council Secretariat

This report is available as an electronic document from the Arctic Council's open access repository: <https://oaarchive.arctic-council.org/handle/11374/2100>

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Inside cover painting "Arctic" by Christopher Walker



Field Guide for Oil Spill Response in Arctic Waters

(Second Edition, 2017)



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.

Regardless of suggested response strategies and procedures shown in this Guide, it is expected that individual Nation's will follow their respective national response system protocols.

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	Environments
 open water (water is free of any ice forms)	 seas
 freeze-up (new ice is forming)	 lakes
 breakup (mature ice is melting)	 rivers
 frozen (ice is solid, usually continuous)	 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 molasses)	 heavy (like tar)

ABOUT EPPR

The Arctic Council was established in 1996 as a high-level forum to provide a means for promoting cooperation, coordination, and interaction among the Arctic States, with the involvement of the Arctic indigenous communities and other Arctic inhabitants. The Council focuses its work on matters related to sustainable development, the environment, and scientific cooperation through six standing Working Groups with input from expert groups and ad-hoc task forces.

Emergency Prevention, Preparedness, and Response (EPPR) Working Group, one of the six standing working groups, is mandated to contribute to the prevention, preparedness and response to environmental and other emergencies, accidents, and Search and Rescue (SAR). While not an operational response organization, members of the Working Group conduct projects to address gaps, prepare strategies, share information, collect data, and collaborate with relevant partners on capabilities and research needs that exist in the Arctic. Projects and activities include development of guidance and risk assessment methodologies, coordination of response exercises and training, and exchange of information on best practices with regards to the prevention, preparedness and response to accidents and threats from unintentional releases of pollutants and radionuclides, and to consequences of natural disasters.

EPPR strives to be the premier international forum for collaboration on prevention, preparedness and response issues in order to advance risk mitigation and improve response capacity and capabilities in the Arctic.

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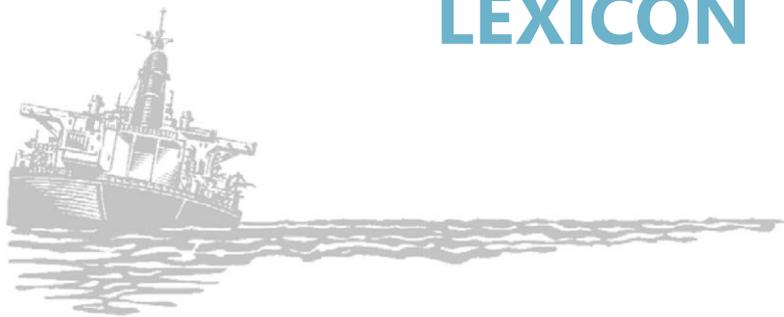
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LEXICON



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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

-  mobile floating barriers
-  stationary barriers
-  subsurface barriers
-  berms
-  trenches or slots
-  diversion booming
-  advancing skimmers
-  stationary skimmers
-  vacuum systems
-  burning oil on water contained in booms
-  burning oil on ice
-  burning oil in broken ice
-  vessel dispersant application
-  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



neutrally buoyant oil submerged under open water



oil on water surface mixed in ice



neutrally buoyant oil submerged under broken ice



oil beneath ice



oil on ice



neutrally buoyant oil submerged under solid ice

1.7 Shoreline Treatment Methods



natural recovery (general method)



washing/recovery (general method)



physical removal (general method)



in-situ treatment (general method)



chemical/biological (general method)



natural recovery



flooding



low-pressure, ambient-water wash



low-pressure, warm- or hot-water wash

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- 5 high-pressure, ambient-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 sediment 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 (flows readily like water)



medium (pours slowly like molasses)



heavy (barely flows like tar)

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INTRODUCTION



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2.1 Introduction

2.1.1 Purpose

This Field Guide has been developed to provide circumpolar countries with operational oil spill response guidance specific to the unique climatic and physiographic features of the Arctic environment. The Field Guide is a companion to the “*Guide to Oil Spill Response in Snow and Ice Conditions in the Arctic*” (EPPR, 2015), which focuses on the strategic aspects of planning and operations.

2.1.2 Objectives

The Field 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 and in nearshore and shoreline environments. Yet much of the Arctic and subarctic marine areas are 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 or other regions with seasonal ice cover (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 ^{NOTE}
- need to improvise a 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

^{NOTE} Southerly areas with extensive marine activities and an annual ice cover for a significant portion of the year may have much more extensive logistics infrastructure, e.g. Canada/US Great Lakes, Baltic Sea, Bohai Bay.

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 (1998).

Table 2.2. *The definition of Arctic for individual countries*

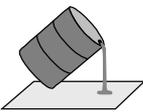
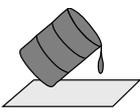
 Canada	(1) the Northwest Territories, Nunavut and the Yukon Territory, (2) the coastal zone and waters of Hudson Bay, James Bay, Quebec north of 60° and Ungava Bay and (3) all contiguous seas including the Arctic Ocean and the Beaufort Sea
 Kingdom of Denmark	Greenland
 Finland	the provincial district 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 sub-arctic cold regions such as the Baltic Sea, North Caspian Sea, Sea of Okhotsk, Bohai Bay, and the Canadian/US Great Lakes.

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		
Light	Medium	Heavy
		
free flowing (like water)	slowly pouring (like molasses)	barely flowing (like tar)
<ul style="list-style-type: none"> ● diesel ● gasoline ● heating oil ● kerosene 	<ul style="list-style-type: none"> ● Bunker A ● Fuel Oil No.4 ● lubricating oil ● medium crudes 	<ul style="list-style-type: none"> ● Bunker B and C ● Fuel Oil No.6 ● weathered crudes ● bitumen

In this Field 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 (seasonal 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 the techniques and strategies recommended in this Guide may not be applicable in some situations. Importantly, the 2015 EPPR Response Guide provides the decision and response planning context for material presented in this Field Guide.

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 oil products or crude oils used locally is essential 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 Safety Considerations

Basic safety concerns of Arctic and other ice- and snow-covered regions are related to operating with 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 and other cold climates, 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, and are discussed in more detail in Section 8 in this Field Guide and in Part VII of the 2015 EPPR Response Guide.

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 and cold climate 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

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- 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 also are 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.

2.5 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 (Section 7.3). These decisions are developed taking into account 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 (Section 7.4). The objectives of response operations are to limit the spread of the oil and minimize the im-

pacts 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.

This assessment process, is called **Net Environmental Benefit** analysis (NEBA) (Section 7.5), and more recently in a more expanded form as Spill Impact Mitigation Analysis (SIMA). The potential effects of the spilled oil and the response actions on subsistence harvesting or other activities with economic impacts are always of serious concern to local residents, and are included in the decision process for determining protection/response priorities.

NEBA/SIMA is discussed briefly where applicable throughout the Field Guide as a key aspect to selecting optimal, environmentally-acceptable response strategies. However, this guide does not examine potential environmental effects associated with specific methods. This important topic also is addressed in Chapter II-4 of the 2015 EPPR Response Guide and in IPIECA (2015).

In summary, the decision process to select appropriate response actions and priorities takes into account among many other variables unique to a particular incident:

- 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

2.6 Organization and Format

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

Section 3	<p>FIRST RESPONDER’S GUIDE</p> <p>Response strategies are described in the context of:</p> <ul style="list-style-type: none"> ● source control ● the control of free oil ● protection <p>Marine, lake, river environments are considered separately.</p>
Section 4	<p>SHORELINE TREATMENT STRATEGIES</p> <p>Shoreline treatment strategies and techniques are outlined for 14 shore types for ocean coasts, lake shores and river banks of Arctic regions.</p>
Section 5	<p>RESPONSE METHODS</p> <p>Information is provided (related to the strategies described in Sections 3 and 4) on response methods or tools for removing or treating oil on water, in ice or on shorelines.</p>

Five sections in Part B (“Technical Support Information”) provide information that is vital to an understanding of the Arctic environment and to the development of an effective response.

Section 6 & 7	<p>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.</p>
Section 8 & 9	<p>New, second edition, sections that relate to HUMAN HEALTH AND SAFETY and WILDLIFE RESPONSE in the Arctic.</p>
Section 10	<p>The COASTAL CHARACTER of the Arctic is summarized according to geographic regions.</p>

2.7 Sources

The original 1998 Field Guide drew from numerous sources and handbooks.

For countermeasures on oil/ice/water, references included *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 Baffin Island Oil Spill (BIOS) Experiment (Sergy and Blackall 1987), 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 techniques were 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 (1995)*; *CONCAWE (1981, 1983)*; *Exon USA (1992)*; *ITOPF (1987)*; *Kerambrun (1993)*; *Michel, et al. (1994)*; *MPCU (1994)*; *NOAA (1994)*; and *Owens (1994)*. Sources that relate to Arctic coasts included *Bird and Schwartz (1985)* and *Owens (1994)*.

This updated Field Guide (2017) has drawn on a substantial body of new work related to Arctic oil spill response identified in Section 10 - References and Bibliography. Examples include:

- The many reports and publications originating with the Arctic Response Technology Joint Industry Project (IOGP, 2012-2017) <http://www.arcticresponsetechnology.org>

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- The SINTEF Oil in Ice Joint Industry Project (2006-2009) summarized by Sorstrom et al. (2010) <http://www.sintef.no/projectweb/jip-oil-in-ice/>
- Tests to determine the limits of in-situ burning in brash and frazil ice (Buist et al. 2003)
- EPPR (2005) report *The Arctic SCAT Manual – A Field Guide to the Documentation of Oiled Shorelines in Arctic Regions*
- EPPR (2009) report on *Guidelines and Strategies for Oil Spill Waste Management in Arctic Regions*
- SINTEF Shore-ice formation study by Øksenvåg et al. in the 2009 AMOP Proceedings.
- Alaska Department of Environmental Conservation (2010) report on *Tundra Treatment Guidelines: A Manual for Treating Oil and Hazardous Substance Spills to Tundra*
- Environment Canada report *Field Guide to Oil Spill Response on Marine Shorelines* (Owens and Sergy 2010)
- Paper covering oil in ice behaviour and the history of major oil-in-ice field experiments (Dickins 2011)
- Summary of the use of herding surfactants to thicken oil spills in ice for burning (Buist et al. 2011)
- Use of controlled burning during the Gulf of Mexico Deep-water Horizon response (Allen et al. 2011)
- National Research Council (2014) report – *Responding to Oil Spills in the US Arctic Marine Environment*
- Testing of Oil Recovery Skimmers in Ice at Ohmsett (Schmidt et al. 2014)

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- Topic papers on different arctic response strategies prepared as part of the National Petroleum Council report (2015), <http://www.npcarcticpotentialreport.org/topic-papers.html>
- Testing of Skimmer Systems at the Ohmsett Facility (McKinney and DeVitas 2015)
- Alaska Clean Seas Technical Manual (2015 update)
- A series of API reports (API 2013 - 2016) on shoreline treatment including sand beach protection, sand beach mechanical treatment, sand beach bioremediation, subsurface oil detection on beaches, oil spill response in marshes, and tidal inlet protection, <http://www.oilspillprevention.org/oil-spill-research-and-development-cente>
- EPPR (2015) report *Guide to Oil Spill Response in Snow and Ice Conditions in the Arctic*

PART A

OPERATIONS

3

FIRST RESPONDER'S GUIDE



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3.1 Introduction

This section provides practical countermeasures guidance for first responders; that is, personnel with a range of technical experience who serve as local, trained, community or regional responders and are typically first at the scene of a spill. Because a responder might receive very limited information when alerted about a spill, response strategies are discussed in this section in the context of environment; seas, lakes, rivers or shorelines (Figure 3.1). Seasonal considerations are also addressed.

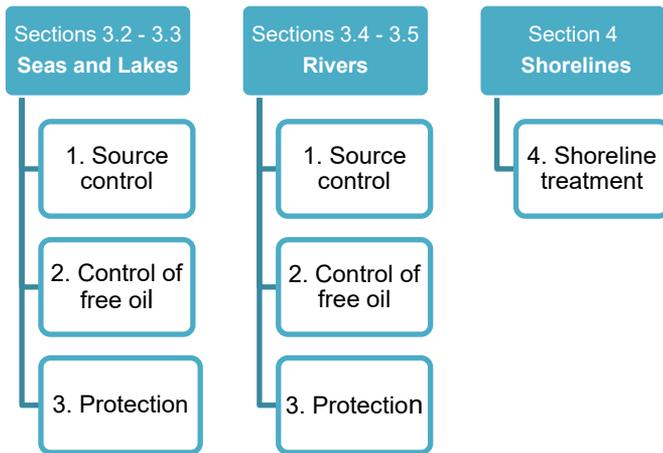


Figure 3.1. Organization of Sections 3 and 4

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 seas and lakes (Section 3.2), source control and off-site control of free oil are combined and discussed as an integrated activity because at-source and off-site response options are almost identical for both seas and lakes. For rivers (Section 3.4), the distinction between the two strategies is maintained.

Shoreline response is discussed separately in Section 4.

For each sea/lake and river situation, a set of four stand-alone tables (e.g. Table 3.1) identify:

environmental conditions - season, water/ice conditions and oil location

response techniques - countermeasure options, the feasibility of these options, and waste management issues

In each table, four seasons are defined as follows:

open water - water is free of any ice forms.

freeze-up - new ice is forming.

breakup - winter ice is melting.

frozen - solid, continuous ice is present.

In each case, the table indicates possible response techniques; that is, 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 Section 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., , are used to denote countermeasures methods in the four summary. The icons are defined in legends on the inside covers and in Section 1; corresponding countermeasures are explained in more detail with references to recent research in Section 5.

STRATEGY 4 → Shoreline treatment

On most large spills, and on some smaller ones, shoreline 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 4.1) are described in Section 4 with a stand-alone table that presents appropriate treatment methods for each shore type.

Details on each of the specific response methods or tools for each of the four strategies listed above are provided in Section 5.

Text bullets in Section 5 refer to:

- ✓ recommended strategies or techniques
- ✘ techniques considered to be inappropriate

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

Assessing conditions and carefully planning a response in the Arctic before taking action are the key priorities (Section 8).

Once the safety of nearby personnel, e.g. ship's crew, rig workers, etc., is assured, the overall objective of initial 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 explained in Section 7. These include:

- Assess the situation. (A quick evaluation of the area should consider local knowledge of currents, ice movements and shoreline composition. Baseline videos and satellite images 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 decides on practical approaches to minimize the spread of oil with the resources available. To carry out such actions, the following general guidelines are recommended:

- Think before acting.
- 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 if safe to do so.

Personnel who respond to cold-climate oil spills must be trained in the hazards associated with exposure to low temperatures, accidental immersion in cold water and other causes of hypothermia.

After ensuring that there is no on-going risk to human life, health, and safety, the first and highest priority is always to stop or reduce the discharge. In the case of a vessel accident, this may involve implementing a lightering operation, such as was conducted with the T/V *Exxon Valdez* response, or applying conventional salvage techniques with temporary patches if possible to stem the flow of oil from damaged tanks or ruptures in the hull. In some cases, it may be necessary to seek a “safe haven” or refuge in protected waters to carry out these operations. Decisions and approvals to move a damaged vessel are complex and subject to multiple levels of government oversight at the national, regional, and local levels.

3.1.1 Response Infrastructure and Logistics in Arctic Marine and Coastal regions

Response strategies in the Arctic Ocean and coastal zones are often constrained by remoteness, which is characterised by sparse local populations and infrastructure, few ports and long supply lines.

In contrast, more southerly areas that experience seasonal ice, such as the Gulf of St. Lawrence, Great Lakes, North Hokkaido-Sea of Okhotsk, and the Baltic Sea, are characterised by much denser coastal populations with correspondingly higher levels of infrastructure and logistics capacity (airports, roads, ports, etc.) to support a large-scale spill response.

An initial remote area response to an accidental spill in ice and/or remote areas may need to rely primarily on airborne strategies and support. It could take many days for additional response vessels to access many areas, even in summer months. In winter, there are few high polar class icebreakers (outside of Russia) that could reach a remote spill site and many of these ships are not available on short notice.

Shoreline and coastal operations may be constrained in tundra

areas for a large part of the year as these environments are extremely vulnerable to surface disturbance during the summer melt periods.

The limitations imposed by lack of infrastructure should encourage the selection of response strategies that place minimal demands on the sparse local infrastructure and long lines of resupply (EPPR 2015). Some exceptions might apply where a response could take advantage of existing infrastructure and include local support, e.g., airstrip and fishing vessels.

Generally, however, the constraints imposed by remoteness favour countermeasures that can be mounted rapidly over long distances and that rely on air support; for example, aerial ignition, and dispersants, as opposed to an over reliance on mechanical recovery with its subsequent generation of large oily waste volumes that require disposal at approved sites (rarely available in the Arctic).

Remote area operations may involve a range of support “resources of opportunity”, such as:

- aircraft and icebreaking/ice strengthened support vessels
- excursion boats, fish processing vessels, barges, military and coast guard vessels

Resources such as vessels of opportunity and helicopters that could be applied locally on short notice to an accidental spill in the Arctic are mostly limited to the, often relatively short, summer open-water season. Note: this constraint applies to the true “Arctic” as opposed to more southerly areas also covered by this guide.

3.2 Seas and Lakes

3.2.1 On-water Control with and without ice cover

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

NOTE: Separate sub-sections include extensive operational guidelines on applying countermeasures to spills in open water, frozen conditions and during the transition seasons of freeze-up and breakup.

3.2.2 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 efficiencies are significantly reduced, and potentially not possible, and/or increasingly unsafe, for many mechanical recovery systems in wave heights exceeding 2 m or in winds of more than 35 km/h. Specialized open ocean boom and skimmer systems developed for the Norwegian North Sea may have higher operational limits (e.g. waves to 3 m and winds to 55 km/h). Containment booms and skimmers should be deployed downdrift from, and as near as possible to, the release point to minimize spreading. Containment of submerged oil might be possible near or at the source using an oil trawl boom.

In the frozen winter season with stable solid ice, oil can sometimes be contained in ice slots cut into the surface. Oil submerged below solid ice can sometimes be contained using a boomed ice slot. With very open pack ice concentrations (30% or less ice coverage) it may be possible to boom oil trapped by wind effects against large ice floes. In general, the use of booms is difficult in any pack

ice over 10% coverage.

3.2.3 In-situ Burning

In-situ burning of oil can be effective on open water, among or on top of ice floes, or in a natural embayment. In many 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 quickly become less effective as ice concentrations exceed 10% coverage. Alternatively, herders can be applied around the perimeter of a slick from the air or small boats in moderate sea states (no breaking waves), and low wind situations. The resulting thickening of the slick can produce conditions for effective ignition and burning without the use of booms. With booms, in-situ burning on water is generally restricted to sea conditions in which containment and recovery are feasible, i.e., long-period waves less than 2 m and winds less than 35 km/h. In the case of herders, seas should be less than 1.5 m without breaking waves and winds less than about 12 km/h.

3.2.4 Chemical Dispersion

Breaking waves higher than 1 to 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 be applied at or near the spill source. Vessels with spray arms, and helicopters with spray buckets can cover small areas or, if broader area coverage is required, fixed-wing aircraft can be utilized.

Dispersants are effective in a range of ice conditions. The slower oil weathering processes in the presence of ice can expand the window of opportunity for dispersant application. As energy levels in the upper water column tend to diminish in very high ice concentrations (>60%) supplemental mixing energy may be required.

This can be provided by directing the stern drives of support vessels to mix the oil and dispersant. Injecting dispersants at a sub-sea wellhead provides another potentially valuable Arctic strategy.

3.2.5 Operational Considerations

3.2.5.1 *Safety and Response Feasibility*

There are a number of concerns and issues to take into account when responding to spills on water or in the presence of ice at sea or on 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.
- Waves can build quickly in shallow water nearshore or in lakes, presenting a significant safety consideration for small boat operators.
- In longer-period swells (wave period over 6 seconds), mechanical containment and recovery, in-situ burning and dispersants are all possible.
- As the wave period decreases and the percentage of breaking waves increases, mechanical and burning options become less viable. For example, containment, recovery, burning and chemical dispersion are not feasible options on highly viscous oil in short-period (1 - 2 second) breaking waves higher than 1 m.
- When slicks on the water surface, or oil films on top of the ice are thinner than 1 mm some means must be found to increase the thickness, either to facilitate skimming operations or enable in situ burning. At present, the only viable countermeasure

to deal with oil layers trapped beneath or within the ice involves waiting for the oil to surface in spring melt. Monitoring the spill in the interim may be the only practical option.

- Generally, dispersant application and burning are feasible in colder climates for two to five days following a spill due to lower evaporation rates. Field trials have proven that oil on the ice surface can be successfully burned after several weeks of exposure.

3.2.5.2 *Open Water – Operational Considerations*

Tracking and Surveillance

Slick tracking and surveillance can utilize a variety of platforms (satellites, helicopters, fixed wing and unmanned air vehicles, Aerostats), trajectory model predictions, GPS and or AIS drifter buoys, and sensors (LLTV, IR/UV, SLAR and SAR, high speed marine radar etc.) to determine optimum response strategies that can be applied to priority areas:

- 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.

Containment

- 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. Longer lengths of boom (>300m) are susceptible to damage and failure during prolonged deployment.

- In open water, 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.
- Booms are generally effective in currents less than 0.5 m/s (1 knot)

Recovery

- Combined boom-skimmers can be effective at relative velocities of several knots with light-to-medium viscosity oil in open water (Section 5.4.1)
- 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.
- Large volume skimming weirs can be used when oil/water separation is available or when there are large accumulations of thick, unemulsified oil.
- Spilled oil that might sink should be controlled before it submerges, if possible. Locating submerged oil is difficult, and control and collection are even more difficult.
- If brush or belt skimmers cannot collect heavy, floating oil then trawl systems can be tried for recovery.
- In addition to the above skimmers, water-based working platforms for oil recovery are useful when equipment cannot be readily set up on the shore of a lake.
- Planning adequate storage capacity is critical to the entire response operation to avoid operational bottlenecks and loss of throughput.

- Storage options include barges, towable tanks, tankers and/or other means that are appropriate for the type and volume of oil being recovered. For Arctic incidents in remote locations, the lack of storage and disposal options can quickly become serious impediments to the success of continued mechanical recovery.

Dispersion

Spills must be assessed to determine if dispersants will be effective:

- 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.
- Unless some means of adding mechanical mixing energy (e.g., vessel stern drives) are available, there needs to be sufficient surface water turbulence to initiate and sustain the dispersion process.
- In conditions of high sea states such as breaking waves over 1 m, natural dispersion may be the most effective strategy (i.e., no response).

Dispersion is not usually considered in northern lakes due to low water circulation/dilution and potentially adverse environmental impacts. In addition, many dispersants display reduced effectiveness in low salinity water. If used at sea, both vessels and aircraft can be used to apply dispersants. Operations should be directed from aerial vantage points – as with any surface response operation, spotter aircraft are essential:

- Use stockpiles of chemicals located strategically to the spill site.

- Use fixed-wing planes on larger offshore spills and helicopters on smaller spills closer to shore (within range).
- Vessels are more practical and more effective for nearshore waters and smaller slicks.
- Record information on dosage rates, areas treated and apparent effectiveness so that the data can be transferred to subsequent responders.

Dispersants can be effective in high sea state conditions when oil properties are appropriate (see Section 5.6). However, breaking waves usually provide sufficient mixing energy to distribute oil naturally into the water column without the need to add chemical dispersants.

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. Effective dispersion with chemicals that are applied subsea at source (SSDI) can occur at much lower dose rates. The American Petroleum Institute recommended dose rate for SSDI is 100:1 (Nedwed, 2017).

In situ Burning (ISB)

- 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.
 - Currents should be less than 1 m/s (2 knots)
 - Wind speed should be less than 35 km/h (20 knots).

- An ignition system is always needed (e.g., Helitorch™; ignitors released upwind from small boats). In low wave and wind conditions, there are two choices to achieve the necessary ignitable thickness: fire-resistant booms or herders. A 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 (populations) downwind that could be affected by the smoke plume.

- Crude oil high in sulfur likely can 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. Consult established guidelines such as those prepared by the Alaska Regional Response Team (2008) to determine safe distances under different atmospheric conditions.
- Ensure that the risk of secondary fires is minimized or have the means to extinguish the burn. In the case of burning a boomed slick, the fire is rapidly extinguished in an emergency by simply increasing the tow speed to >1kt (1.85 km/h).

3.2.5.3 *Spills in Frozen Conditions – Operational Guidelines*

Frozen conditions facilitate response operations in many ways, providing a solid working platform, reduced oil mobility, slower oil weathering leading to extended windows of opportunity for dispersants and burning, and natural storage and containment on and under ice. However, darkness, extreme weather conditions and the potential for mobile, breaking ice make it necessary to maintain awareness of many safety factors.

- Personnel must wear appropriate cold weather clothing, footwear and protective gear, and be able to recognize signs of

frostbite, hypothermia and fatigue. Frequent rest breaks and warm-ups are essential as well as a strong ‘buddy’ system similar to diving.

- Diesel, heating and crude oils can remain largely unweathered and can be burned or dispersed weeks or even months after being spilled.
- Oils exposed to atmosphere at temperatures below their pour point have increased viscosity that can contribute to the complexity of their recovery, transfer and storage.
- Ice topography can be modified to contain spills, for example building snow berms to limit oil spreading on the surface.
- 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. Heat tracing and the ability to defrost equipment quickly are important.
- 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 continuous strict attention.
- Knowledge of safety is critical in remote areas (Section 8):
 - 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
- The control of oil spills at sea, on lakes and in rivers is often possible on, in and under continuous ice, with or without snow cover.
- Various structures can be built or erected, or the ice can be excavated, to facilitate the containment and removal of spilled oil. The strategies and basic techniques described below can be adapted to meet the requirements of a specific situation.
- When required, specialists should determine whether ice will safely support the weight of equipment and personnel. Published information is available that accounts for factors like the presence of cracks and leads, and ice temperature.
- Dynamic (moving) pack ice in even small concentrations interferes with, and prevents, the containment and mechanical recovery of spilled oil. Herders and the addition of mechanical mixing energy can facilitate the successful implementation of ISB and chemical dispersion of spilled oil, respectively, in a wide range of ice concentrations. Work crews can possibly work on the surface of large, thick floes offshore in the pack ice zone but any such activities require continuous monitoring for safety and an on-going risk assessment with evacuation systems such as helicopters on site. Solid landfast ice facilitates oil containment, recovery and burning. Oil usually remains unweathered under ice; therefore, burning the oil may be possible on the ice surface several weeks or even months following a spill if the oil is present in thick enough films for successful ignition.

- Spilled oil that becomes distributed in pack ice may be burned if slicks are sufficiently thick, i.e., at least 2-3 mm. ISB can still be effective even if the oil is mixed into slush and brash ice. Expect the burns to take much longer. Mechanical recovery under these conditions is limited to isolated small patches of oil trapped between floes or in leads.

Containment

Ice usually is an effective oil barrier and snow is an effective oil sorbent. Equipment, including loaders and scrapers, and manual methods can be used where safe access is available to a spill site on stable landfast ice. These methods can remove large quantities of oil and snow from the ice surface, but this mixture usually will usually have a very low oil content.

Graders, bulldozers, and snow blowers 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 synthetic 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. Continuous ice monitoring is essential whenever work parties are on the ice.
- Under-ice pockets of oil tend to accumulate in naturally-occurring subsurface depressions (i.e., areas of thinner ice corresponding to variations in snow cover):

- 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.

Recovery/Removal

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 hose fittings
- brittle failure of hoses, connectors and fittings

Dispersion

Dispersants are not applicable in solid ice; however, they have been tested successfully with oil between floes in high ice concentrations (70 to 80%) as well as proposed as an effective means to disperse oil from a subsea blowout, by injection into the escaping oil. The injection process could continue from the surface in moving ice with the necessary vessel ice management or potentially in the future from a subsea installation at the wellhead independent of ice conditions at the surface.

In-Situ Burning

Burning oil on solid ice or on snow is usually feasible and follows the same guidelines as those for open water conditions except that burning naturally surfacing oil in the spring can occur many months after a spill under solid ice.

Burning pooled oil on ice requires one or more igniters:

- A propane torch or hand-held igniters 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.
- Oil accumulations that occur in depressions, or that have been exposed by cutting through the ice, may be ignited. The air temperature appears to have little effect on the ability to ignite fresh crude either on its own or mixed with snow. A sustained burn is possible at very cold temperatures (-25°C or lower).
- Fuel can be added to initiate or promote combustion.
- When burning oiled snow on ice, it is important to trench the perimeter to contain the oil since large volumes of melt water are created that can cause the oil to spread laterally on the surface and become too thin to maintain combustion or result in safety issue.

3.2.5.4 *Spills during Transition Seasons – Operational Guidelines*

The transition seasons are characterized by a wide range of broken ice types and concentrations. During freeze-up under calm conditions large areas of unconsolidated ice crystals (called grease ice), as well as areas of smooth, thin new ice (<10 cm) can develop. With any significant wind, the new ice sheets quickly deform by buckling and riding over themselves to create multiple layers called rafting. Oil on the surface at this time will become incorporated in these deformed ice features. Breakup is characterized by larger, thicker ice floes and pieces in various states of deterioration. Much of the ice will have holes completely through, as well as many melt pools over a highly uneven surface that can

extend over vast areas.

Safety is the key response consideration in broken ice

- Do not deploy personnel or equipment on ice that might be hazardous, i.e., thin, moving, unstable, cracked, melting.
- Plan booming and/or skimming operations in slicks of several millimetres or more in open water areas, within the pack whenever possible.
- Ice movement is subject to changing wind conditions, which often requires relocation of equipment to newly-accessible slicks.

Selecting Response Strategies

Response to spills in broken ice frequently requires flexible strategies to deal with moving ice. Significant changes in ice concentration due to wind shifts should be expected.

- During early freeze-up and the latter stages of breakup (up to 30% ice cover), conventional open-water response techniques can be considered, depending on the spill area and available resources such as offshore storage and marine support. Alternative strategies involving a combination of dispersants and burning (with and without herders) should be considered, especially for larger spills covering an extensive area. Note that although certain silicone-based herders (e.g., OP40) have demonstrated continued herding in the presence of ice crystals in the water, herding agents are generally viewed as a tool that is most applicable to situations where the air temperature is above freezing, i.e., during breakup or summer.
- When possible, burn or skim wind-herded oil that collects at ice edges.

- 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. As ice concentrations decrease during breakup (e.g., <40% coverage) slicks can quickly spread to be less than 1 mm thick. In these cases a combination of applying small quantities of herder surfactant to thicken the oil followed by burning can prove effective in wind speeds less than ~ 10-13 km/h (3-4 m/s)
- If oil is widely distributed as thin films throughout broken ice in concentrations greater than ~40%, there are two practical countermeasures: (1) apply dispersants in conjunction with some form of mechanical mixing energy as required in higher concentrations; and/or (2) burning oil patches of opportunity that are wind herded against floes into thick enough slicks to ignite.
- Oil that migrates to the ice surface during the melt period presents timing and potential access problems. There is a period of three to five weeks in most areas where the oil is pooled on the ice surface and available for burning before the ice disintegrates and releases the oil as widely dispersed thin films on the water surface. The only way to safely ignite the oil during this period is aurally, by using the Helitorch™ near-shore or offshore from platforms or support vessels. In the future, it may be possible to use long-range ignition systems carried by fixed-wing aircraft and larger helicopters (IOGP 2012-2017)
- The recovery effectiveness of mechanical systems during the transition seasons is greatly diminished by the presence of any significant ice coverage. In addition, during freeze-up, vessel mobility is steadily diminished as ice conditions deteriorate.

- Once oil becomes mixed or encapsulated into the ice as freeze-up progresses there are no practical countermeasures for recovering or removing the oil unless icebreakers are used to deliberately break up the ice and release the oil for possible burning or dispersion. This concept is not proven and could create a worse situation than tracking the oil and burning in the spring as the oil surfaces naturally. In landfast ice, it may be possible to access the oiled area once the ice has thickened enough to allow safe vehicle and equipment operations. At that point, a number of response options discussed above under the 'Frozen Season' become possible – trenching and burning, or trenching and recovery to shore.
- Cold temperatures may also limit operations during freeze-up especially offshore where later ice formation is often associated with temperatures well below freezing.

Containment

The source control of spills during transition seasons requires the use of rugged, 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 fabrics 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 if not 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 when positioned in concentrated oil in open water and in leads between ice pieces:

- Time is generally less of a factor than with an open water spill since oil will tend to remain trapped in ice. However, wind can cause ice pieces to move rapidly outside the recovery area, taking the oil with it.
- Drum, brush, drum-brush and disc systems are the most useful skimmers when operated from a hydraulic arm over the side of a vessel or when positioned in localized areas of open water between floes.
- 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 still practical so long as marine resources such as icebreakers or small support vessels are available to add artificial mechanical mixing energy. When dispersants are applied to oil in low-to-moderate concentrations of ice, even with minimal wave energy, the likelihood of oil dispersion increases compared to a similar application in relatively

calm open water. Application of dispersants to spills in ice can utilize a variety of platforms such as helicopters, fixed wing aircraft and vessels.

In-Situ Burning

- In-situ burning is often the optimum response strategy for spills in broken ice when suitable conditions are met to facilitate ignition and sustained burning:
 - Maximum 25% oil emulsion.
 - Minimum slick thickness 2-3 mm.
 - Maximum waves of 2 m and not breaking.
 - Maximum wind speed 35 km/h (20 knots).
- Ignition can be conducted from the surface (small boats), or the air (manned helicopters and in the near future, potentially unmanned aerial vehicles (UAVs)).
- Where oil films are too thin to ignite and temperatures are above freezing, the application of herders in very open or open drift ice (1-6/10) can expand the opportunity to use burning during breakup. A system tested in 2016 and 2017 involves a carousel of 15 cartridge ignitors combined with a herder spray head and retractable hose reel mounted on a helicopter (IOGP 2012-2017).
- Aerial surveillance is essential to direct the application of herding agent and the deployment of ignitors. UAVs with video downlink can provide the most effective means of surveillance to assist the boat operators (IOGP 2012-2017).
- The deployment of fire-resistant boom will not often be feasible in broken ice unless positioned in the lee of an island or in another area that remains relatively ice-free.

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- A safety plan for response workers is required that addresses the sulphur content of the oil, methods of ignition, possible areas that would be affected by the smoke plume in terms of respiratory issues, emergency escape routes, and any risk of secondary fires. Safe exclusion zones for the local populace should be based on established ISB guidelines such as the multi-agency document developed by the Alaska Regional Response Team (2008). Depending on the proximity to local media outlets, a Temporary Flight Restriction should be filed with the national aviation authorities to prevent unauthorized aircraft from entering the burn area.

Table 3.1. Seas and Lakes – Control with and without Ice

Environment		Response					
Season	Water/Ice Conditions	Oil Location	Contain/Recover	Countermeasures	Disperse	Feasibility	Waste Management
	• no ice			(A)			• barge • tanker • workboat • towable tank
	• open water			(A)			
	• open water			(A) (C)			• barge • tanker • workboat
	• ice floes			(A) (C)			
	• broken ice			(C)			
	• frazil/grease ice			(C)			
	• slush			(C)			
• pancake ice				(C)			
	• solid ice			(B)			• drums • tanker truck • workboat • porta-tank
	• multi-year ice			(B)			
	• ice floes			(B)			
	• broken ice			(B)			
	• brash ice			(B)			
• ice hummocks				(B)			
	• open water			(A) (C)			• barge • tanker • workboat
	• ice floes			(C)			
	• broken ice			(C)			
	• melt polls			(C)			
• leads				(C)			

NOTE: Dispersants are not applicable to fresh-water lake environments.

3.3 Seas and Lakes Protection

The objective of protection at sea and in lakes is to prevent or minimize contact between the oil and resources at risk in the anticipated spill path. Protection involves selecting site-specific defensive strategies when source control or other on-water operations cannot intercept, contain, recover or divert slicks. At sea, all three spill response options (mechanical, burning and dispersion) may be applicable to protect sensitive or threatened areas. On lakes, the most likely response option will focus on mechanical containment and recovery, with possible in-situ burning in remote areas where permitted by agencies and local authorities.

Traditionally, the term 'Protection' when used in the context of an oil spill response has referred to the use of some sort of boom or deflector to divert oil from its natural path, to avoid contact with sensitive biological or cultural resources/habitat and to prevent where possible, oiling of the shoreline. Burning and dispersants are both countermeasures that are generally employed some distance from shore and consequently are not commonly discussed in terms of protection. Clearly, the more oil that can be removed offshore by either of these methods will greatly contribute to the success of nearshore protection activities by significantly reducing the volume of oil available to come ashore and threaten sensitive resources.

3.3.1 Operational Guidelines

Operational guidelines associated with burning and dispersants are covered in depth in Section 3.2. The following section deals primarily with response tactics that are specific to the use of booms for protection, often during the open water and transition seasons where oil can move rapidly. Protection during the frozen

season is not usually an issue as the shoreline is generally protected by a band of ice and the oil is contained under, on or in the ice with no movement. An overview of each of the three response options is first presented in the context of protection followed by more specific operational considerations that consider safety as well as the open water, ice cover and transition seasons.

3.3.2 Mechanical Diversion

The effectiveness of mechanical containment and recovery depends on the wave and wind conditions at the spill site as discussed in Section 3.2.2. In ice-free conditions and very open drift ice (up to ~10%), booms can be used to divert oil from sensitive areas.

3.3.3 In-situ Burning

Oil slicks threatening a sensitive area can potentially be burned on open water with fire-resistant boom or after thickening with herding agents. Refer to further discussion in Section 3.2.3.

3.3.4 Chemical Dispersion

Dispersants can be used in many situations involving open water and pack ice when a slick threatens a sensitive area. Dispersants can be applied to relatively small areas from a vessel or helicopter or from a fixed-wing aircraft if larger areas are involved. Note that sensitive resources below the water surface in shallow areas, e.g., shellfish, are potentially vulnerable to dispersed oil. Although some dispersant formulations are effective in fresh or brackish water, approvals to use dispersants in shallow water nearshore or in lakes are problematic in many national jurisdictions.

3.3.5 Operational Considerations – Open Water

3.3.5.1 *Safety and Response Feasibility*

Guidelines for protecting resources at risk from a spill that occurs at sea or on lakes are similar to those employed for response operations at, and remote from, the source (3.2.1). When large spills occur nearshore, the protection of one shoreline area can result in the oiling of adjacent areas unless spilled oil is mechanically removed or burned before it can escape containment.

3.3.5.2 *Containment/Recovery - Open Water*

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.

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 prevent the oiling of sensitive resources, if possible.
- Angle booms in currents of more than 0.4 m/s but no more than approximately 1 m/s to divert slicks preferably for collection so as to avoid further impacts.
- Secure and then regularly monitor anchoring systems.
- Oil recovery using small, oleophilic skimmers (disc, drum, brush and rope mops) and water or land-based storage systems are often required

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

3.3.5.3 *Spills in Frozen Conditions – Operational Guidelines*

With a winter ice cover, the containment and diversion of slicks is not usually an issue. Oil is naturally contained in relatively small areas under the ice, trapped within the ice or mixed with snow on top of the ice. Recovery and removal strategies that can be used during this season range from in situ burning to mechanical removal and transport to shore over landfast ice where safety and ice stability permit.

3.3.5.4 *Spills during Transition Seasons*

Protection strategies in broken ice may not always be possible:

- If booms are deployed in very open pack ice, they should be made of highly durable material (conveyor belting or logs). Ice movement could prevent the exclusion or diversion of slicks and quickly overwhelm and damage even the most robust and securely anchored boom systems.
- Movement of oil in broken ice close to shorelines should be expected unless the 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 remote areas with broken ice nearshore when an aerial ignition source is available. When slicks are too thin to ignite, for example in

low ice concentrations at breakup, herding agents and possibly fire-resistant booms can be used to thicken the oil.

Fire-resistant booms are difficult to deploy in ice and can be easily be damaged. Their use during freeze-up is extremely limited and not likely to be effective. During break-up fire-resistant booms can be deployed successfully to collect and burn oil among small ice pieces as long as the surrounding ice coverage is less than 30% (Potter and Buist, 2010).

- Oil that concentrates at ice edges or is trapped in ice leads can be burned when at least 2 - 3 mm thick.
- In very open pack ice conditions at breakup, herding agents can be applied from small boats or a helicopter system, and ignited from the surface or using a helicopter tool such as the integrated herder/burn system developed through the IOGP 2012-2017.
- ✦ Although theoretically possible, chemical dispersion in shallow waters nearshore as a protection measure is unlikely to receive the necessary state and federal approvals Note that the long-term environmental impacts on the intertidal benthic community through the use of dispersants in very shallow water has been determined to be no more severe, and in some cases preferable, to allowing the oil to strand onshore.

Table 3.2. Seas and Lakes - Protection

Environment:		Response:				
Water/Ice Conditions	Oil Location	contain/recover	burn	disperse	Feasibility	Waste Management
<ul style="list-style-type: none"> no ice open water 			(A)	(A) (A)	○ ●	<ul style="list-style-type: none"> barge tanker workboat towable tank
<ul style="list-style-type: none"> open water ice floes broken ice frazil/grease ice slush pancake ice 			(A) (C)	(A) (B)	○ ● ●	<ul style="list-style-type: none"> barge tanker workboat
<ul style="list-style-type: none"> solid ice multi-year ice ice floes broken ice brash ice ice hummocks 			(B)		○ ● ● ●	<ul style="list-style-type: none"> drums tanker truck workboat porta-tank
<ul style="list-style-type: none"> open water ice floes broken ice melt polls leads 			(A) (C)	(A) (B)	○ ● ● ●	<ul style="list-style-type: none"> barge tanker workboat

NOTE: Dispersants are not an appropriate response option in lakes or shallow

3.4 Rivers

3.4.1 Control at Source and Downstream

The objective of source control in rivers is to minimize the spread of the spill and minimize potential environmental impacts.

Controlling free-floating oil in rivers can 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 at or remote from a spill source in rivers may be possible during open-water, frozen and transition seasons. The response options of mechanical containment/recovery and in situ burning are discussed followed by operational considerations that address seasonal differences.

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

3.4.2 Mechanical Containment/Recovery

The effectiveness of mechanical containment and recovery in rivers depends greatly on current speed. In large rivers, wind can also be a factor. Containment and recovery become increasingly impossible, and may be unsafe to attempt, in currents greater than 1 m/s and in winds exceeding 35 km/h. In ice-free conditions, booms and stationary skimmers should be deployed as near as possible to the release point to minimize spreading. A combination boom-skimmer might also have applications in such conditions (see Section 5.4.1). The containment of submerged oil might be possible near the source using an oil trawl boom but deployment difficulties are likely.

In the frozen or transition seasons, boom deployment is difficult but containment may be possible in solid ice using angled ice slots or booms placed in ice slots or in natural embayments. Any on-ice work will depend on conditions governing personnel safety such as stability and bearing capacity. The containment of oil submerged under ice might be possible using a boomed ice slot.

3.4.3 In-situ Burning

The in-situ burning of oil at or near the source of a river spill or downstream can be successful in open water, in or on ice, and in a natural embayment. The major impediments to contained burning in northern rivers are the timely availability of equipment, currents that often exceed the limits of booms, and the difficulty of obtaining approvals, especially in close proximity to shorelines and residential areas. Wind and wave conditions are less likely to be an issue compared to the open sea or large lakes but similar criteria still apply, i.e., winds less than 10 m/s (20 kt).

Herders have demonstrated little or no loss of effectiveness in fresh water and could theoretically be applied in slow moving very wide rivers to thicken slicks and enable burning. Ignition systems could include surface-deployed ignitors from small boats, the proven Helitorch™ system and in the future an integrated herder/burn system developed and tested in prototype form (IOGP 2012-2017).

In-situ burning with a fire-resistant boom is possible in a river as long as there is no ice and currents are low (under 1 kt). When used, a fire-resistant boom must be anchored a safe distance from the spill source to avoid any secondary uncontrolled burning

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.

3.4.4 Operational Considerations

There are a number of concerns when containing and recovering/removing spills in rivers:

- ✦ Many northern rivers are fast flowing, have high sediment loads and feature long lengths of inaccessible shoreline. These factors often make it impractical to control oil spills, particularly during spring runoff when the water level rises rapidly to overflow the still remaining river ice cover and potentially carries oil tens of kilometres offshore as the overflow waters fan out over the nearshore bottom fast sea ice, for example off the Colville River in Alaska.
- Spill response in rivers requires extremely quick action if cleanup operations are to be successful.
- Oil usually reaches shore rapidly, such that shore treatment often is the only response option.
- Selected control points with good access and low currents can serve as equipment staging and deployment areas.
- ✦ Conditions must be safe if any response is attempted. Monitors must be used to guard the health and safety of response personnel. An explosive, toxic atmosphere can develop in spills of high-sulfur crude oils and volatile oils.
- ✦ In large, fast-flowing rivers, currents that exceed 1 m/s will preclude successful containment, recovery and burning.

3.4.4.1 *Containment and Recovery*

- In currents 0.4 to 1 m/s, diversion of the oil to shore may be possible using angled booms that redirect oil to a recovery area or point.

- A combination boom-skimmer can be tried in larger river systems where this technology is available and conditions make it feasible to consider (see Section 5.4.1).
- 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.
- Other potential hindrances to spill response in large coastal rivers that make locating slicks and deploying booms difficult include:
 - reversing tides
 - back eddies
 - eroding banks
 - debris
- 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 continue to operate effectively as oil properties and environmental conditions change.
- Often River Boom can be used with the following design features:
 - top and bottom tension members
 - maximum height of approximately 35 cm
 - high buoyancy-to-weight ratio
 - heavy duty fabric
- 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 where circular current patterns or eddies that commonly occur can facilitate oil collection.
- When possible, re-selecting control points as part of geographical response planning for a specific area will facilitate boom deployments.
- 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 if the banks are not already separated from the oil by a natural barrier of shore ice.
- 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 often have a low probability of efficient oil capture in rivers.

3.4.4.2 *In situ Burning*

Generally, burning is not feasible in ice-free conditions more than two to five days following a spill because of oil weathering and excessive emulsification.

Interception, containment, recovery and burning can be attempted on fresh and partially emulsified oils but, typically,

are not feasible in currents exceeding 1 m/s.

A safety plan for response workers is required that addresses the location of ignition, expected transport of oil in the river, downstream amenities at risk, and areas that would be affected by the smoke plume for established burn guidelines laying out recommended exclusion zones and other safety procedures for in situ burning (e.g. Alaska Regional Response Team, 2008).

Exposed oil distributed in broken river ice may be skimmed and/or 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 oil patches later in the season. Monitoring the spill may be the only practical response alternative.

3.4.4.3 *Ice Conditions*

- Dynamic (moving) broken ice usually interferes with, and prevents, the containment, diversion, interception and removal of spilled oil in a river. In contrast, solid ice facilitates oil containment, recovery and burning. Oil can remain unweathered under ice or trapped within ice for several months following a spill.
- Unlike sea ice where oil naturally migrates to the surface and becomes exposed three to five weeks before breakup, river ice often breaks up in an extremely violent manner, with ice jams and overflowing. Oil mixed with the ice in this situation is inaccessible for any kind of response. Recovery and cleanup would have to wait until the ice has disappeared and the extent of shoreline and river bottom oiling can be fully assessed.

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- During the winter when the ice cover is stable, 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).
- Specialists should determine on a daily basis whether ice will safely support the weight of equipment and personnel. Ice conditions need to be carefully monitored in areas where strong currents can erode the ice undersurface and create dangerous thin spots even in mid-winter.

Table 3.3. Rivers – Control at Source and Downstream

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

3.5 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. This is much more challenging than protecting lake or ocean shorelines because of the effect of currents in rapidly transporting oil long distances from the source – hundreds of kilometres in many cases. 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.

3.5.1 Mechanical Diversion

In ice-free water, booms should be deployed where possible to divert oil from sensitive areas.

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

During transition seasons, diversion is unlikely because of safety concerns operating on thin or melting ice. In particular, during the often highly dynamic breakup period, on-river operations are usually impossible.

During the frozen season with thick ice cover, snow berms, or trenches may prevent oil from spreading. The diversion of oil submerged below the ice might be possible using a boomed ice slot

or an oil trawl boom deployed in an ice channel or slot.

3.5.2 In-situ Burning

Due to the highly dynamic nature of oil spills in a river environment, burning while possible as a control method, is not applicable to site-specific protection.

3.5.3 Chemical Dispersion

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

3.5.4 Operational Considerations

Guidelines for protecting resources at risk from a spill that occurs in a river are similar to those employed for response operations at, and remote from, the source. Several additional points are added here, specific to protection.

- 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 oiling of downstream areas unless the oil is mechanically removed or burned immediately on containment.
- Protection techniques may not be needed, nor be feasible, in broken and solid ice. The natural barrier formed by ice attached to the banks can protect resources from the impacts of oil spilled into the main stream or reduce its effects. Burning concentrated oil remains the most effective response technique when conditions and safety allow. Slicks should be at least 2 to 3 mm thick before burning would be feasible.

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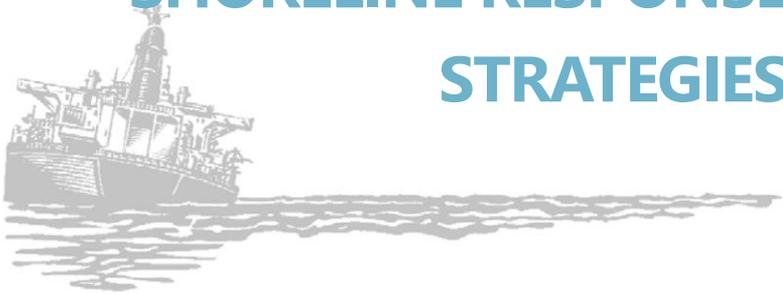
- Protection measures usually are not feasible when thin slicks (less than 1 mm), oil droplets and particles are widely distributed in ice-free conditions or throughout broken ice during breakup. Monitoring the spill may be the only practical option.
- In many cases, the deployment of equipment from shore may be safer and more practical, eliminating or reducing the need for response vessels and personnel.
- Sorbent booms or sweeps are sometimes effective in protecting shorelines in quiet, low-current areas, but should be inspected regularly and replaced when damaged or when the sorbent material becomes saturated with oil.

Table 3.4. Rivers - Protection

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

4

SHORELINE RESPONSE STRATEGIES



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SHORELINE RESPONSE STRATEGIES

The objective of treating oiled shorelines is to either accelerate natural recovery or remove the stranded oil.

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 EPPR *Guide to Oil Spill Response in Snow and Ice Conditions in the Arctic* (2015) provides a description of coastal processes and shore types in ice- and snow-affected coastal regions (Chapter III-3) and discusses strategies for coastal response in ice and snow (Part VI).

The 14 shore types are based on the permeability of the substrate (Figure 4.1) as follows:

- Impermeable or solid shorelines have no surface sediments; are (except for ice) stable, and oil cannot penetrate.
- 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. Shore types are illustrated in photographs in Section 10.9.

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 4.3 (Ice or Ice-covered Shores) and 4.14 (Shorelines with Snow).

IMPERMEABLE OR SOLID SHORES

4.1 Bedrock

4.2 Man-made Solid Structures

4.3 Ice or Ice-covered Shores

BEACHES

4.4 Sand

4.5 Mixed-sediment

4.6 Pebble/Cobble

4.7 Boulder and Rip-rap

FLATS

4.8 Sand

4.9 Mud

4.10 Salt Marshes

4.11 Peat Shores

4.12 Inundated Low-lying Tundra Shores

4.13 Tundra Cliff Shores

4.14 Shorelines with Snow

Figure 4.1. Shore types

Treatment involves the use of one or more of 20 physical, biological and chemical techniques that are described in Section 5.7, in which a set of a summary tables of appropriate methods is provided for each of the 14 shore types defined in this section.

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

4.1 Bedrock

- A bedrock shore (Figure 10.10) 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 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.

SHORELINE RESPONSE STRATEGIES

- ✓ 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 ambient-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, ambient-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, ambient-water washing and low-pressure, warm/hot-water washing may be useful for more viscous oils that cannot be removed by low-pressure, ambient-water washing.
- ✓ Manual removal 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.

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

SHORELINE RESPONSE STRATEGIES

- ✘ High-pressure, warm/hot-water washing (including steam cleaning and sandblasting) 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 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 4.1. Treatment Methods for Bedrock Shores

Treatment Method		light oil	medium oil	heavy oil
				
 natural recovery		<input type="radio"/>	<input type="radio"/>	
 flooding		<input type="radio"/>	<input type="radio"/>	
 low-pressure, ambient-water		<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
 low-pressure, warm/hot-water			<input type="radio"/>	<input checked="" type="radio"/>
 high-pressure, ambient-water				<input checked="" type="radio"/>
 high-pressure, hot-water				<input checked="" type="radio"/>
 manual removal		<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
 vacuum systems		<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
 sorbents		<input checked="" type="radio"/>	<input checked="" type="radio"/>	
 dispersants			<input checked="" type="radio"/>	
 shoreline cleaners			<input checked="" type="radio"/>	

good fair (for small amounts of oil only)

4.2 Man-made Solid

- Solid, man-made structures (Figure 10.11) are very similar in many respects to bedrock shorelines as the substrate is impermeable and stranded oil remains on the surface. Examples include retaining walls, harbour walls and solid breakwaters. Open, i.e., permeable, structures, constructed of materials such as rip-rap, are discussed in Section 4.7.
- On coasts where ice is common on water, the biological community usually is scraped off each year, so that plants and animals 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 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 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 ambient-water washing techniques 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 and sorbents or skimmers.

SHORELINE RESPONSE STRATEGIES

- ✓ Flooding 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, ambient-water washing 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 and sorbents or skimmers.
- ✓ High-pressure, ambient-water washing and low-pressure, warm/hot-water washing may be useful for more viscous oils that cannot be removed by low-pressure, ambient-water washing. High-pressure, warm/hot-water washing 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, steam cleaning or sandblasting may be appropriate.
- ✓ Manual removal is recommended for small amounts of medium and heavy oils, but foot traffic should be minimized in areas where organisms could be trampled.
- ✓ Sorbents can be deployed to passively collect small amounts of light and medium oil.
- ✓ Dispersants and shoreline cleaners 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 and low-pressure washing, with collection and recovery for oil that is easily mobilized, can be followed by higher-pressure and/or higher-temperature techniques to remove any residues.
- Shoreline cleaners can be used in conjunction with flooding or low-pressure washing 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.) on the shore, avoid washing oil from the upper to lower intertidal zones. Frequently, 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) should be avoided as these 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.
- ✗ 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 and chemicals 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 4.2. Treatment Methods for Man-made Solid Structures

Treatment Method		light oil 	medium oil 	heavy oil 
	natural recovery	○	○	
	flooding	○		
	low-pressure, ambient-water	○	○	◐
	low-pressure, warm/hot-water		○	◐
	high-pressure, ambient-water			◐
	high-pressure, hot-water			◐
	steam, sand blasting			◐
	manual removal		◐	◐
	sorbents	◐	◐	
	dispersants		◐	
	shoreline cleaners		◐	

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

4.3 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 (Figures 10.12 and 10.13). Ice may form seasonally on any of the shoreline types on coasts, lakes and rivers (Figure 10.27). 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.

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, Figures 4.2 and 10.27).
- 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 4.14, 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.

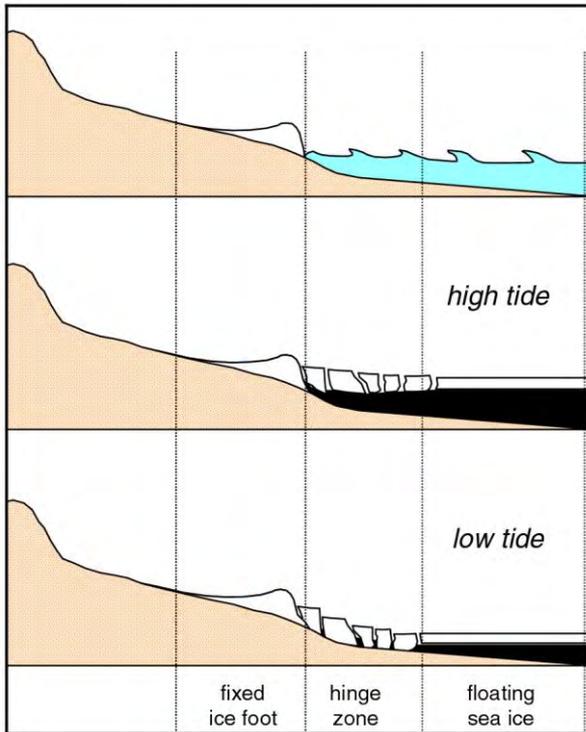


Figure 4.2. An ice-foot (Figure 10.27) develops when waves or water freeze at the water line (top). In tidal areas, a zone of cracks separates the fixed ice foot from the nearshore floating ice (middle - at high tide, bottom - at low tide).

- If shore ice forms in relatively calm wave conditions, then a continuous, simple rampart (or ice foot, Figure 4.2) 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.

- 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 °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 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 and sorbents or skimmers.
- ✓ Washing (flushing and collection) may be useful if water does not freeze and encapsulate the oil.
- ✓ Flooding 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 or sorbent skimmers), vacuum units or burning all have potential application. Where access permits, vertical rope-mop skimmers 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, or possibly mechanically if accessible.

Typical Combinations of Response Methods

- On wet ice, low-pressure washing can be combined with the collection and recovery of oil that is easily mobilized, followed by the manual removal of residue using hand tools, vacuum systems or sorbents.
- Mechanical scraping or removal can be followed by manual removal 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 4.3. Treatment Methods for Ice or Ice-covered Shorelines

Treatment Method	light oil	medium oil	heavy oil
 natural recovery	<input type="radio"/>	<input type="radio"/>	
 flooding	<input type="radio"/>		
 low-pressure, ambient-water	<input type="radio"/>	<input type="radio"/>	<input checked="" type="radio"/>
 low-pressure, warm/hot-water		<input type="radio"/>	<input type="radio"/>
 manual removal	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
 vacuum systems	<input type="radio"/>	<input type="radio"/>	
 mechanical removal	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
 sorbents	<input checked="" type="radio"/>	<input checked="" type="radio"/>	
 in-situ burning	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

good fair (for small amounts of oil only)

4.4 Sand Beaches

- Sand beaches (Figure 10.14) 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 4.6.
- 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 (API 2016d).
- 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 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

SHORELINE RESPONSE STRATEGIES

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 and low-pressure ambient-water washing can remove light and medium oils. These techniques become ineffective as the viscosity, penetration or burial of the oil increases.
- ✓ Manual removal 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 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 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.
- ✓ Sediment mixing or sediment relocation 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 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 or skimmers.
- Mechanical removal can be followed by mixing or sediment relocation.

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.

SHORELINE RESPONSE STRATEGIES

- ✘ 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 spreading oil to previously clean areas.
- ✘ 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). Sediment 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.

Table 4.4. Treatment Methods for Sand Beaches

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	
 flooding	○	○	
 low-pressure, ambient-water	○	○	
 manual removal	◐	◐	◐
 vacuum systems	○	○	
 mechanical removal	◐	○	○
 sorbents	◐	◐	
 sediment mixing	◐	◐	
 sediment relocation	◐	◐	

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

4.5 Mixed-sediment Beaches

- Mixed-sediment beaches (also referred to as gravel beaches) are composed of sands, granules, pebbles and cobbles (Figure 10.15). 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 (Figure 4.3) so that these beaches are permeable only for some medium oils and all light oils. These beaches can have a dynamic, mobile surface layer.

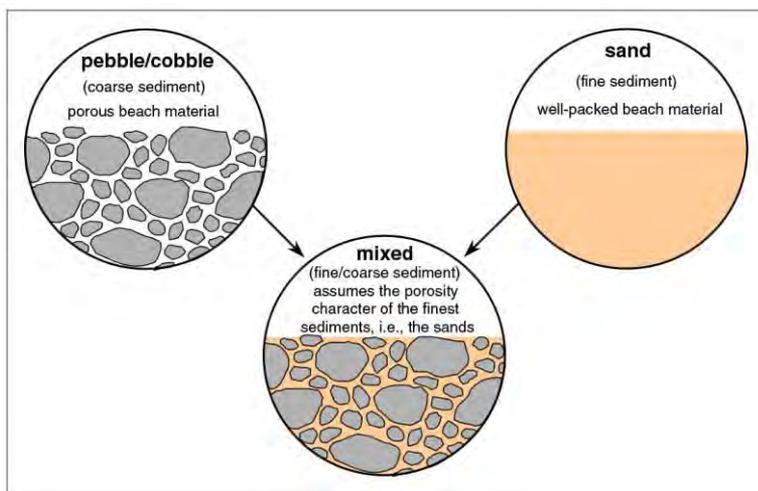


Figure 4.3. Beach types

- 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.

SHORELINE RESPONSE STRATEGIES

- Depth of oil penetration is a function of the oil type whereas the depth of burial or reworking of oiled sediments is 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.

Preferred Response Options

- ✓ Natural recovery 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 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, ambient-water washing 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 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 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.***

SHORELINE RESPONSE STRATEGIES

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 may be useful for recovering small volumes of light and medium oils.
- ✓ Mechanical mixing is appropriate for light oils in surface or subsurface sediments.
- ✓ Sediment relocation 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, with trenches or sumps to collect oil that is floated, can be used with vacuum systems to recover the oil.
- Mechanical mixing can be followed by sediment relocation and/or bioremediation.

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 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); sediment 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.

SHORELINE RESPONSE STRATEGIES

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

Table 4.5. Treatment Methods for Mixed-sediment Beaches

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	
 flooding	○	○	
 low-pressure, ambient-water	○	○	
 manual removal	◐	◐	◐
 vacuum systems	○	○	
 mechanical removal	◐	○	○
 sorbents	◐	◐	
 sediment mixing	◐	◐	
 sediment relocation	◐	◐	

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

4.6 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 4.7.
- 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 (Figure 10.16) are distinguished from mixed- sediment or gravel beaches (Section 4.5) as the interstitial or pore spaces between the individual pebbles or cobbles are open, rather than being filled by sand (Figure 4.3).
- 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 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 is a non-intrusive technique than can flush mobile oil from surface and subsurface sediments for collection. Effectiveness decreases with increasing viscosity and stickiness.
- ✓ Low-pressure, ambient-water washing 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 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 oiled pebbles and cobbles.
- ✓ Mechanical removal 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.

SHORELINE RESPONSE STRATEGIES

- ✓ Sorbents may be useful for recovering small volumes of light and medium oils.
- ✓ Mechanical mixing is appropriate for light oils in surface or subsurface sediments. This method can be used in combination with sediment relocation.
- ✓ Sediment relocation 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, vacuum units or the use of sorbents on surface oil patches.
- Flooding can be combined with low-pressure washing.
- Mechanical mixing can be followed by sediment relocation and/or bioremediation.

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 may temporarily mobilize viscous oil that can then possibly migrate more deeply into the beach. Heat loss as 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); sediment 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.

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Table 4.6. Treatment methods for Pebble/Cobble Beaches

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	
 flooding	○	○	
 low-pressure, ambient-water	○	○	
 manual removal	◐	◐	◐
 vacuum systems	○	○	
 mechanical removal	◐	○	○
 sorbents	◐	◐	
 sediment mixing	◐	◐	
 sediment relocation	◐	◐	
 bioremediation	◐	◐	

○ good

◐ fair (for small amounts of oil only)

4.7 Boulder Beaches and Rip-rap Shores

- Boulder beaches or rip-rap shores (Figures 10.17 and 10.18) 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.

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

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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 is the preferred option, in particular for small amounts of oil. There is probably little that can be achieved 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 can flush mobile oil from surface and subsurface sediments for collection. The effectiveness of flooding decreases with heavier oils.
- ✓ Low-pressure, ambient-water washing 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 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 (either from the land side or from a barge), and the subsurface oil could then be removed or treated and the boulders replaced.
- ✓ Sorbents 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 of surface oil or the application of sorbents.
- Flooding 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 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

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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 4.7. 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, ambient-water	○	○	
 9 manual removal	◐	◐	◐
 13 sorbents	◐	◐	

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

4.8 Sand Flats

- Sand flats (Figure 10.18) 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.

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- 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 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 and collection with sorbents may be effective for light or medium oils.
- ✓ Manual removal or vacuum systems may be effective for smaller amounts of oil that have pooled or have collected in natural depressions.
- ✓ Heavy oils may be removed mechanically 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

SHORELINE RESPONSE STRATEGIES

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); sediment 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 4.8. Treatment Methods for Sand Flats

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	
 flooding	○	○	
 manual removal	◐	◐	◐
 vacuum systems	○	○	
 mechanical removal			○
 sorbents	◐	◐	

○ good

◐ fair (for small amounts of oil only)

4.9 Mud Flats

- Mud flats (Figure 10.19) 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 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.

SHORELINE RESPONSE STRATEGIES

- ✓ In practical terms, few techniques can be effective in this type of shoreline environment. Less intrusive strategies, such as herding by flooding or washing and collection using sorbents or vacuum systems 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 with hand tools can be used 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 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 4.9. Treatment Methods for Mud Flats

Treatment Method	light oil	medium oil	heavy oil
 natural recovery	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
 flooding	<input type="radio"/>	<input type="radio"/>	
 low-pressure, ambient-water	<input type="radio"/>	<input type="radio"/>	
 manual removal	<input checked="" type="radio"/>	<input checked="" type="radio"/>	<input checked="" type="radio"/>
 vacuum systems	<input type="radio"/>	<input type="radio"/>	
 sorbents	<input checked="" type="radio"/>	<input checked="" type="radio"/>	

good

fair (for small amounts of oil only)

4.10 Salt Marshes

- Marshes (Figure 10.20) 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 4.12) 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 (API 2013).
- 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.

SHORELINE RESPONSE STRATEGIES

- ✓ 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, ambient-water washing 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 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 and low-pressure, ambient-water washing can be used with rope mop skimmers, or with sorbents for smaller amounts of light and medium oils.
- Manual removal can be combined with vegetation cutting of stems on marsh edges, or for heavy, viscous oils.

What to Avoid

- ✗ Most activities that involve people or machinery in a marsh delay natural recovery.
- ✗ Cutting oiled plants 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 should be avoided if the lower stems and roots of a plant are dry and therefore are not insulated from the heat.

- ✘ Sediment removal, 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 (Table 4.10) can be used.

A recent summary of treatment strategies and methods is provided in *Oil Spills in Marshes - Planning and Response Considerations* (API 2013).

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Table 4.10. Treatment Methods for Marshes

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	○
 flooding	○	○	
 low-pressure, ambient-water	○	○	
 manual removal	◐	◐	◐
 vacuum systems	○	○	
 sorbents	◐	◐	

○ good

◐ fair (for small amounts of oil only)

4.11 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 (Figure 10.21).
- 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 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, in combination with booms and skimmers, 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 cannot be deployed or are not effective.
- ✓ Low-pressure, ambient-water flooding and/or washing can raise the local water table to float oil and peat downslope into a boomed area for recovery. These methods would probably erode large quantities of peat for subsequent transport and disposal. Customized net panels in shore-fast booms help to retain oiled peat slurries.
- ✓ Sorbents, 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 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.

SHORELINE RESPONSE STRATEGIES

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

Typical Combinations of Response Methods

- Manual methods can be used to remove the most oiled portions of peat mats by raking, followed by mixing of any remaining materials to accelerate physical and biological cleaning processes.
- Low-pressure, ambient-water washing can be used with sorbents or rope mop skimmers for recovery.

What to Avoid

- ✘ Trampling vegetation and the use of heavy machinery 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 and vegetation cropping should be minimized unless there is very heavily oiling. If removal of peat or 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 peat or oiled debris near living plant communities. Fires can quickly spread.
- ✘ Drainage and nutrient application 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.

A summary of protection and treatment methods for peat shorelines is provided by Little et al. 1992.

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Table 4.11. Treatment Methods for Peat Shores

Treatment Method	light oil 	medium oil 	heavy oil 
 1 natural recovery	○	○	○
 2 flooding	○	○	
 3 low-pressure, ambient-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)

4.12 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 (Figure 10.22).
- 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.

SHORELINE RESPONSE STRATEGIES

- 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 4.4), mixed-sediment (Section 4.5) or pebble/cobble (Section 4.6) 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, ambient-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 or low-pressure, ambient-water washing can be combined with berms or shore-seal booms for containment, and with sorbents or rope mop skimmers 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 and vegetation crop-

ping 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 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.

SHORELINE RESPONSE STRATEGIES

Table 4.12. Treatment Methods for Inundated Low-lying Tundra Shores

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	
 flooding	○	○	
 low-pressure, ambient-water	○	○	○
 manual removal		◐	◐
 vacuum systems	○	○	
 sorbents	◐	◐	

○ good

◐ fair (for small amounts of oil only)

4.13 Tundra Cliff

- Tundra cliffs are an erosional feature composed of a tundra (vegetation) mat that usually overlies peat and exposed ground ice (Figure 10.23). Ice-rich tundra cliffs are distinct and different from ice-poor unconsolidated sediment cliffs that are predominantly exposed sediment (Figure 10.24).
- 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 back-shore 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 using a large or small front-end loader is more practical for larger amounts of oil or oiled material.
- ✓ Sediment relocation and mixing 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 or floating of oil into lined collection trenches or sumps, dug by a backhoe, can be followed by recovery with vacuum systems or skimmers.
- Mechanical removal can be followed by mixing or by sediment relocation.

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); sediment 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 4.13. Treatment Methods for Tundra Cliff Shores

Treatment Method		light oil	medium oil	heavy oil
				
 natural recovery		○	○	○
 low-pressure, ambient-water		○	○	○
 manual removal			◐	◐
 mechanical removal			○	○
 sorbents		◐	◐	
 sediment mixing		◐	◐	◐
 sediment relocation		◐	◐	◐

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

4.14 Shorelines with Snow

- Snow is common on all Arctic and cold-climate shores (Figure 10.26). 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 4.14. Treatment Methods for Snow-covered Shores

Treatment Method	light oil 	medium oil 	heavy oil 
 natural recovery	○	○	○
 manual removal		◐	◐
 vacuum systems	○	○	
 mechanical removal		○	○
 sorbents	◐	◐	
 in-situ burning	○	○	

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

5

RESPONSE METHODS



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5.1 Introduction

Specific spill response methods implement the strategies outlined in Sections 3 and 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. Spill movement, detection and tracking and trajectory modelling are covered briefly in 6.2, 6.3 and 6.4.

Table 5.1. Response method categories

On Water or Ice	
	mechanical containment (Section 5.2)
	mechanical diversion (Section 5.3)
	mechanical recovery (Section 5.4)
	in-situ burning (Section 5.5)
	chemical dispersion (Section 5.6)
On Shorelines	
	natural recovery (Section 5.7.1)
	physical washing/recovery (Section 5.7.2)
	physical removal (Section 5.7.3)
	physical in-situ treatment (Section 5.7.4)
	chemical/biological treatment (Section 5.7.5)

5.2 Mechanical Containment

The objective of mechanical containment is to concentrate the oil (unless naturally contained for example by ice edges or shore embayments), 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:

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; rainbow and silvery blue coloured 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 usually work best.

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- Fuel, lubricants, spare parts and tools must be carefully planned when conducting oil spill containment operations in remote areas.

5.2.1 Mobile Floating Barriers

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 planned placement 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 (freeboard) 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.

ARCTIC WATERS FIELD GUIDE

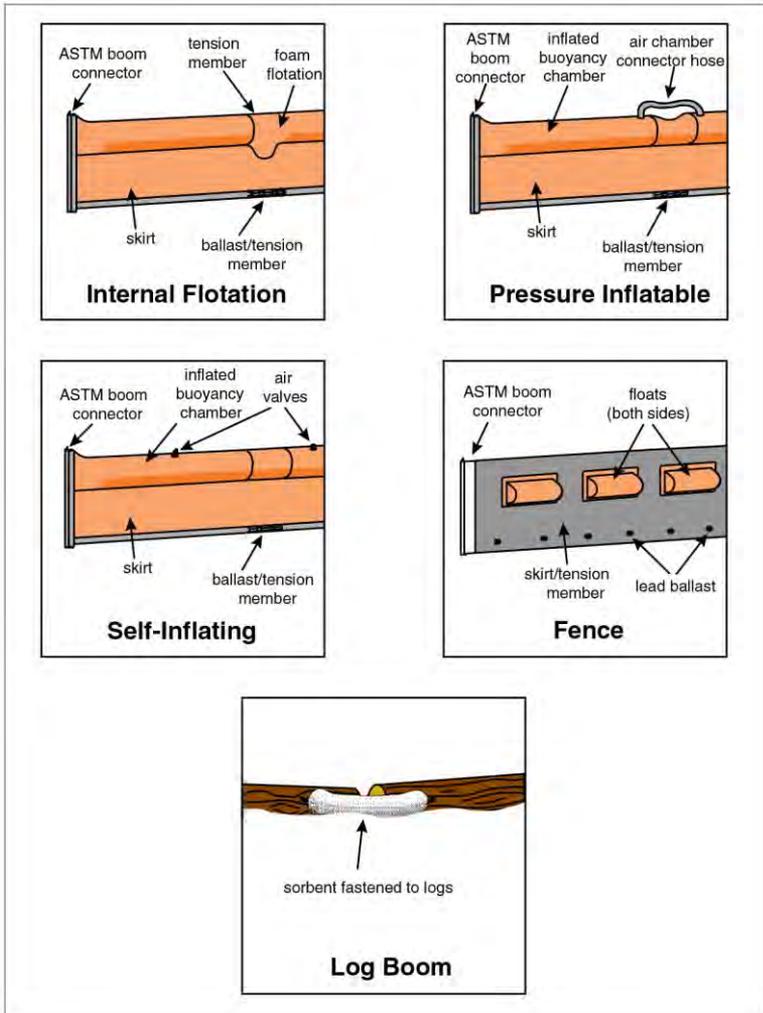


Figure 5.1. Mobile floating barrier types

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Self-inflating booms are constructed of PVC or polyurethane-coated material with air chambers that are normally compressed when stored, and inflate through one-way air intake valves when deployed.

Fence booms are constructed of a rigid or semi-rigid fabric with internal foam, bolted-on foam blocks, or outrigger flotation.

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.

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 local containment; however, oil can become trapped within a moving ice frame of reference including: freezing ice, brash ice or on the surface of ice chunks. These effects can make oil recovery very difficult.

If waves or other turbulence are present, oil can mix and disperse into the water column, making containment and 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 moving scattered ice is more difficult than in open-water conditions (Bronson et al., 2002; Potter

et al., 2012). Generally, heavy duty or more durable booms are required in ice to withstand additional wear and damage. 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 30%.

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 U- configuration to collect oil. This is accomplished by drifting downstream, holding in a stationary position or moving upstream toward the spill source.

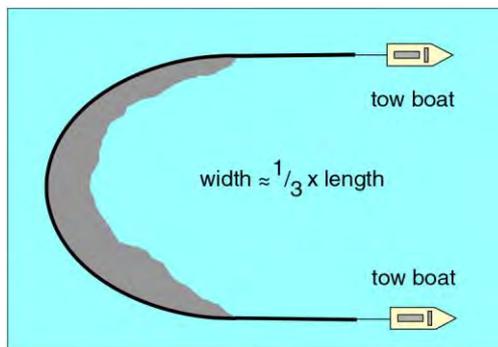


Figure 5.2. U-boom configuration

For this and other boom configurations, a boom vane can replace one of the towing vessels (see Section 5.3.1)

V-Booming

Booms can be deployed in a V-configuration using three vessels and a skimmer or two boats and a trailing skimmer.

J-Booming

Booms can be towed in a J-configuration that diverts the oil to a skimmer to allow simultaneous containment and recovery.

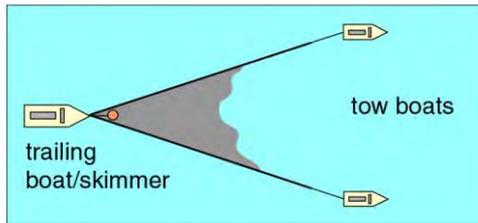


Figure 5.3. V-boom configuration

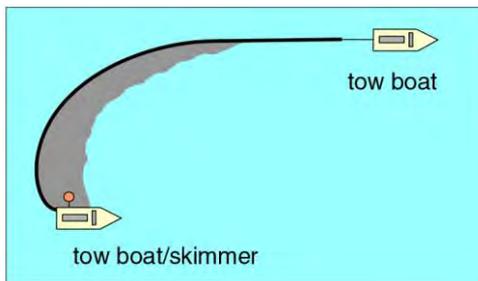


Figure 5.4. J-boom configuration

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

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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.

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.

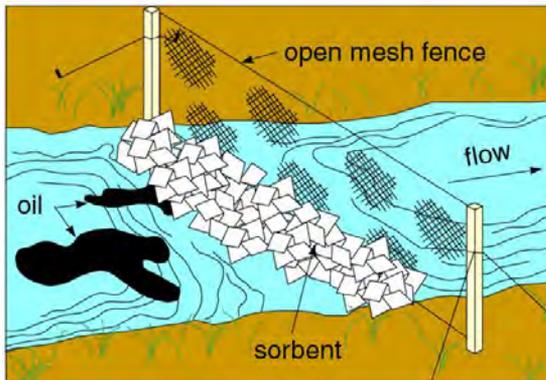


Figure 5.5. Filter fence

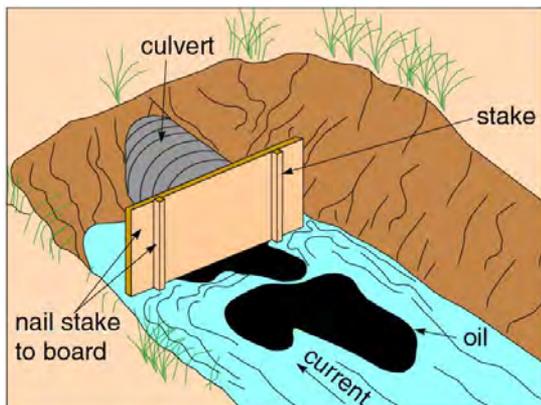


Figure 5.6. Culvert block

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 sand-bag 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.

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. A 90° elbow or T connection can also be added to the upstream end of the pipe to further prevent oil from entering it. 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

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pipe should be positioned to create a continuous, smooth flow.

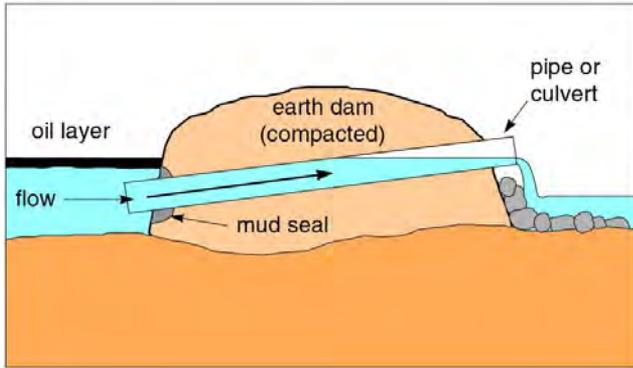


Figure 5.7. Inverted weir

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 oiled 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.

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.

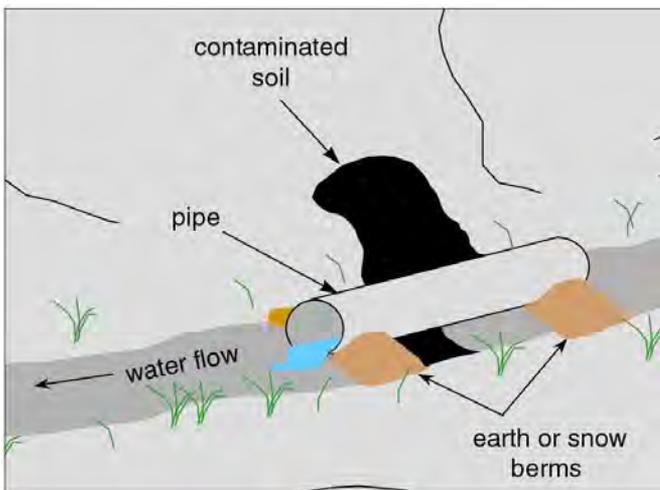


Figure 5.8. Flume

5.2.3 Subsurface Barrier

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.

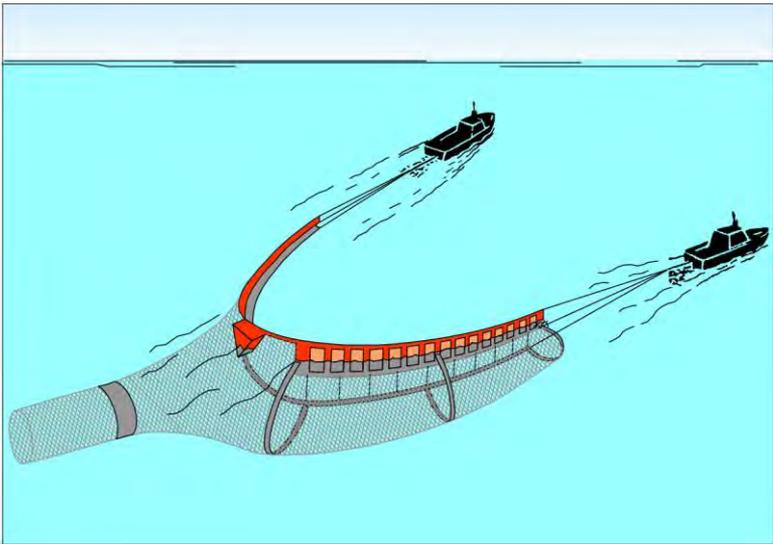


Figure 5.9. Oil trawl boom for surface and submerged oil

At a towing speed of 1 to 2 m/s, submerged and floating oil is forced into the net tunnels (one on each side), which extend 4 m 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 On-ice Safety Considerations

Prior to any operations being conducted on ice utilizing the equipment, materials, and techniques described in this section, it is critical to assess the safety of deploying personnel and equipment. Cracks and other anomalies can quickly develop in ice that is even several metres thick.

The following procedures are recommended prior to the on-ice containment and removal of oil:

- Determine the thickness and nature of ice especially its internal temperature affecting bearing capacity. Refer to proven operating guidelines for on-ice activities such as ACS (2015)
- Conduct core tests.
- Cracks and spaces reduce strength.
- Reinforce ice if necessary.

Before personnel or equipment are placed on ice, an assessment should be conducted by an experienced specialist on a case-by-case basis who is aware of local conditions.

5.2.5 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.

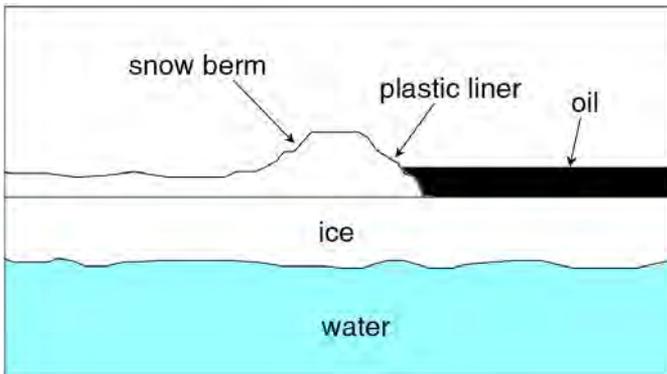


Figure 5.10. Snow berm

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 synthetic or 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 synthetic/plastic sheets to make them impermeable. The berm/trench should be located sufficiently downslope of the release point to intercept the oil.

5.2.6 Trenches or Slots

On land or solid ice surfaces, trenches, slots or pits can be excavated to intercept, contain and collect spilled oil.

Two methods used to create pits, slots, openings and trenches in ice include a simple auger, chain saws, and a Ditch Witch. Variations of these are illustrated below.

An auger can be used to both assess ice thickness as well as to access oil under ice (Figure 5.11). Chain saws are also used to create slots, sometimes being supported on frames to decrease safety hazards and facilitate cutting as depicted in Figure 5.12. The Ditch Witch (Figure 5.13) is a commercial device that is available in various formats to allow the quick and accurate creation of trenches and slots usually to access oil under ice or divert a spill to a collection area for removal.



Figure 5.11. Ice auger

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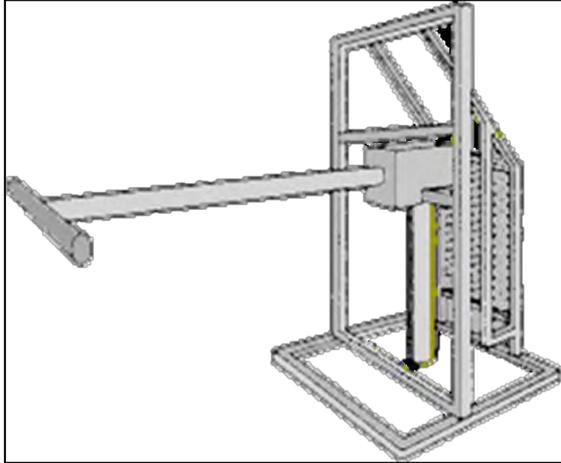


Figure 5.12. Chain saw and support frame

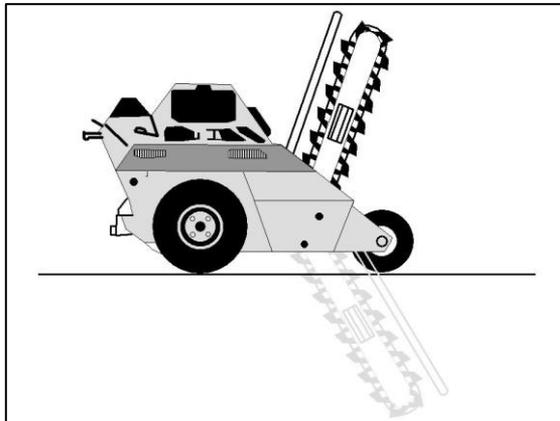


Figure 5.13. Ditch Witch

Ice Trench

On solid ice, a trench can be used to intercept and collect spilled oil.

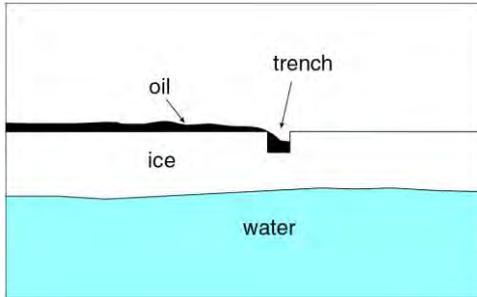


Figure 5.14. Ice trench

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.

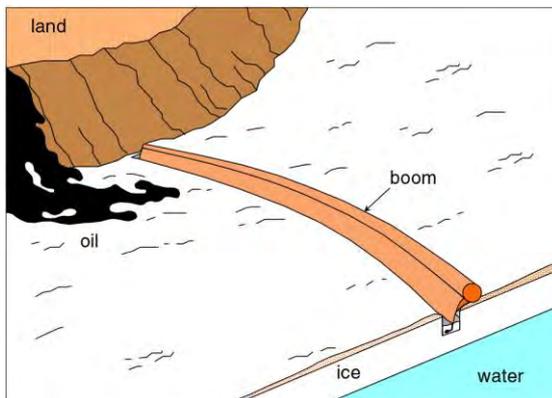


Figure 5.15. Boom/ice trench

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.

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.

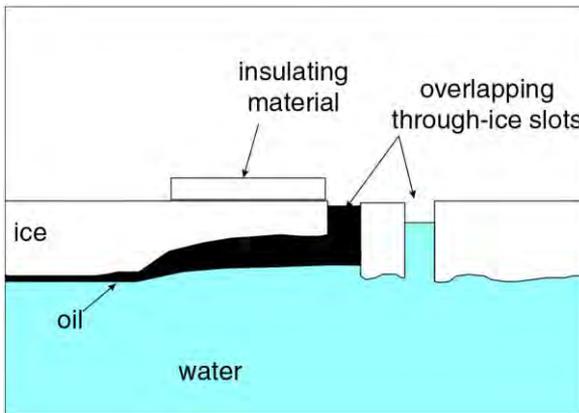


Figure 5.16. Ice slots

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.

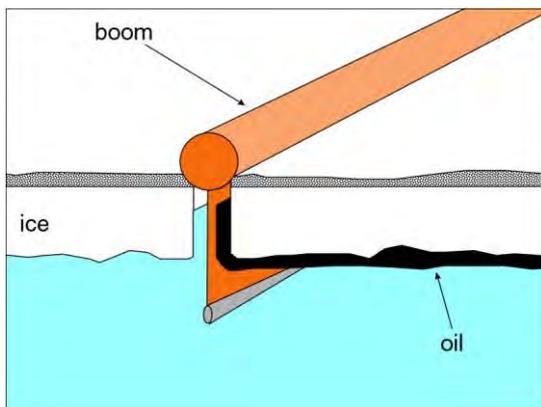


Figure 5.17. Boom/ice slot

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.

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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 (Figure 5.15) the diversion angle is approximately 60°.

Typically, in fast moving currents, or where the area requiring protection is extensive, a number of cascading booms are required to divert the oil.

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.

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.

Table 5.4. Boom type versus water conditions - diversion at sea

Condition	Internal Flotation	Pressure Inflatable	Self-Inflating	Fence
calm	○	○	◐	◐
protected	○	◐◐	●	●
open	○	○	●	●

○ good ◐ fair ● poor

River Diversion

Booms have been specially designed for operation in rivers. River booms feature both top and bottom tension members to provide vertical stability (and improved oil deflection) in relatively high current, i.e., up to approximately 1 m/s. Such booms can be effective where there is uni-directional flow. In a large, coastal river with reversing tides, repositioning a boom can be difficult and time-consuming. Deploying booms in rivers when ice is present is also questionable, because of damage to the fabric.

Boom vanes are used to deploy booms in rivers as well as from vessels. They position boom in currents using a single anchor line and kite-like principles.

When current speeds exceed 1.4 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.

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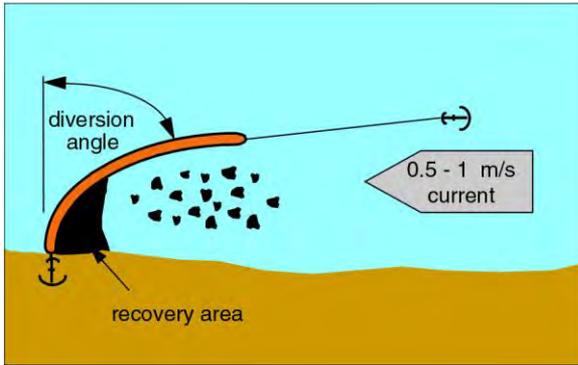


Figure 5.18. Diversion booming

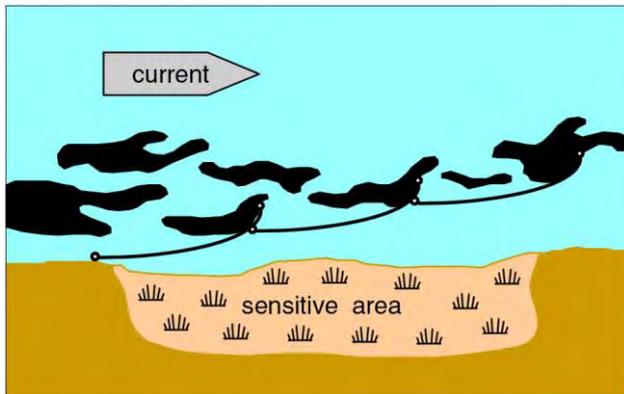


Figure 5.19. Cascading diversionary booming



Figure 5.20 Boom Vane

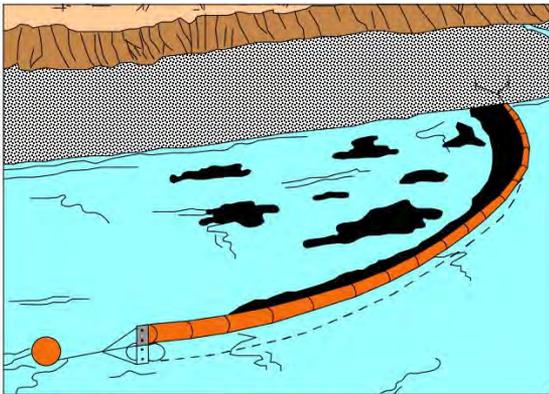


Figure 5.21. River booming

Table 5.5 shows the application of the four basic boom types to calm and protected rivers. Ice has not been considered because of the limited effectiveness of booms in ice in a river

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Table 5.5. Boom type versus water conditions - diversion in rivers

Condition	Internal Flotation	Pressure Inflatable	Self-Inflating	Fence
calm	○	○	◐	◐
protected	○	◐◑	●	●

○ good ◐ fair ● poor

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 5.22 and 5.23) can be used to ensure that an effective seal is maintained at the waterline.

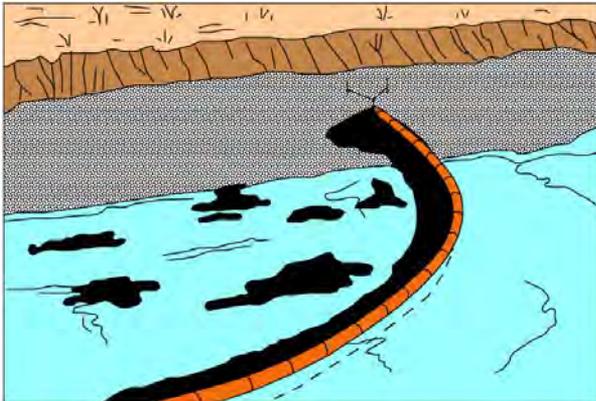


Figure 5.22. Shore-seal boom

These booms employ water-filled lower and air-filled upper chambers that adjust to changing water levels (Figure 5.23).

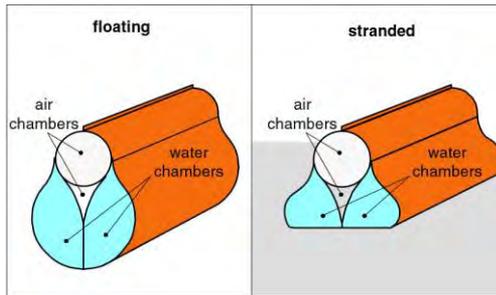


Figure 5.23. Boom design

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

The objective of mechanical recovery is to collect contained oil and to transfer the oil to temporary storage for subsequent disposal. Three basic types of skimmers are used to recover oil:

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 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 Stationary Skimmers

- advancing weir
- zero relative velocity rope mop
- oleophilic lifting belt
- oleophilic brush
- submersion plane/belt
- paddle/belt
- oleophilic brush
- hydrodynamic
- simple weir
- self-levelling weir
- screw auger weir
- oleophilic drum
- oleophilic disc
- oleophilic rope mop

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.

Even with advances that have been made recently with skimmers and their ability to process small ice pieces, the challenges that remain for mechanically removing oil from ice, particularly if it is scattered or moving, can be summarized as follows:

- ✘ Limited access to oil
- ✘ Reduced oil flow to the skimmer
- ✘ Icing/freezing/jamming of equipment
- ✘ Separation of oil from ice
- ✘ Oiling/cleaning of ice
- ✘ Deflection of oil together with ice
- ✘ Strength and durability considerations
- ✘ Detection, monitoring of slick.

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 5.24. 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.

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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 identifies each of the basic advancing skimmer types in terms of its general applicability to light, medium and heavy oils in various sea states and operational conditions, including 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 collect oil are less effective in ice than simple brush devices.

More recent advancing skimming technologies

Advancing skimmers have continued to evolve based on the same basic principles initially investigated. The brush drum and brush belt have seen significant progress being made.

Twin brush drum models have been manufactured that incorporate multiple screw auger pumps. Hot water injection and steam enhance oil collection. This skimmer is suited to medium-to-highly viscous oil and operates where ice can be deflected and contact with the oil is possible (Figure 5.25).

Brush belts have been used as side collectors, often incorporated into the vessel on which they are mounted (Figure 5.26). Some ice deflection is possible as the vessel advances through an ice field. Medium- to highly-viscous oil can be collected although ice can impede contact of the oil with the brushes.

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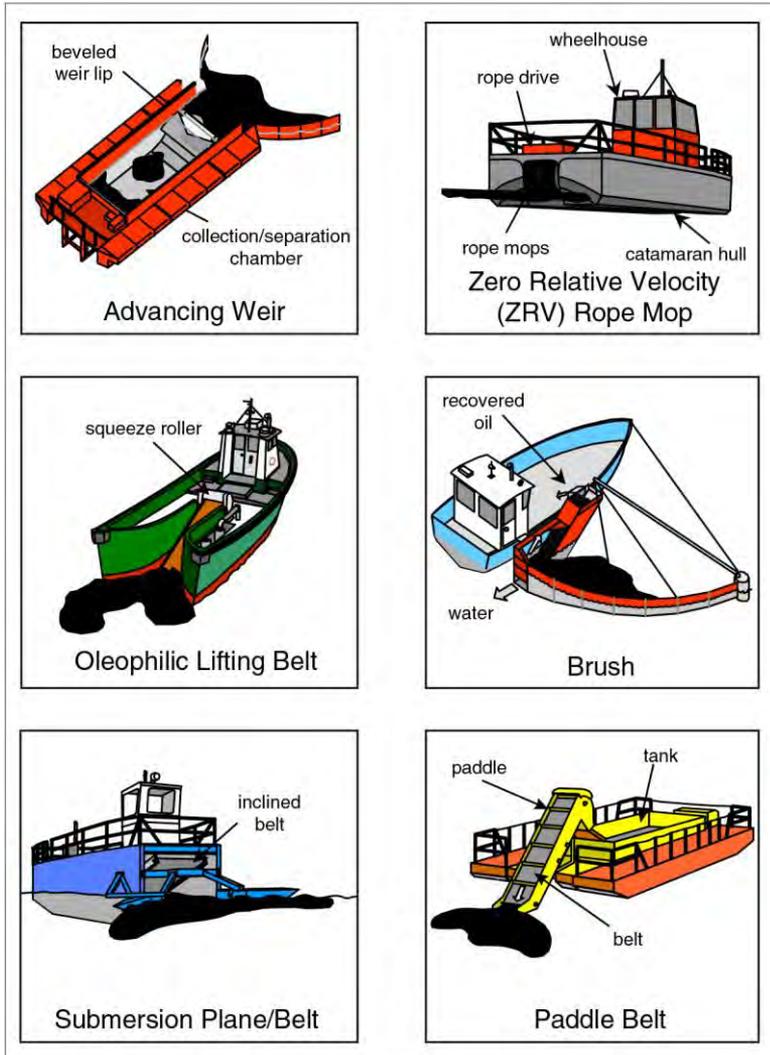


Figure 5.24. Older advancing skimmer types

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Figure 5.25. Twin brush drum. *Photo credit: Lamor website.*



Figure 5.26. Brush side collector. *Photo credit: Lamor website.*

Two additional advancing skimmers have been researched that

rely on brush technology to collect oil yet are based on two different oil/ice processing approaches. In Figure 5.27 a grated belt lifts ice out of the water and washes oil off the ice to feed it to brush drums located below the grate while in Figure 5.28 a grid submerges ice and directs oil to an upward rotating brush conveyor. In both cases, brushes actually collect the oil. Although tested in oil and ice, these devices remain to be fully proven as highly effective in ice environments .



Figure 5.27. Lifting grated belt *Source: Solsberg, 2006*



Figure 5.28. Lifting brush conveyor. *Photo credit: Lamor website.*

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The brush skimmer (Figure 5.29) has also been fabricated as double brush drum system on a mobile platform that can be remotely operated from a mother ship. Radio controls are used to operate the brushes and manoeuvre the skimmer among ice floes. Again, the brushes are more suited to the recovery of medium to viscous oils.



Figure 5.29. Mobile brush drum. *Photo credit: Frank Mohn website.*

A combination boom-skimmer allows the collection and removal of oil in open water at relative velocities of several knots. The removal of oil with a wide range of viscosity should be possible (Figure 5.30).



Figure 5.30. Combination boom skimmer. *Photo credit: Nofi website.*

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Table 5.6. Advancing skimmers

		Skimmer Type						
		advancing weir	ZIV 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

5.4.2 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 5.31). 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.

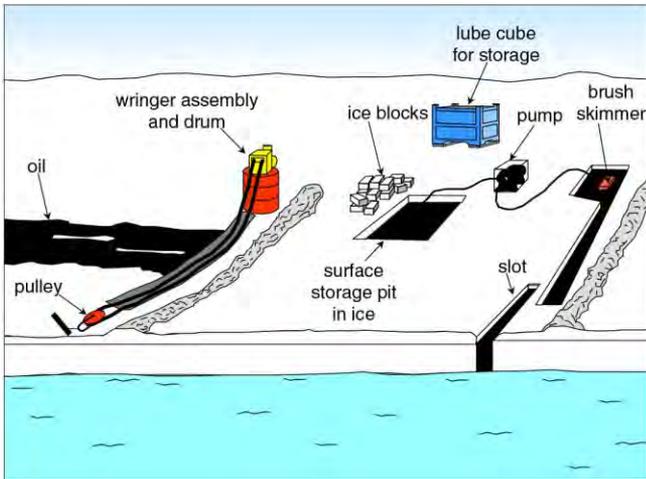


Figure 5.31. Stationary skimming (ACS, 2015)

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 5.32.

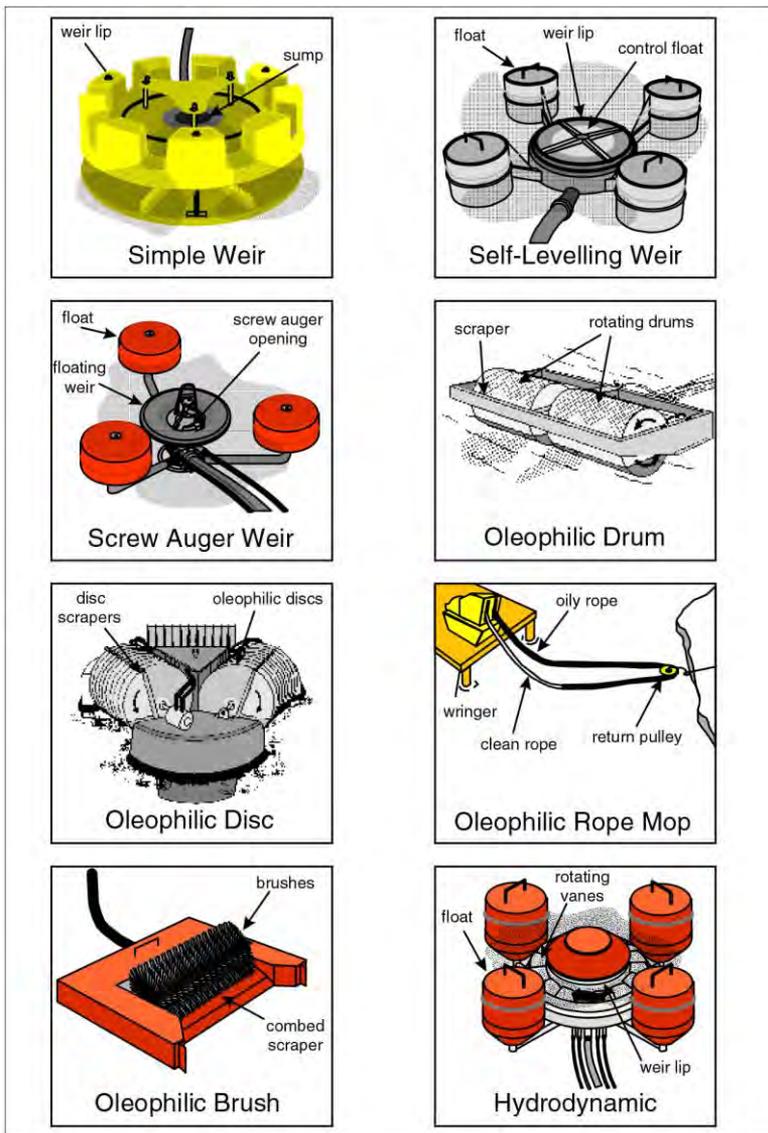


Figure 5.32. Older stationary skimmer types

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Table 5.7. Stationary skimmers

		Skimmer Type								
		simple weir	self-levelling	screw auger	oleophilic	oleophilic disc	oleophilic	oleophilic	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

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.

More recent stationary skimming technologies

The most versatile type of stationary skimmer determined to be applicable to ice conditions is based on the brush. Various models are available that can recover oil albeit in the presence of relatively small ice pieces, usually of the order of several centimetres in size.

The brush adapter is fitted to a screw auger pump. Circular and square brush arrays are available. These skimmers recover light to medium viscosity oils. Small ice pieces can be deflected by the brushes unless ice accumulates to block the entry of oil into the skimmer (Figure 5.33).

Six-sided brush module skimmers have been developed that feature an ice-strengthened body and screw auger pump (Figure 5.34). Again, light to medium viscosity oils can be collected in limited ice conditions unless ice pieces halt oil flow to the skimmer.

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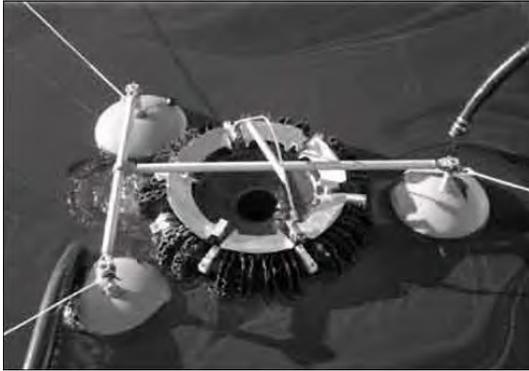


Figure 5.33 Brush adapter skimmer (Solsberg, 2006)



Figure 5.34. Six-sided brush skimmer (Sørstrøm et al., 2010)

Brush belts are usually applied to inland waters, bogs, fens, and other similar situations (Figure 5.35). An impeller behind the brushes aids in oil collection. More suited to medium to highly viscous oils, these skimmers can process small ice pieces unless ice impedes oil flow to the brushes.



Figure 5.35. Brush belt skimmer (Solsberg, 2006)

A brush drum skimmer has evolved into an over-the-side device that can be readily positioned in oil between ice pieces (Figure 5.36) . Newer models feature heated surfaces and twin scrapers to allow bi-directional skimming. These skimmers are suited to medium to highly viscous oils (Counterspil Research Inc. 2011).



Figure 5.36. Over-the-side brush drum (Finnish Environment Institute (SKYE))

Another variation of the brush skimmer intended for use in ice is pictured below at right (Figure 5.38). Robust construction, hot water injection and a screw auger pump make the skimmer suitable for medium to viscous oils. Ice intrusions can hamper operation of this skimmer. In the photo at left (Figure 5.37) is another trend in

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which more versatile hydraulic arms are used to deploy over-the-side skimmers for positioning between ice floes.



Figure 5.37. Skimmer and hydraulic arm (Sørstrøm et al., 2010)

Figure 5.38. Arctic brush skimmer (Solsberg, 2006)

The simple drum skimmer has been improved with the addition of grooves in the drums to create more surface area and therefore a higher recovery rate (Figure 5.39). Drums made of High Density Polyethylene (HDPE) can recover a relatively wide range of viscosity oils ranging from light to medium.

Disc skimmers have also advanced in a manner similar to drum devices with grooved surfaces that can recover light to medium viscosity oils at higher rates (Figure 5.40).

Disc skimmers have also had modifications made to them that include coated discs. This increases recovery capacity particularly in light to medium viscosity oils (Figure 5.41).



Figure 5.39. Grooved drum skimmer. *Photo credit: Elastec website.*



Figure 5.40. Grooved disc skimmer *Source: S.L. Ross and MAR Inc., 2013.*

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Figure 5.41. Coated disc skimmer. Source: S.L. Ross and MAR Inc., 2013.



Figure 5.42. Compact belt skimmer. Source: S.L. Ross and MAR Inc., 2013.

Another recent trend is the availability of small conveyor belt skimmers. These can recover medium to highly viscous oils in the presence of ice.

Each skimmer has operating functions, e.g., disc, drum or belt speed, weir height, that must be optimized for the conditions in which the device is used. Managing the ice is also required to ensure the skimmers remain in contact with oil.

A diesel-hydraulic power pack is usually required to power the skimmers. and must be suitable for cold weather operations.

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 5.43) 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.

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.

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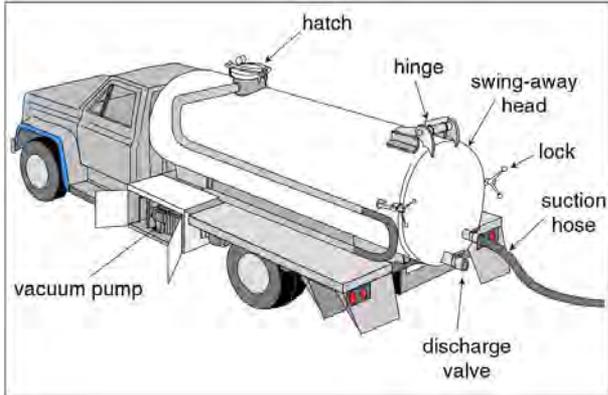


Figure 5.43. Vacuum truck

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

The objective of in-situ burning (ISB) is to remove oil in one step, i.e., in many cases without the need for collection and disposal. In-situ burning is a treatment method that can be used for oil on open water, on ice and in pack ice (with and without herding

agents).

Using controlled ISB as an oil spill response technique in cold water and the Arctic dates back to 1958 when ISB was used to respond to a pipeline spill in the Mackenzie River, NWT. Since then, many large-scale oil-in-ice and ambient-water experimental spills have successfully employed ISB in Canada (Fingas et al., 1995) and Norway, with the most recent field trials with herding and burning occurring off Norway in 2016 (Cooper et al., 2017). The massive ISB operation in response to the *Deepwater Horizon* blowout provided a unique set of full-scale operational data on burning applicable to response planning for Arctic offshore open water areas in the summer. In that incident, ~400 controlled burns removed an estimated 220,000 to 310,000 barrels of oil from the Gulf of Mexico (Allen et al., 2011)

In some cases, burn residue recovery may be warranted for environmental reasons (e.g., crude oils where the residue is likely to sink). In the case of the *Deepwater Horizon* response, the decision was made to leave the residue to attenuate naturally. Utilizing the available crews and fire booms to continue collecting, concentrating and igniting the oil more than offset any negative impacts from the residue.

	burning oil on water contained in booms
	burning oil on ice
	burning oil in broken ice

5.5.1 Burning Oil On Water Contained in Booms

Oil on water can generally be ignited and burned if the thickness is greater than 2 or 3 mm. Typically, slicks spreading in open water or very open drift ice conditions (10 to 30%) must be contained and concentrated to achieve this thickness using fire-resistant

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booms or thickened by applying very small volumes of a herder agent around the periphery of the slick. The strategy of using herders provides a number of key advantages: the whole operation can take place aerially without the need for support vessels and herding can continue in ice concentrations that would interfere with or prevent booming operations.

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).

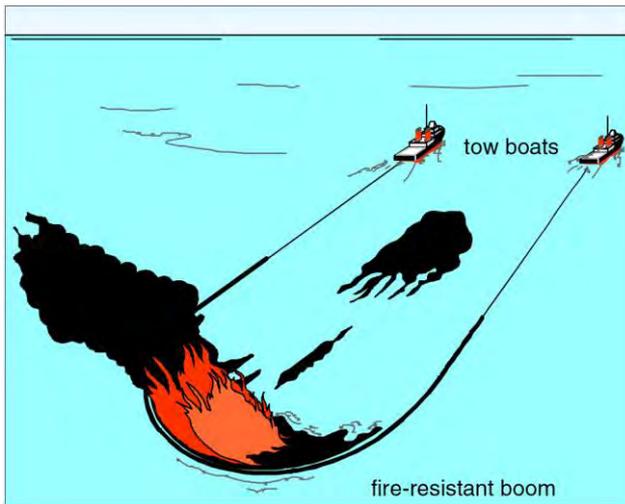


Figure 5.44. Open water containment/burning

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.

Fire-Resistant Booms

Fire-resistant booms (fire booms) can be used for the containment, diversion or exclusion of spilled oil. Typically, fire booms are heavy and can be difficult to deploy and retrieve without the proper lifting gear. The main objective in fire boom design is survivability in repeated burns exposing the above water components to extremely high temperatures (1,000s of °F). Initially, most fire-resistant booms in the 1980s and 90s incorporated mineral-based fabric and ceramics in their structure, resulting in very heavy, unwieldy booms. More recent alternatives have better survivability and greater ease of deployment. There are two common design types currently in production. The first employs wire-reinforced refractory fabric for the above water barrier and glass foam-filled steel hemispheres for flotation. The second design uses an inflatable boom that can be stored on reels unlike previous fire booms, together with a water spray system to cool the boom and protect it from the burn. Inflatable booms are unlikely to see use in the Arctic because of their susceptibility to damage in ice and to functionality problems in sub-freezing temperatures.

Like conventional booms, fire-resistant booms have limited effectiveness in pack ice concentrations over 30% because the boom quickly collects a large mass of ice that quickly overrides the flotation collar, resulting in loss of containment. In addition, the forces involved in towing a boom filled with heavy ice can easily exceed the booms tensile strength, resulting in failure of connections and fasteners.

In very open drift ice concentrations up to about 30%, field trials in Svalbard in 2008 and 2009 showed that fire booms can successfully collect a substantial amount of ice in small piece sizes (metres or less) without failing. Oil deliberately introduced into the contained ice field was then successfully ignited and burned with

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high efficiency (>90%). The presence of ice did extend the burn times compared with burning an equivalent contained spill in open water. (Potter and Buist, 2010)



Figure 5.45. Burning oil in ice collected by a fire boom during field trials in Svalbard, 2009. *Photo: SINTEF*

Igniters

An effective aerial ignition system is characterized by the following features:

- Igniters survive falling into water while maintaining a reliable, long lasting and intense heat source that rapidly ignites the vapours above a slick
- simplicity in design, fail safe and easy to use, with a long shelf-life
- minimal special permit requirements for transportation

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. While these methods were successfully employed in the 1970s and 80s, they no longer meet present day safety standards. Aerial application of igniters today may require testing and certification by national aeronautical agencies such as the US Federal Aviation Administration (FAA) or the European Aviation Safety Agency (EASA). An exception can be made if the ignitron system is slung from the cargo hook where the pilot can immediately drop the load in case of a problem. The Helitorch™ is an example of such a system (see below) .

Two types of ignition systems are commercially available: Igniters used from a vessel or from shore and igniters for use from helicopters both manned and in the near future robotic (unmanned air systems). Vessel deployed igniters are often fabricated on site with easily obtainable components: marine flare, flotation foam, and bags of gelled gasoline (made up by mixing pyrotechnic powder with raw fuel). Similar “home-made” igniters were used successfully in the Deepwater Horizon incident to successfully ignite over 400 burns.

One airborne device originally developed for the forest fire fighting industry, the Heli-Torch®, has received wide acceptance for Arctic spill response 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 (Allen, 1987). Although safe to use with proper safeguards and standard operating procedures, the Heli-Torch suffers from a number of drawbacks when used to respond to any spill much further than a few tens of kilometres from shore. The range of helicopters carrying a sling load is restricted to relatively short distances at low speeds.

Basin and air tests in 2016/17 successfully evaluated a cartridge-

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based ignitor system integrated with a herder application package capable of mounting on a wide variety of helicopters (Fig. 5.46). An additional option tested successfully in 2015, involves using a robotic helicopter to ignite slicks that are either thick enough on their own or following herder application. (<http://www.arcticresponsetechnology.org/publications-data>)



Figure 5.46. Canadian Coast Guard Bo-05 slinging a Helitorch during the 1993 NOBE burn experiment offshore Newfoundland. *Photo: D. Dickins*

Future activities include developing and certifying a much larger gelled fuel tank (300 gal +) and higher speed (85 knots) ignition

ejection system capable of deployment on longer range, heavier helicopters as well as fixed wing aircraft. Timing on when such a system may become available depends on demand from industry and Arctic drilling activity. A conceptual engineering design for such a system is available at <http://www.arcticresponsetechnology.org/publications-data>

Simple igniters that can be stored over long periods, and manually deployed are more practical in remote communities or other situations where a helicopter is not immediately available. These can be readily deployed upwind from small boats and allowed to drift into the oil as was achieved successfully in hundreds of burns during the Deepwater Horizon Response (Allen et al., 2011).

5.5.2 Burning Oil on Ice

On Solid Ice

On continuous, solid ice, oil deposited on the surface is quickly absorbed by the snow cover. 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.

In the case of spills in solid ice near shore, the choice of whether to burn on site or remove the oil to shore will depend on the time of year, ice conditions and water depth (ice roads cannot be safely constructed to access deeper water sites in the fast ice zone). On-site burning might become the preferred option late in winter when there would be insufficient time to transport the recovered oil to shore prior to breakup. During this time, the preferred response tactic would be selective burning of oil on melt pools with aerial ignition (see following).

Backhoes, bulldozers and graders can be used to build piles or cones (Figure 5.47) of oiled snow. By adding a suitable combustion promoter, e.g., diesel, the contained oil can be ignited and

burned. Compacted snow berms or trenches surrounding the cones prevent the spreading of oil in the melt water that forms during the burn.

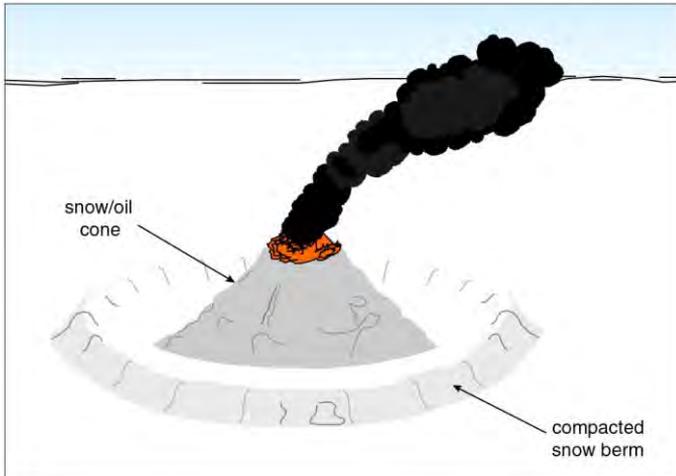


Figure 5.47. Burning snow cone

Melt Pools

Oil spilled under cold continuous sea ice will spread and fill the natural undulations related to differing snow thickness and rougher voids created by ice deformation (rafting, rubble and ridges). If ice is still growing, the oil will become encapsulated in the ice over a fairly short period of time depending on ambient temperatures – typically 12 to 72 hours. Once the ice growth stops and the sheet begins to approach $\sim -5^{\circ}\text{C}$ or warmer through much of its depth, most of the oil will rapidly rise up through brine channels and pool on the surface where it can potentially be burned.

This potential depends on several important factors:

- The oil thickness under the ice at time of initial deposition – ice moving drifting over a fixed discharge point on the seabed can result in very thin films that may be too thin to burn when they surface in the spring.
- The effectiveness of wind herding to thicken the oil patches within individual melt pools.

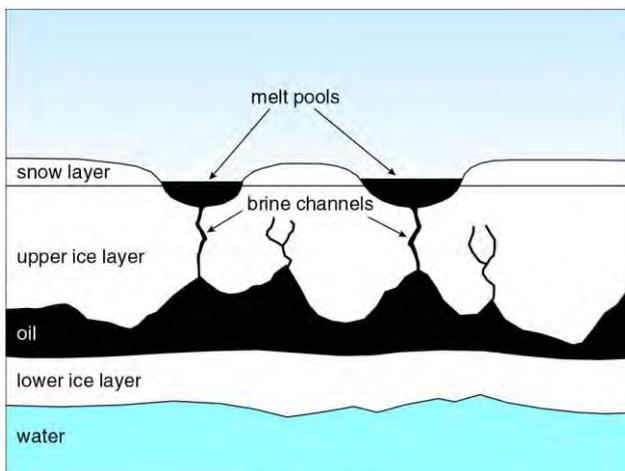


Figure 5.48. Melt pools

Melt pools develop over a period of several weeks and can exist for a similar period again before the ice sheet is finally broken up by wind action and the remaining oil dispersed into the water surface.

While relatively easy to implement with spills under static ice near-shore, the logistics of implementing this strategy on a large scale offshore spill months after the event are complex. 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 along a meandering ice drift track that can stretch for hundreds of kilometres. Fortunately there are techniques to help locate the oil in the spring, for example deploying GPS tracking buoys at the spill site in regular intervals as the ice moves past. Airborne remote systems using high resolution infra-red sensors have a good chance of seeing oil on melt pools heated by solar radiation in the spring. A potential problem is that in some cases the phenomenon of melt pools can be relatively short-lived and spilled oil can then re-enter the sea if the ice disintegrates prematurely. A recent (2016) conceptual engineering design looked at the practicality of developing a long-range aerial ignition system that is capable of igniting multiple melt pools over ~50 kilometres of oiled ice track in a single mission (IOGP 2012-2017).

Burn removal efficiencies have been determined to range from 65 to over 90%, depending on the oil film thickness and size distribution of the melt pools on ice (it is not practical to ignite all small pools). In an experimental spill under solid ice in Norway, 3,400 litres of crude oil were allowed to surface naturally through the ice and then burned with an overall removal efficiency of 96%. A portion of this oil was exposed to weathering on the ice surface for over one month before being successfully ignited (Brandvik et al., 2006).

5.5.3 Burning Oil In Broken Ice

In pack or drift ice, oil can be transported by wind and currents around larger ice floes, and into leads, depending on the presence and amount of slush and brash between the thicker ice pieces. In openings within the ice field (referred to as polynyas) wind will herd the oil to one side of the opening and naturally create thicker films that can in many cases be ignited in situ. The ability to burn slicks without containment booms or the addition of herders

(5.5.4) depends to a large degree on the ice concentration. In very open drift ice conditions spills can rapidly spread at rates similar to open water and quickly become too thin to ignite (e.g., 1 mm or less).

Experience with burning fresh, weathered, and emulsified oils and petroleum products in a range of ice and wind conditions provides some basic “rules of thumb” (Buist et al., 2003). Wind speeds should not exceed 10 m/s (20 kt). The rules defining the minimum thickness needed to ignite and sustain combustion are summarized here in terms of the oil type and degree of weathering:

- 1 mm for light crudes and gasoline
 - 2-5 mm for weathered crudes and middle-distillates (diesel and kerosene)
 - 10 mm for residual fuel oils and emulsified crudes
- Other important rules of thumb for burning in ice are:
- For a given spill diameter, the burn rate in calm conditions is about halved on relatively smooth frazil/slush ice and halved again on rougher, brash ice.
 - Wave action within the ice also tends to reduce the burn rate.
 - The oil to be ignited should not exceed an emulsification of ~25% water-in-oil.
 - Ignition is most likely to be successful when winds are below ~20 knots (10 m/s).
 - Cold air temperatures are not an impediment to successful ignition.
 - Ignition is easiest with fresh, unemulsified oils, a condition more likely to last for a longer period of time in the Arctic as result of lower weathering rates.

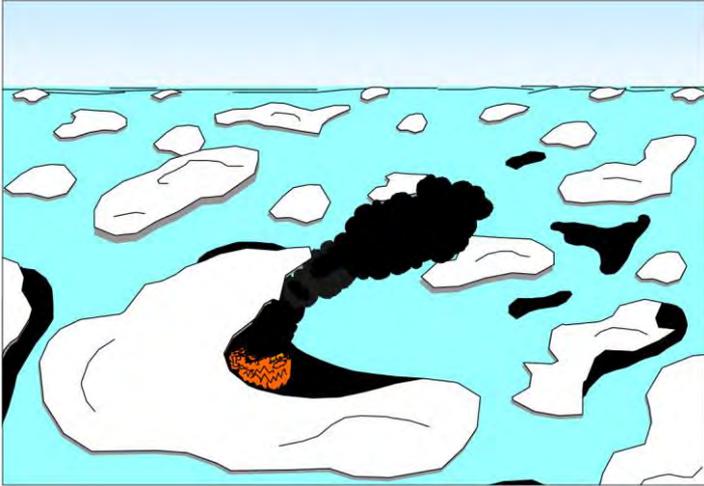


Figure 5.49. Burning in open water/ice embayments

Ignition of oil contained in ice can use the same igniters developed for open water, either deployed from small boats or helicopters, manned and potentially in the near future, robotic helicopters as successfully tested in trials in Alaska and Ottawa in 2015 (IOGP 2012-2017).

5.5.4 Burning after herder application

Oil slicks can be thickened to an ignitable layer, 3 mm or more, with the addition of small volumes of chemical herder for example, several litres or less for a spill size in the order of 5 m³ (30 bbls). The herder is applied around the perimeter of a slick creating a monolayer of herding agent (basically a surfactant) that changes the surface tension and causes the slick to naturally contract and thicken in a short period of time – tens of minutes. Laboratory and basin tests have been conducted in cold water and slush ice up to

70% coverage. The technique of herding and burning was successfully field tested in open drift ice in 2008 (Sørstrøm et al., 2010; Buist, et al., 2011). Burn removal effectiveness was estimated to be in the order of 90%. The residue floated readily and was recovered manually from the water surface and ice edges.

In general, burn efficiencies measured for herded slicks are only slightly less than the theoretical maximums achievable for equivalent-sized, physically contained slicks on open water (Buist et al., 2011).



Figure 5.5011. Photo sequence showing before and after shots during the first field test of herders under arctic conditions off Svalbard, 2008. *Photos: DF Dickins.*

Herders can also provide a viable alternative to booms in open water with moderate winds and sea states. During trials off Norway in 2016, the herder and igniters were applied from small Man Overboard Boat (MOB) boats but future applications of the herder/burn strategy could use an integrated herder/burn system

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mounted on a helicopter – see previous discussion of ignitor technology. The photo below shows the herder hose retracted. In operation, the hose is reeled out and the nozzle suspended together with an ignitor launcher ~35 m below the helicopter and 10 m above the water surface (Potter et al., 2017).



Figure 5.51. Herder application reel and spray nozzle mounted on a helicopter for field testing in Fairbanks, Alaska 2015. *Photo: D. Dickins*

5.6 Chemical Dispersion

The objective of chemical dispersion is to promote the formation

of suspended fine 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 as very small droplets (avg. diameter $<100 \mu$) into the water column, and thereby reduce environmental impacts caused by surface slicks (e.g., impacts to marine mammals, seabirds, marshes, etc.). In this manner, the amount of oil that might otherwise enter bays and estuaries or reach shore and affect sensitive habitats can be significantly reduced. 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

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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 general, dispersants can be used over a wider range of metocean conditions than other response options. They can be applied in relatively rough seas that would otherwise preclude effective boom containment and on oil films too thin to ignite ($\ll 1\text{mm}$).

Dispersed oil rapidly dilutes to concentrations below toxicity thresholds and compared to a surface slick or shoreline stranded slick, allows more rapid biodegradation of the oil by naturally occurring bacteria.

Cold temperatures do not reduce the dispersibility of many oils or the activity of the dispersant. Most oils remain dispersible until they are cooled well below their “pour point” (temperature at which the oil behaves like a semisolid).

In addition, and most critical for response in ice, extensive research since 2004 has shown that the motion and interaction of broken ice pieces actually enhances – rather than detracts from – the dispersion process by providing surface turbulence to replace that generated by breaking waves in open water (Nedwed, 2014).

Application Method

Dispersants can be applied from work/tug boats, single-engine aircraft, helicopters, multi-engine aircraft, and direct injection at a seabed discharge point (SSDI) or through any combination of

these platforms. For surface application, large aircraft offer the advantage of being able to treat very large ocean areas in a short period of time, as well as being able to transit at high speed to a remote Arctic spill location. Recent (2015) developments in this area saw the first jet aircraft (B727 and B737) certificated in the UK and USA respectively for dispersant application. Dispersants are not the only response option that can be entirely delivered by aircraft. Recent trials (2016/17) validated the practicality of using helicopters to both apply herder and drop ignitors in a single flight (see 5.5.4).

The limitations of wind, sea state and wave height are shown in Table 5.8 for each basic mode of dispersant application. Note that in extreme weather and sea conditions, it is unlikely that dispersants would be applied to a spill because natural dispersion occurs readily under these conditions without the need to add chemicals.

In the case of vessel application, communication with spotter aircraft 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.

There is a significant difference in the rate of application between platforms as shown in Table 5.9 contrasting vessels (slowest rate) with a large fixed wing aircraft (highest rate).

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Table 5.8. Comparison of dispersant application platforms

Application Method	Weather Limitations	Advantages	Disadvantages
work/tug boat	<ul style="list-style-type: none"> ● 10 – 35 km/h winds ● 0.3 – 3 m waves 	good control mixes water	limited to small spills small swath width
single-engine airplane	<ul style="list-style-type: none"> ● 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	<ul style="list-style-type: none"> ● 30 – 50 km/h winds ● 2 – 5 m waves 	highly manoeuvrable lands almost anywhere	relatively expensive uses dispersant only (neat)
large, multi-engine airplane	<ul style="list-style-type: none"> ● 50 – 60 km/h winds ● 5 – 7 m waves 	high payload high coverage rate	very expensive requires runway uses dispersant only (neat)

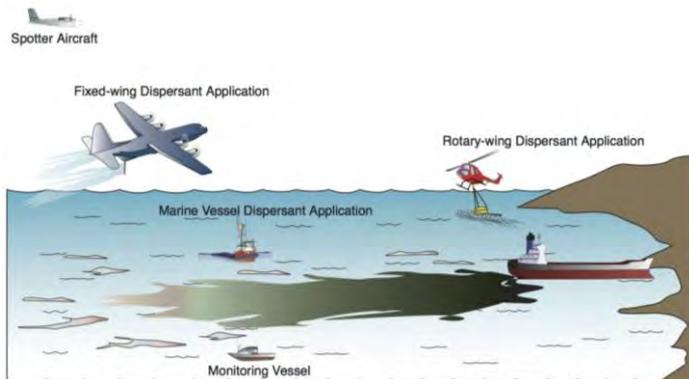


Figure 5.52. Dispersant application platforms. *Source: Nedwed (2014)*

Table 5.9. Comparison of dispersant treatment rates. Source D6

	C-130/ADDS Pack	Typical Vessel System
Payload	5,000 gal	1,000 gal*
Maximum speed	150 kts	10 kts
Minimum speed	130 kts	3 kts
Maximum pump rate	800 gal/min	12 gal/min
Swath width	150-200 ft	90 ft
Mobilization time (hr)	8	5
Total time per sortie (hr)	2.7	5.7
Dispersant time window (hr)	81	84
Sorties possible per unit	14	7
Number of units	1	1
Dispersants applied (gal)	70,000	7,000
Maximum amount of oil that could be treated at dispersant: oil ratio of 1:20 bbl	33,000	3,300

5.6.1 Vessel Dispersant Application

Various vessels, such as workboats, tugboats and icebreaking/ice strengthened support vessels can be used to apply dispersants, but they are effective only on relatively small spills due to their slow speed and small swath width.

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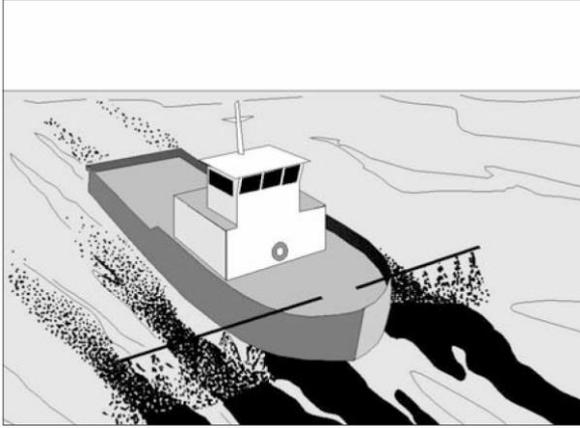


Figure 5.5312. Vessel-based dispersant application

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 gal/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 for smaller spills or isolated oil patches trapped among ice floes, with helicopters equipped with an underslung bucket or smaller single engine aircraft. Typically, aerial application should begin at the outer, leading edges of the thicker parts of the slick.

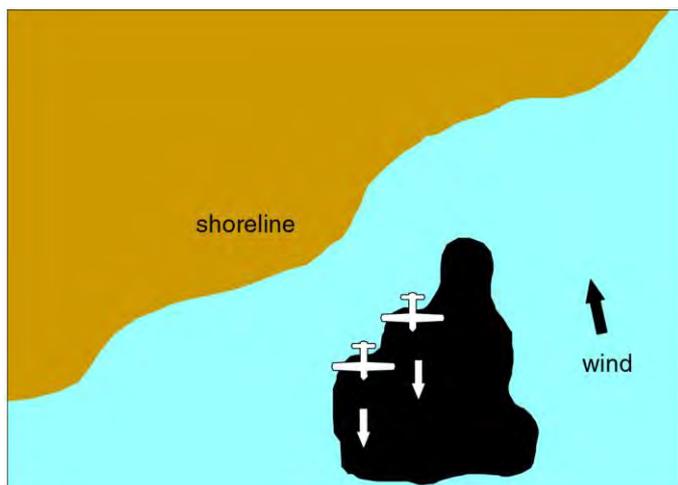


Figure 5.54. Aerial dispersant application

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 and close coordination is required when using multiple aircraft in close proximity (the “air boss” concept).

Helicopter Systems

Helicopters fitted with underslung buckets are used to apply dispersants to localized spills. Deployment specifics, e.g., air speed and bucket altitude, depend on the type of helicopter, bucket design, and dispersant used. Helicopters must be equipped with radar altimeters.

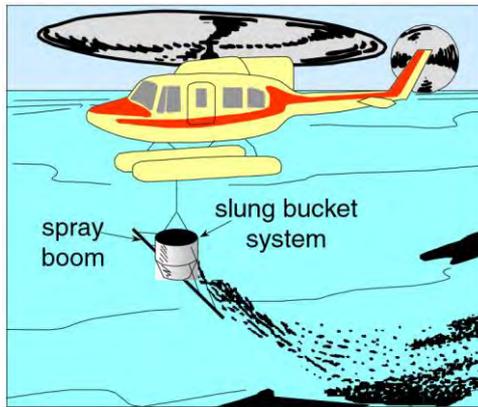


Figure 5.5513. Helicopter-based system

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).

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, varying in size from a C-130 (L-100) to smaller aircraft normally used for agricultural spraying. Appropriate nozzles need to be used ensure the correct dispersant drop size – agricultural nozzles produce too fine a spray pattern.

Application at sub-freezing temperatures may also require larger nozzle, supply line and orifices due to higher product viscosity.

There are practical constraints governing large-scale airborne dispersant application in remote Arctic areas as well as more southern applications. These include: the need for daylight and good weather (visibility and ceiling), and the availability of a large enough dispersant stockpile to sustain an intensive operation.



Figure 5.56. Fixed-wing application showing the recently certificated B727 of OSRL (2015). *Photo: Aviation Week & Space Technology*

5.6.3 Dispersants in Ice

A series of tank and basin tests and field experiments since 1996 have proven that oil can be dispersed successfully in cold ice-covered waters including brackish water encountered in the Arctic in the presence of melting ice and river outflows (e.g., Mackenzie River, Lena River). (Nedwed 2014). Part of this research included the development and field testing of an articulated applicator arm to deliver dispersant more effectively to isolated oil pockets trapped in the ice (Sørstrøm et al. 2010).



Figure 5.57. Specialized dispersant application arm being tested in the Norwegian Barents Sea, 2009. *Photo: D. Dickins*

The presence of ice can increase the window of opportunity when a dispersant is effective by slowing the rate of weathering and emulsification. Wind-wave action that facilitates dispersion in open water is effectively reduced by the presence of ice. However,

the energy generated by individual ice floe interactions can result in more effective dispersion than would otherwise be possible under similar wind conditions in open water (Nedwed, 2014).

In extremely low energy environments where the ice interaction is insufficient to promote or sustain dispersion, it is possible to use the mixing energy from the propeller/jet wash of icebreakers or even small work boats to disperse oil effectively after dispersant is applied. (Nedwed et al., 2007; Sørstrøm et al., 2010). This was accomplished successfully in the 2009 test shown above even though the oil had undergone six days of weathering in the ice. Conventional wisdom based on weathering in warmer open water climates would have suggested a window of opportunity of only one to two days.

5.6.4 Subsea Injection

Injecting dispersant subsea into a jet of oil resulting from loss of well control is a recent innovation. Subsea dispersant injection (SSDI) was utilized for most of the Deepwater Horizon incident to keep a significant amount of the oil from reaching the surface and oiling shorelines. The implementation could be as simple as employed in the Gulf of Mexico. In that case an ROV held the dispersant supply line from a surface support vessel into the jet of oil emanating from the oil broken riser. Future SSDI implementation will likely rely on purpose built systems connected directly to the well bore from subsea storage or surface vessels. With ice moving past the well site, ice management may be necessary to maintain dispersant supply vessels on location.

A major benefit of direct subsea dispersant injection (SSDI) is the ability to continuously respond without being impacted by darkness, extreme temperatures, strong winds, rough seas, or drifting ice. Because of the high efficiency associated with adding dispersant directly to fresh oil at the discharge point under very turbulent

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conditions, the dispersant volume can be substantially less 1:100 Dispersant to Oil Ratio (DOR) compared with 1:20 for a typical surface application. This is a key advantage given the long and difficult logistics resupply chain in most Arctic areas. An additional significant benefit to applying dispersants subsea at an early stage in a response to a subsea blowout is the rapid reduction in hazardous (volatile organic compound - VOC) concentrations encountered by responders at the sea surface working to cap and secure the well or apply other response measures. Recent modelling studies by the Arctic Response Technology JIP show that SSDI greatly reduces the area of surface oil in water depths over ~300 m. Any remaining slicks tend to be very thin, less persistent and easily dispersed naturally by wave action.

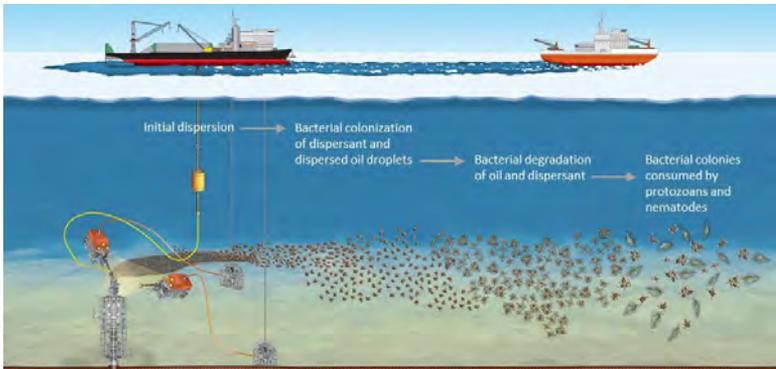


Figure 5.58. Subsea injection as it might be applied in ice. *Source: National Petroleum Council (2015)*

Based on research performed in a variety of mixing regimes, it is expected that a significant percentage of the oil discharged from the *Macondo* well was converted at the discharge point to droplet

sizes in the 10-20 μ range, resulting in stable dispersion with minimal resurfacing. More work is required to understand the effectiveness, systems design, and short- and long-term impacts of subsea dispersant delivery in the Arctic.

5.7 Shoreline Treatment

The objective of shoreline treatment is to accelerate the recovery of an oiled area. 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 Sections 4 and 6.6.

This section provides practical information on 20 shoreline response techniques that are grouped on the basis of five primary treatment strategies below:

Natural recovery	Section 5.7.1
Physical methods	
<ul style="list-style-type: none"> • washing 	Section 5.7.2
<ul style="list-style-type: none"> • removal 	Section 5.7.3
<ul style="list-style-type: none"> • in-situ treatment 	Section 5.7.4
Chemical/biological methods	Section 5.7.5

More detailed information on each method is provided in Owens and Sergy (2010)

Table 5.10 lists the 20 response techniques or tools. 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 5.10 summarizes the relative potential level of impact that each technique or tool may have for the shore-

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line 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.

The amounts and types of waste generated by shoreline treatment vary according to shore type and the amount and type of stranded oil. An EPPR job aid (EPPR 2009) provides a planning tool to estimate waste generation.

5.7.1 Natural Recovery

Optimum Use

The objective of natural recovery is to allow a site to recover without intervention or intrusion. All shoreline types that are affected by small amounts of non-persistent oil can naturally recover, even in Arctic conditions, given appropriate circumstances.

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.

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Table 5.10. Summary of the relative potential impact of response techniques in the absence of oil (modified from API/NOAA, 1994)

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

○ good (low potential impact) ◐ fair (medium potential impact)
 ● poor (high potential impact)

Applications

The natural recovery option may result from a NEBA process of 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 - Section 7.5) analysis for natural recovery considers among other variables such as exposure, sensitivity and resilience of different species:

- 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

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 oil 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 5.11). Generally, the equipment used for these techniques is not manufactured

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specifically for spill response but is available commercially for other purposes.

The seven 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 relevant shoreline types and oil characteristics.

Table 5.11. Summary of physical washing technique ranges

	Technique	Pressure Range		Temperature Range
		psi	bars	(°C)
②	flooding (deluge)	<20	<1.5	ambient water
③	low-pressure, ambient wash	<50	<3	ambient water
④	low-pressure, warm/hot wash	<50	<3	30 – 100
⑤	high-pressure, ambient 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

Table 5.12. Summary of washing techniques applications

Technique	Objective	Optimum Use
 flooding	flood a site so that mobile or remobilized oil is lifted and carried downslope to a collection area	<ul style="list-style-type: none"> ● most shoreline types ● light to medium oils
 low-pressure, ambient-water wash	wash or flush oils toward a collection area using normal temperature sea, lake or river water at low pressure	<ul style="list-style-type: none"> ● impermeable shorelines and marshes ● light to medium oils
 low-pressure, warm or hot-water wash	wash and flush oils at low pressure, using heated toward a collection area	<ul style="list-style-type: none"> ● impermeable shorelines water ● light to medium oils
 high-pressure, ambient-water wash	wash or flush oils toward a collection area using normal temperature sea, lake or river water at high pressure	<ul style="list-style-type: none"> ● impermeable shorelines ● medium to heavy oils
 high-pressure, warm or hot-water wash	wash and flush oils at high pressure, using heated water, toward a collection area	<ul style="list-style-type: none"> ● impermeable shorelines ● medium to heavy oils
 steam cleaning	remove stains or dislodge thin layers of viscous oil from hard surfaces	<ul style="list-style-type: none"> ● impermeable man-made structures ● stains or heavy weathered oils
 sand blasting	remove stains or dislodge thin plates or viscous oil from hard surfaces	<ul style="list-style-type: none"> ● impermeable man-made structures ● stains or heavy weathered oils

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In flooding, 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 5.59). Flooding and low-pressure washing techniques 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 5.12).

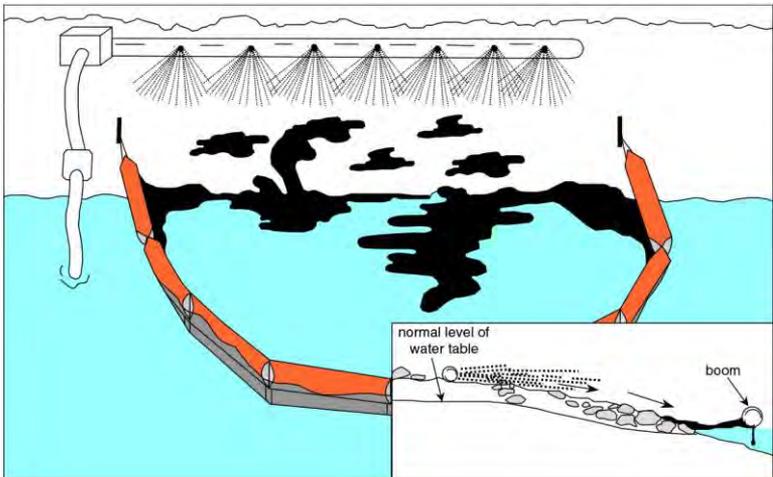


Figure 5.59. Flooding technique

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, ambient-water washing can be practical and effective on most impermeable shoreline types and on some permeable shores (beaches) or marshes (Figure 5.60). 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.

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. 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 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 and sand blasting are very intrusive in terms of ecological effects and may remove all organisms, leaving a clean and pristine but barren surface.

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Figure 5.60. Low-pressure ambient washing on an oiled river bank and a marsh fringe (*bottom photo. H.C Dubach*)

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 5.13 in terms of the objective of each technique, the preferred or

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recommended application and the relevant shoreline types and oil character. Table 5.14 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 physical removal techniques

Technique	Objective	Optimum Use
 manual removal	remove oil or oiled materials (including oiled type sediments) with manual amounts labour and hand tools	<ul style="list-style-type: none"> ● any shoreline type ● small amount of surface oil
 vacuum systems	remove oil by suction from areas where it has pooled or collected in sumps	<ul style="list-style-type: none"> ● light to medium, non-volatile, pooled or collected oil
 mechanical removal	remove oil and oiled materials using mechanical equipment	<ul style="list-style-type: none"> ● most fine to coarse-sediment beaches ● large volumes of medium, heavy or solid oil
 vegetation cutting	remove oiled stems to prevent remobilization of the oil or contact by animals and birds, or to accelerate the recovery or the plants	<ul style="list-style-type: none"> ● marshes, vegetated shorelines ● where remobilization of oil will affect other resources
 passive sorbents	place sorbents in a fixed location(s) so that they pick up oil by contact	<ul style="list-style-type: none"> ● any shoreline type ● light to heavy non-solid, non-volatile oils

Table 5.14. 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/scrapper	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

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Manual removal involves cleanup teams picking up oil, oiled sediments or oily debris with gloved hands, rakes, forks, trowels, shovels, sorbent materials or buckets (Figure 5.40). 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 5.14), 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.

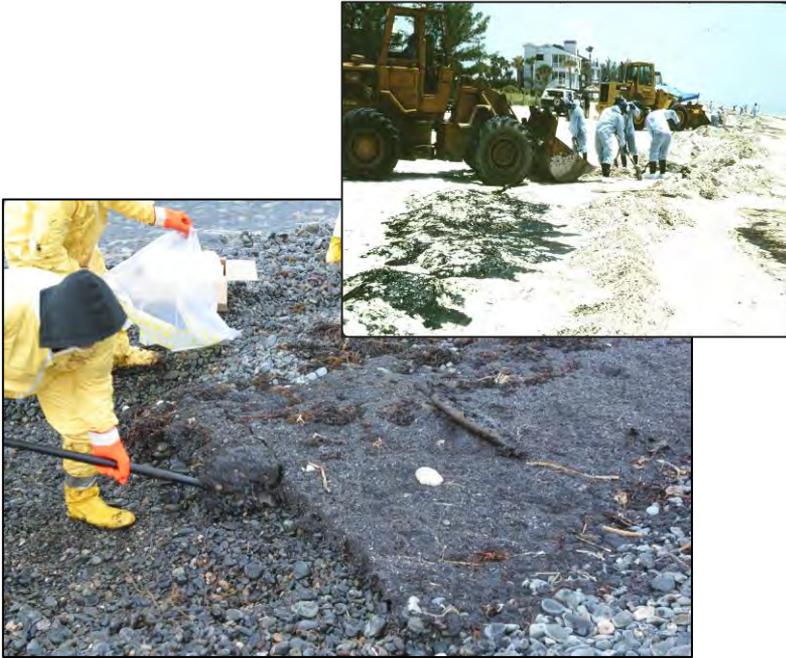


Figure 5.61. Manual removal: inset illustrates shovelling oiled sediments directly into front-end loader to reduce a transfer step

Vacuum systems 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 5.62). This technique can be used in combination with flooding 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.

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Figure 5.62. Vacuum pump removing oil from a collection trench or sump

Mechanical removal can involve a range of devices to remove oil and oiled surface and subsurface materials from shorelines (API 2016d). Mechanical removal is more rapid than manual removal but generates larger quantities of waste. Operating methods varies considerably depending on the type of equipment (Tables 5.15 and 5.16) and its ability to operate on a particular section of shore. Table 5.14 indicates the relative efficiency of each type of equipment, in terms of the rate of cleaning that can be achieved and the amount of waste generated.

Some equipment, e.g., elevating scrapers, loaders, backhoes or vacuum trucks, removes and transfers material directly to a truck or temporary storage area in a single step (Figures 5.63, 5.64 and 5.65). Other equipment types (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 scrapers, loaders or backhoes) for transfer (Figures 5.66 and 5.67).

Table 5.15. 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	can operate on most sediments or on steep slopes to remove surface and subsurface oil; traction reduced as sediment size increases

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Device	Technique	Applicability
	reach from a platform or clean area	
dragline/ clamshell	bucket lifts oiled sediments for transfer to truck or temporary storage site; extended arm can reach from a platform or clean area; poor control of depth of cut	can operate on most sediments or on steep slopes to remove surface and subsurface oil

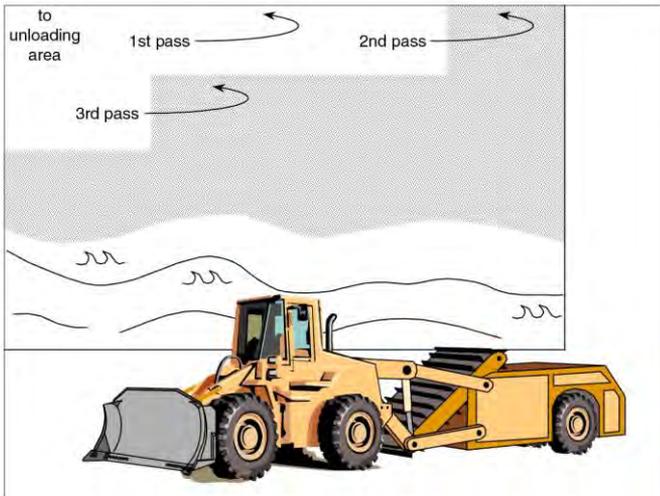


Figure 5.63. Direct mechanical removal with elevating scraper

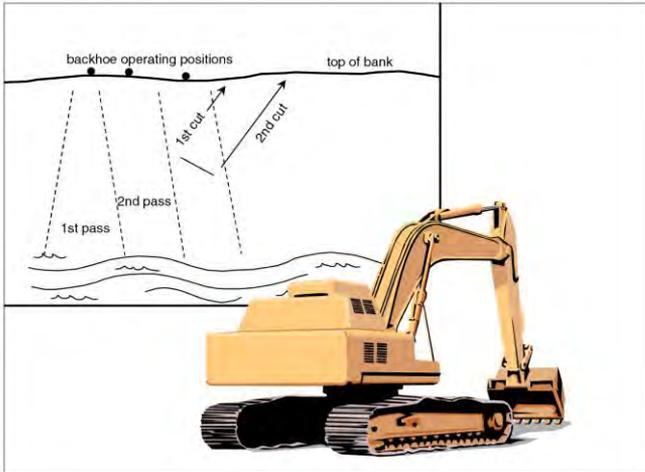


Figure 5.64. Direct mechanical removal with backhoe

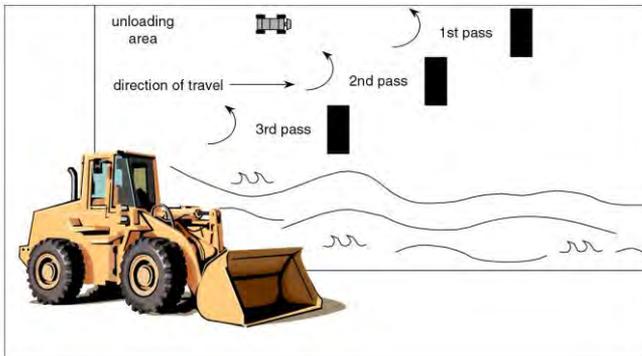


Figure 5.65. Direct mechanical removal with front-end loader

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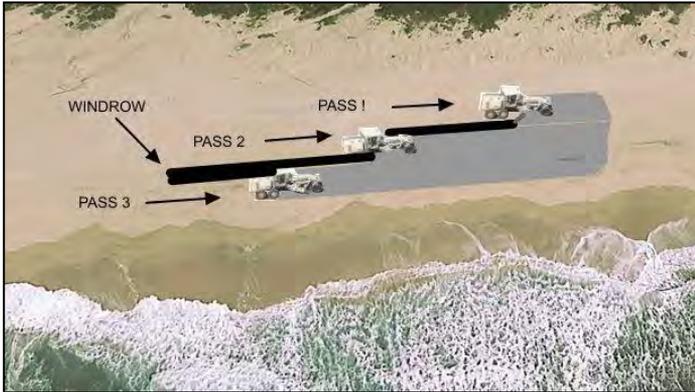


Figure 5.66. Two-stage removal with grader supported by loader and/or scraper (API, 2016d)

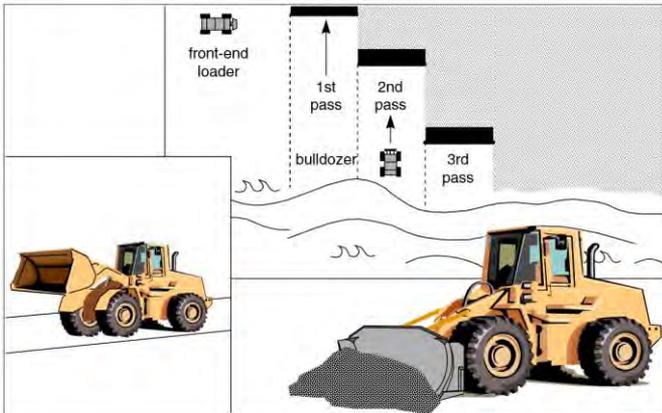


Figure 5.67. Two-stage removal with bulldozer supported by front-end loader

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 back-shore area and can reach to pick up material.
- Beach cleaning machines operate in a number of different ways (Table 5.16). Mobile equipment operates on a beach, e.g., Figure 5.68, 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.

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Figure 5.68. Sand beach cleaning machines

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 5.16. 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 throughput
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 5.63 to 5.67 are intended as a guide. Operators usually can provide suggestions or improvisations to meet the cleanup objectives for a particular section of beach.

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Vegetation cutting 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	sediment mixing
15	sediment relocation
16	burning

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 5.17 with respect to the objective of the techniques and the preferred or recommended application, and in terms of shoreline types and oil character.

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Table 5.17. Summary of physical in-situ techniques

Technique	Objective	Optimum Use
14 sediment mixing	expose or breakup surface and/or sub-surface oil to accelerate evaporation and other natural degradation processes	<ul style="list-style-type: none"> ● 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	<ul style="list-style-type: none"> ● 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	<ul style="list-style-type: none"> ● 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 sediment 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, the oiled surface or subsurface sediments are excavated, exposed or mixed in place without being moved to another part of the beach (Figure 5.69). This technique is also known as “tilling” or “aeration”.



Figure 5.69. Sediment mixing on a sand beach (left) and in a stream bed (right)

In sediment relocation, 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 (Figure 5.70). 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”.



Figure 5.70. Sediment relocation on a remote area coarse beach

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Sediment mixing and sediment relocation are particularly useful:

- where oiled sediments are located above the limit of normal wave action, e.g., when a beach is 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 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 remains, such as Stains
- immediately prior to expected storm events or periods of high wave-energy levels

More information is provided in two recent documents “*Shoreline In Situ Treatment (Sediment Mixing and Relocation) Fact Sheet and Job Aid*”: API 2016a, 2016b.

Burning 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 (Figure 5.71). Burning can also be used where vegetation, such as that found in a wetland, has been heavily oiled.

Constraints/Limitations

The objective of sediment mixing and sediment relocation is to expose the oil to natural degradation. Burying the oil must be avoided as this may 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.



Figure 5.71. Burning oiled large woody debris on a remote shoreline

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.

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

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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 5.18 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

Dispersants or shoreline cleaners 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 agitated 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.

Table 5.18. Summary of chemical and biological techniques

Technique	Objective	Optimum Use
 dispersants	create fine oil droplets that are dispersed into the adjacent waters where they then are naturally weathered and degraded	<ul style="list-style-type: none"> ● light to medium, fresh oils
 shoreline cleaners	remove and recover oil using a cleansing agent that lifts the oil from the substrate	<ul style="list-style-type: none"> ● coarse- sediment beaches ● non-solid oils ● as a pre-treatment with collection methods
 solidifiers and visco-elastic agents	alter the viscosity of oil to enhance recovery and collection	<ul style="list-style-type: none"> ● sands or mixed-sediment beaches ● medium oils
 nutrient enrichment/ bioremediation	accelerate natural biodegradation processes by the addition of nutrients (fertilizers containing nitrogen and phosphorus)	<ul style="list-style-type: none"> ● all shorelines ● small amounts of residual oil

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 5.72).

Solidifying agents 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

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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 5.72). 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.

Agent	Oil Type/Degree of Weathering		
	light	medium	heavy
19 solidifiers			
19 visco-elastic agents			
18 shoreline cleaners			
18 shoreline cleaners as a pre-soak			

Key

most effective	
moderately effective	
least effective/appropriate	
ineffective	

Figure 5.72. Potential application of treatment agent by oil type.
after Walker, et al. 1993

Bioremediation 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 (Figure 5.73). 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.



Figure 5.73. Applying a slow-release fertilizer to a remote oiled experimental beach after mixing

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.

RESPONSE METHODS

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.

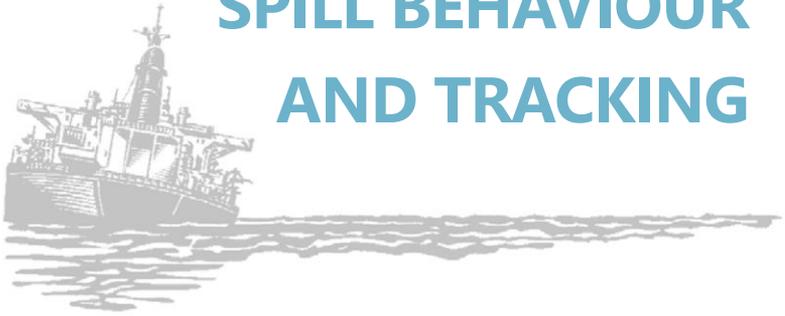
Bioremediation is an effective but relatively slow process compared to other response options. The rate of biodegradation decreases with lower temperatures so that nutrient enrichment is more effective during warmer summer months.

PART B

TECHNICAL SUPPORT INFORMATION

6

SPILL BEHAVIOUR AND TRACKING



CONTENTS

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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).

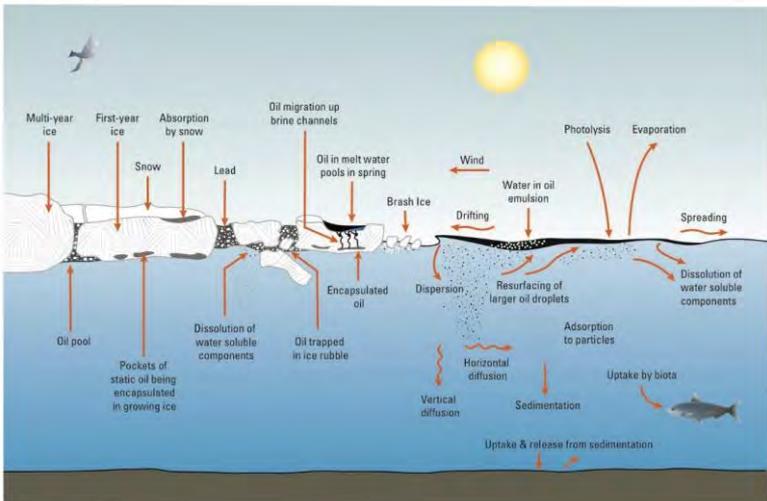


Figure 6.1. Oil weathering processes in mobile pack ice and in open water at the ice edge. *Source: NRC (2014) – adopted from original illustrations by ITOPF and Allen*

Natural processes that occur initially and that are important for response operations include:

- dispersion
- emulsification
- evaporation
- spreading
- dissolution
- sinking or sedimentation

Slower 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)
- slick thickness – thin films evaporate more rapidly and naturally disperse more readily with wave action
- 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 or encapsulated in ice. 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). Evaporation accounts for the loss of 20-50% of many crude oils and 75% or more of some refined products and condensates. In contrast heavy residual fuel oils may only lose 10%.

Comparisons of evaporative loss of crude oil as a function of ice concentration resulted in values of 30% for open water, 25% for low ice coverage and 19% for heavier ice coverage (over 6/10), mainly due to differences in equilibrium oil film thickness. (Sørstrøm et al., 2010; Brandvik and Faksness, 2009)

Persistent oils weather and break down more slowly. Water-in-oil emulsification is an important process affecting all aspects of response. It not only results in a dramatic increase in viscosity but also a significant increase in storage volume needed to deal with any recovered oil. 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. For example, ISB loses its applicability when the water content of the emulsion exceeds 30%. The presence of ice in high concentrations effectively damps the wave action that promotes emulsification and this leads to longer windows of opportunity where the options of using response strategies like ISB and dispersants remain open.

Gelling is a potentially important oil-property change that becomes more likely in cold water or with oil spilled on ice in winter. Oils that

are fluid in temperate climates can gel when the ambient temperature falls below their pour point. Knowing which oils are most likely to gel could greatly affect the choice of response options. The following table provides information on pour points for different crude oils and refined products.

The presence of ice, the harsh environmental conditions, and remoteness adds challenges to oil spill assessment and response in the Arctic. Ice cover and cold temperatures affecting oil behaviour, however, may provide a critical advantage. Oil spill responders understand that “speed is the key” for a spill in open water. This is because of the very dynamic nature of oil on water. It can rapidly spread, drift, break into smaller slicks, interact with natural sediment / vegetation, weather, emulsify, and strand on shorelines before response equipment can be deployed. In contrast, an ice cover can immediately contain oil to limit spreading thereby keeping the oil thick. Cold temperatures and the thicker oil will limit the rate of evaporation and dissolution. Further, land-fast ice can protect shorelines from oil stranding for many months of the year. Thus, ice conditions may give response personnel more time to bring response strategies into play and this advantage may counteract some of the disadvantages caused by Arctic conditions such as extreme cold temperatures, darkness and remoteness (Dickins, 2011).

SPILL BEHAVIOUR AND TRACKING

Table 6.1. Oil properties table. A higher group number is normally associated with a higher persistence in the environment. *Source: ITOFF*

CLASSIFICATION OF OILS ACCORDING TO THEIR SPECIFIC GRAVITY

Group 1 oils						Group 3 oils					
A: *API > 45 (Specific gravity < 0.8) B: Pour point < °C C: Viscosity @ 10–20°C: less than 3 Cst D: % boiling below 200°C: greater than 50% E: % boiling above 370°C: between 20 and 0%						A: *API 17.5–35 (Specific gravity 0.85–0.95) B: Pour point < °C C: Viscosity @ 10–20°C: between 8 Cst and semi solid D: % boiling below 200°C: between 10 and 35% E: % boiling above 370°C: between 30 and 65%					
Low pour point <6°C						Low pour point <6°C					
Asgard	49	-28	2 @ 10°C	D	E	Alaska North Slope	28	-18	32 @ 15°C	D	E
Arabian Super Light	51	-39	2 @ 20°C			Arabian Heavy	28	-40	55 @ 15°C	21	56
Cossack	48	-18	2 @ 20°C	51	18	Arabian Medium	30	-21	25 @ 15°C	22	51
Curlew	47	-13	2 @ 20°C	57	17	Arabian Light	33	-40	14 @ 15°C	25	45
F3 Condensate	54	<-63	1 @ 10°C	81	0	Bonny Light	35	-11	25 @ 15°C	26	30
Gippsland	52	-13	1.5 @ 20°C	63	8	Iranian Heavy	31	-36	25 @ 15°C	24	48
Hidra	52	-62	2.5 @ 10°C	60	11	Iranian Light	34	-32	15 @ 15°C	26	43
Terengganu condensate	73	-36	0.5 @ 20°C	>95	0	Khafji	28	-57	80 @ 15°C	21	55
Wolybutt	49	-53	2 @ 20°C	55	4	Sirri	33	-12	18 @ 10°C	32	38
Gasoline	58	58	0.5 @ 15°C	100	0	Thunder Horse	35	-27	10 @ 10°C	32	39
Kerosene	45	-55	2 @ 15°C	50	0	Tia Juana Light	32	-42	500 @ 15°C	24	45
Naptha	55		0.5 @ 15°C	100	0	Troll	33	-9	14 @ 10°C	24	35
						IFO 180	18-20	10-30	1,500-3,000 @ 15°C		-
Group 2 oils						Group 4 oils					
A: *API 35–45 (Specific gravity 0.8–0.85) B: Pour point < °C C: Viscosity @ 10–20°C: between 4 Cst and semi-solid D: % boiling below 200°C: between 20 and 50% E: % boiling above 370°C: between 15 and 50%						A: *API <17.5 (Specific gravity >0.95) or B: Pour point >30°C C: Viscosity @ 10–20°C: between 1500 Cst and semi-solid D: % boiling below 200°C: less than 25% E: % boiling above 370°C: greater than 30%					
Low pour point <6°C						High pour point >5°C					
Arabian Extra Light	38	-30	3 @ 15°C	26	39	Cabinda	33	12	Semi-solid	18	56
Azeri	37	-3	8 @ 20°C	29	46	Coco	32	21	Semi-solid	21	46
Brent	38	-3	7 @ 10°C	37	33	Gamba	31	23	Semi-solid	11	54
Draugen	40	-15	4 @ 20°C	37	32	Mandji	30	9	70 @ 15°C	21	53
Dukhan	41	-49	9 @ 15°C	36	33	Minas	35	18	Semi-solid	15	58
Liverpool Bay	45	-21	4 @ 20°C	42	28						
Sokol (Sakhalin)	37	-27	4 @ 20°C	45	21						
Rio Negro	35	-5	23 @ 10°C	29	41						
Umm Shaif	37	-24	10 @ 10°C	34	31						
Zakum	40	-24	6 @ 10°C	36	33						
Marine Gas oil (MGO)	37	-3	5 @ 15°C								
High pour point >5°C						High pour point >5°C					
Amna	36	19	Semi-solid	25	30	Bachaquero 17	16	-29	5,000 @ 15°C	10	60
Beatrice	38	-18	32 @ 15°C	25	35	Boscan	10	15	Semi-solid	4	80
Bintulu	37	19	Semi-solid	24	34	Crta	33	43	Semi-solid	10	54
Escravos	34	10	9 @ 15°C	35	15	Handil	33	35	Semi-solid	23	33
Sarir	38	24	Semi-solid	24	39	Meray	17	-21	7,000 @ 15°C	7	70
Stafford	40	6	7 @ 10°C	38	32	Nile Blend	34	33	Semi-solid	13	59
						Pilon	14	-3	Semi-solid	2	92
						Shengli	24	21	Semi-solid	9	70
						Tachung	12	35	Semi-solid	12	49
						Tia Juana Pesado	31	-1	Semi-solid	3	78
						Widuri	33	46	Semi-solid	7	70
						IFO 380	11-15	10-30	5,000-30,000 @ 15°C		-

Note: High pour point oils only behave as Group 3 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Note: High pour point oils only behave as Group 2 at ambient temperatures above their pour point. Below this treat as Group 4 oils.

Example oils classified according to their API (American Petroleum Institute gravity). Indicative ranges of expected viscosities and distillation characteristics are provided for each group. Generally, when spilt, persistence increases with group number. However, if an oil cools to below its pour point temperature, it will change from a liquid to a semi-solid. This can occur for certain oils irrespective of whether they are classed as Group 2, 3 or 4. The pour points of oils classed as Group 1 are sufficiently low so as not to be a concern in the marine environment.

6.1.1 Oil on Water

The behaviour of oil on water and in ice depends greatly 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 more rapid weathering. Oil that is more dense than water will submerge and is subject only to dissolution, which is usually a fairly minor weathering process. Consequently, submerged oil will degrade slowly. Floating oil with almost the same density as sea water (neutrally buoyant) may submerge if the oil meets less dense, freshwater or remain just awash under the surface, making detection and recovery/removal difficult with any response strategy.

The most dramatic difference between spills in ice and open water is found by comparing the spreading behaviour. For example, as 'rule of thumb' for slicks in open water, about 90% of the oil covers only 10% of the total spill area with most of the oiled area made of a very thin sheen less than a micron in thickness. This distinction between thin and thick portions of the slick also applies to situations of light ice coverage up to ~30%. As the ice coverage increases, slicks may never reach anything close to their natural equilibrium thickness as spreading is effectively slowed or stopped by presence of ice floes in close contact or slush filling the spaces and leads in the pack. Oil spills on top of the ice area are similarly constrained from spreading by the natural surface roughness and snow cover. See following discussion.

6.1.2 Oil in or on Ice

Oil spilled between floes in close pack ice, under or on ice will result in film thicknesses and oiled areas thousands of times less than the equivalent spill in open water or very open drift ice. In one example computed for crude oil, the estimated final oil thickness' were: 0.016 mm in open water vs. 4 cm under on top of snow

covered ice. This difference has far-reaching, mostly positive, implications for response by reducing the weathering rates (extending time available for response) and reducing the risks of wildlife exposure.

Oil present on the water surface at freeze-up will become incorporated into the top surface of the newly forming ice sheet and subsequently covered by snow until the spring melt when the oil again becomes exposed.



Figure 6.2. View of the main 7 cubic metre spill in 8/10 pack ice while being discharged during the 2009 SINTEF Oil in Ice field experiment in the Norwegian Barents Sea. The effectiveness of the closely packed floes in trapping and containing the oil in this situation is clearly apparent. Very little additional spreading occurred in subsequent days.
Photo: SINTEF .

Buoyant oil released under ice will rise through the water column to collect in the natural undulations in the underside of level ice (variability is ~10% of the thickness) and in void spaces between

blocks in ridges and rubble. In most Arctic areas this oil will remain relatively close (within a few hundred metres) to the point where it initially contacts the ice. Under-ice currents in the order of 0.2 m/s or more are usually required to move oil along the underside of the ice beyond the distance that it naturally spreads to reach an equilibrium thickness. In most Arctic areas, winter currents beneath sea ice are below this threshold. Exceptions would be rivers, fjord-like areas with strong tidal flows or narrow Straits such as Kara Gate or narrow passages between barrier islands, for example off the Alaskan North Slope.

During early winter, this oil will quickly (within 12 to 24 hours) become encapsulated by a layer of new ice growing beneath the oil layer. As the ice thickens and the growth rate slows down, this process could take several days. Eventually, the rate of encapsulation slows to zero and stops altogether when the sheet begins to warm in the spring.

As the brine drains down through the warm ice, the oil utilizes the now vacant channels as a pathway to migrate through buoyancy to the ice surface. Very thin oil films trapped in the ice may not migrate effectively. In that case, exposure occurs later, after the ice surface has melted down to the level where the oil resides in the sheet. Once it reaches the surface, the oil collects on melt pools where, depending on the film thickness, ISB can provide an effective removal strategy – see related discussion in 5.5.2.

The oil that surfaces in the spring from being trapped through the winter is essentially fresh, having been sealed off from exposure to air for many months. Normal weathering processes begin once the oil surfaces or becomes exposed through ice melt, primarily evaporation and to a lesser degree emulsification (at a slow rate due to the lack of wave action).



Figure 6.3. Oil on the surface of melt pools in early June during a field test in landfast ice where oil was released subsurface and allowed to encapsulate and then migrate. Note people on the ice for scale. *Photo: D. Dickins*

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.

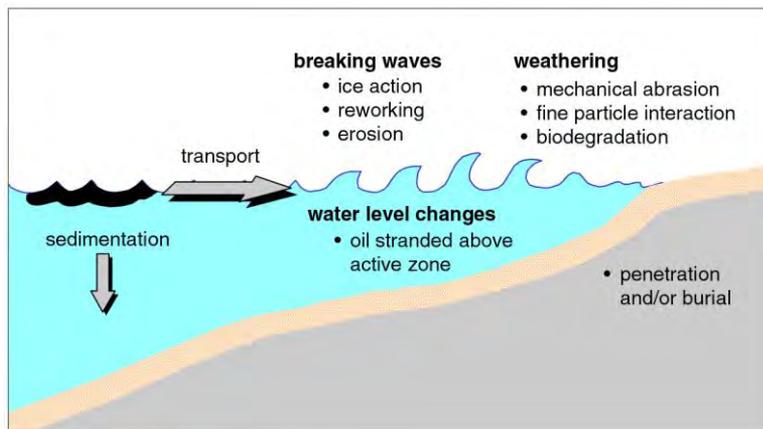


Figure 6.4. Oil stranding on shore

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.

Oil on water spreads and disperses, in part, due to the effects of winds, waves 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 6.5).

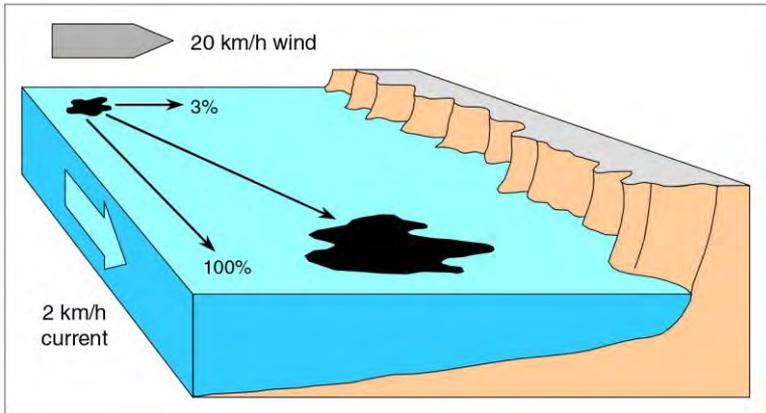


Figure 6.5. The movement of oil on water by wind and current.
adapted from ITOPF, 1987

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.

6.2 The Movement of Spilled Oil

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 trapped within areas with more than 60% pack ice coverage

tends to move with the ice at ~3 to 5% of the wind speed with a turning movement of 20 to 30° to the right of wind direction due to the Coriolis effect. In many cases these drift speeds can exceed (by up to 50%) rates associated with oil on open water, mainly due to the wind drag on rough ice combined with currents acting on deep draft ice features. Oiled ice drift in one field experiment in the Norwegian Barents sea was measured as ~37 km over a 24 hour period (Sørstrøm et al., 2010).

Oil in very open to open drift ice (1-6/10) can move at different rates from the ice cover. For example, thick rough floes with a lot of windage and draft can experience very different driving forces from currents and winds than an oil slick on the water surface. It is not unusual to see an iceberg or old ice floe moving against the wind and predominant oil drift direction in response to currents at depth.

A different trajectory modelling challenge involves predicting the distribution, movement and possible resurfacing of subsea dispersant plumes under ice. This problem received considerable attention following the Deepwater Horizon incident. This work may have value in the future for predicting the plume behaviour for Arctic subsea releases. See related reports on recent (2016) research in this area conducted by the Arctic Response Technology JIP.

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.

Where these rivers flow into the Arctic Ocean it is not unusual for the spring freshet from downstream snow melt to flow out on top of the still bottom-fast ice in the delta and continue for tens of kilometres with water depths to several metres on top of the sea ice. The Colville River off the Alaska North Coast is a prime example where this annual phenomenon covers a vast area and is clearly

visible on satellite imagery. A surface oil spill during this transient 'river overflow' period could be rapidly redistributed beneath the ice as the river water drains through holes and cracks in the melting sheet as it lifts off the bottom. Figure 6.6 (following) shows the annual variability in river stage, using the Mackenzie River as an example.

6.3 Detection, Surveillance and Tracking

The main purpose of detection and surveillance is to locate slicks, map the oiled area and to provide regular updates to the command center on directions and rates of oil movement. Data from overflights provides valuable real time input to recalibrate the trajectory models. In addition, aerial observations help to identify marine resources at greatest risk and help responders reassign or redirect assets to achieve the greatest benefit.

At present, aircraft and helicopters are the most common platforms for tactical reconnaissance while satellites can provide coverage of large ocean areas in the case of a major spill incident. In the near future, expanded use of unmanned air systems or vehicles (often referred to as UAVs) will likely provide more frequent, economical surveys with lower risks to personnel (Jacobs et al., 2015). This is especially important in the Arctic where flights involve long distances in remote areas, with few alternate airfields and minimal SAR facilities.

Most of our knowledge of which sensors are most likely to succeed in different arctic open water and oil in ice scenarios is based on extrapolations from experiences with temperate spills (e.g. Leifer et al., 2012), supported by a small number of actual field tests and tank/basin experiments. Overall conclusions from this work are that the current generation of airborne systems have a high potential for detecting and mapping arctic spills in open water or in very open pack ice but less potential as the ice concentration

increases.

For oil on the surface in open water or low ice concentrations (<4/10), the following surface, airborne or space sensors may have applications, depending on factors such as wind speed, cloud cover and moisture in the air, and oil thickness:

- Human observers with high definition hand held still or video cameras (LLTV)
- Optical: Electro-optical/Forward Looking IR turret
- UV/IR line scanner
- Laser fluorosensor
- Marine or airborne search radar
- Side Looking Airborne Radar (SLAR)
- Satellite Synthetic Aperture Radar (SAR)
- Infrared imaging spectrometer satellite data

Most non-radar sensors are blocked or seriously degraded by darkness, cloud/fog, moisture and precipitation. As ice concentrations increase and wave action diminishes, so does the ability to detect oil slicks with SLAR/SAR and marine/airborne radar. Under these conditions the primary sensors become human observers and potentially, infrared sensors operating over a range of wavelengths. Recent research in this area focused on measuring and modeling the capabilities and limits of these and other sensors in a variety of oil in ice situations. Watkins *et al.*, (2016) provides a practical operational guide for responders who need to select the most effective remote sensors and platforms for different oil in ice scenarios.

Advanced pollution surveillance aircraft carrying many of the sen-

SPILL BEHAVIOUR AND TRACKING

sors mentioned here are operated by Arctic and Baltic nations exposed to the risks of spills in ice for much of the year: for example Norway, Sweden, Iceland, Denmark, Finland, Canada, and Germany. The capabilities of these aircraft are summarized in the following table.

Table 6.2. *Pollution Surveillance Aircraft – Arctic Nations and Baltic States*

Country	Operator	Aircraft	Fleet Size	IIV/IR	FLIR/Visible Turret (E/INT)	SLAR (1)	IFS	Search	Artic Exp.	HELCOM Members (Baltic ice operations)
US	USCG	HC-144a/C27J	32		x			x		
Canada (2)	Environment	Dash 8/Dash 7	3	x	x	x		x	x	
Iceland	Coast Guard	Dash 8 Q-300	1	x	x			x	x	
Denmark	Air Force	Challenger 604	4		x	x (1)		x	x	x
Sweden	Coast Guard	Dash 8 Q-300	3	x	x			x	x	x
Finland (2)	Border Guard	Do 228 (2)	2	x	x	x		x		x
Germany	Navy	Dash 228	3	x	x	x	x	x		x
Norway	Coastal Admin.	King Air 200/350 ER	2		x	x		x	x	

Note 1: Planned addition in 2018 major systems upgrade

Note 2: Major systems upgrades 2012/2013

All aircraft have high resolution hand held digital still and video.

For detecting oil under ice, rapid advances in autonomous underwater vehicle (AUV) technology together with proven capabilities of modern remotely operated underwater vehicles (ROVs) point to possible platforms that can carry a suite of sensors under the ice (Wikinson et al., 2013). Promising sensors identified in an extensive cold basin test program in 2015 include: Acoustic (sonar); Laser Fluorosensor (LFS); and Optical - high definition cameras. Challenges include the lack of bandwidth to transmit real time images back to a support vessel from a submerged AUV, positioning under the ice, and slow survey speed (Wikinson et al., 2015). As an oil layer beneath the ice becomes encapsulated by new ice growing beneath the oil, it becomes increasingly difficult to detect. Available test data indicates that current sonar and LFS technology can detect oil layers through ~8 to 10 cm of new ice growth. As this degree of encapsulation can occur within a week, depending on the starting ice thickness and time of year, it becomes essential to arrive on site as quickly as possible after a spill under ice.

The only other alternative for detecting oil under or in ice at present involves the use of commercially available ground penetrating radar (GPR) operated from the ice surface – possible nearshore on landfast ice and offshore with large floes. The main requirement is that the ice sheet be cold and not close to the melt season where increasing conductivity blocks the radar energy. Specialized airborne radar systems for oil in ice detection are in the development stage but not yet fully proven or operational. Further testing took place in early 2017 with a prototype system that is helicopter compatible – results in process at time writing (IOGP, 2012-2017)

For oil spilled on the ice surface there are a number of options. In the case of oil that is exposed to view, for example on melt pools in

the spring, a combination of visible cameras, human observations and infrared sensors can be used to detect and map the oiled area. The IR sensors can take advantage of the significant solar heat gain in the Arctic spring – oil on melt pools have been measured at 10°C above the surrounding surface water.

For oil on ice covered by snow, two sensors stand out as having the most promise: (1) GPR from the surface or flown at low altitude (15-20 m) from a helicopter (Bradford et al., 2010); and (2), trained oil detection dogs. The GPR was successfully tested in this application on an experimental spill in a fjord on Svalbard in 2006 and dogs were tested at the same location two years later. With GPS tracking collars, the dogs consistently found very small volumes of oil buried in holes drilled into the ice from long distances (up to 5 km in one instance). This capability is equally applicable to finding oil buried under beach sediments as demonstrated in actual spill in Norway. Recent studies and real-world experience in North America have greatly expanded our understanding of the capabilities of dogs in both detecting fresh oil and clearing an already cleaned area for sign off (see Section 6.6, API 2016c, Owens et al., 2016).

There will always be a need for trained airborne observers to detect and map oil and transmit critical information to responders on the ground. For example, spotter aircraft were essential to the success of hundreds of ISB operations during the Deepwater Horizon response (Allen and Dale, 1997).

Detection and tracking are very difficult, and often impossible if the oil is more dense than the water, i.e., submerged below the surface.

Oil on water or in ice can be described and recorded with reference to a standard set of terms. The Bonn Agreement Oil Appearance Code (BAOAC) is used worldwide to systematically report oil on water appearance (colour) and associated estimates for film

thickness and volume per unit area.

Table 6.3. Bonn Agreement Oil Appearance Code. *Source: AMSA 2014*

Code	Description of Appearance	Approx. Thickness (um)	Approx. volume (m ³ /km ²)
1	Sheen	0.04 – 0.030	0.04 – 0.3
2	Rainbow	0.30 – 5.0	0.3 – 5.0
3	Metallic	5.0 – 50	5.0 – 50
4	Discontinuous true oil colour	50 – 200	50 – 200
5	Continuous true oil colour	>200	>200
Other	Mousse or emulsion		

There are numerous national manuals and guides to oil spill reporting for airborne observers available on the web. One comprehensive example is the Open Water Oil Identification Job Aid produced by NOAA in both English and Metric units. http://response.restoration.noaa.gov/sites/default/files/OWJA_2012.pdf

By using the following steps, an observer can arrive at a fairly reliable estimate of minimum and maximum oil spill volumes in a given area:

- Estimate slick length and width
- Estimate the coverage of oil as a per cent within this area
- Calculate the total slick area
- Estimate the relative proportions of oil present that correspond to the different BAOAC codes
- Calculate the spilled oil volumes (min and max) for each code area

- Sum to arrive at min and max total spill volume present.

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 a reasonable estimate of the movement of oil on open water (Figure 6.5). Trajectory models can provide more sophisticated forecasts of probable oil movements if suitable wind and current data are available. In remote arctic areas, this information is often sparse or lacking.

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 6.6) with lower (1) flow conditions during winter months, a sharp rise and higher (2) flows during spring melt and breakup, and a gradual lowering (3) of discharge during summer months.

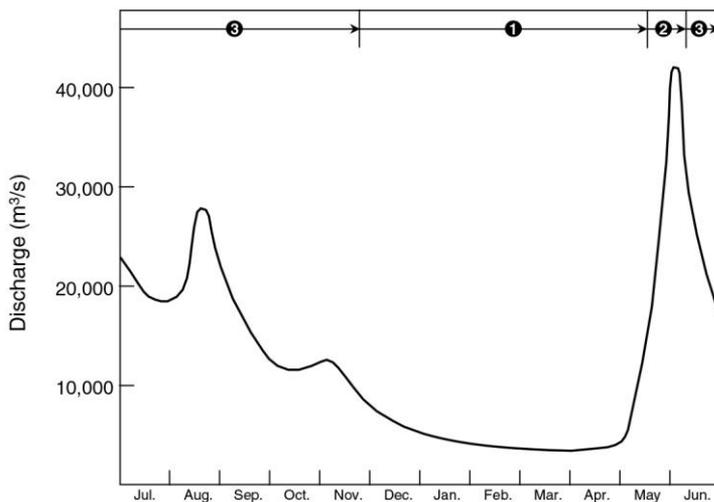


Figure 6.6. Typical seasonal variation in river discharge, Mackenzie River, Canada

The movement of oil in pack ice is discussed in Section 6.2. Existing trajectory models are presently limited in their ability to predict oil drift, not only because of the lack of input data but also the lack of spatial resolution in state of the art ice drift models. Recent advances in these models by the Nansen Environmental Remote Sensing Centre will lead to more accurate oil in ice trajectory models in the near future. (Olason et al., 2016). The outputs from these higher resolution ice models are now available in a standard data exchange format that several of the most commonly used oil fate and behaviour models (e.g. OSCAR and OILMAP) can accept (Beegle-Kraus et al., 2017).

In an actual response, trajectory models are supported by daily aerial overflights to map the extent of the oil and the spill boundaries. In addition, for a continuous oil release over a period of time, for example a subsea blowout, a series of ice GPS ice drift buoys

deployed at regular intervals can provide an accurate track plot of where the oiled ice is likely to be found weeks or months later.

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.

As discussed earlier, the transport of oil under sea ice offshore is unlikely because the current velocities under ice are usually far lower than the ~ 15 to 20 cm/sec threshold needed to initiate or sustain oil movement. Oil transport may occur under ice near-shore where narrow channels accelerate the water flow and in rivers where under-ice currents routinely exceed the minimum threshold and could carry oil a considerable distance downstream under the ice. In these cases, accurate current measurements are required to predict the likely speed and extent of oil movement.

6.5 Sampling and Monitoring

Spill response often involves the collection of samples for a wide range of the following reasons (adapted from Swedish Coast Guard, 1993):

health and safety	Substances maybe flammable or toxic and a sample collection and monitoring plan may be desirable to identify real or potential risks to responders and the public
legal liability	Comparison of sample analyses from the spill site and the suspected source (fingerprinting).
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.

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short-term environmental protection	Oil properties can indicate acute or damaging effects and a sample collection and monitoring program may be desirable to identify real or potential risks to the environment.
long-term environmental protection	Assessments of oil can allow the development of environmental restoration strategies for longer periods.
treatment end-points	Determination that target endpoints have been achieved, for example ,for drinking water quality
environmental assessment	Assessment of the short- and long-term effects of a spill and of the environmental recovery
information service	Clarification can be provided on the spill source, oil properties and impacts.
disposal	Oil volume and properties dictate appropriate, safe disposal methods.

- Sampling and monitoring of spills in the Arctic may be particularly important because most available data is from prior studies or spills in warmer, open water environments where the oil behaviour, fate and effects are fundamentally different.
- Fingerprinting for identification purposes may not be necessary if the source is obvious but would be important in the event of a “mystery spill”.
- In most cases, oil characterisation would also be conducted to define potential safety risks for responders (IPIECA/OGP, 2012). Samples would be collected and analysed to address key working environment safety issues that include:
 - Potential risk of explosion or fire
 - Levels of volatile organic compounds (VOCs)

SPILL BEHAVIOUR AND TRACKING

- Potential for mitigation measures including Personal Protective Equipment (PPE)
- Risks to responders or the public
- Safety or exclusion zones
- Monitoring for flammable or toxic fumes
- Sampling and monitoring may not be necessary on all spills, for example, if the volume is small and no environmental risks are involved, as may be the case for an oil spill on stable ice with ample opportunities for vapours to disperse downwind.
- Typically an oil sampling and monitoring plan will be developed early in a response and may be part of a broader national contingency plan that could include oiling assessment and ecological surveys (Owens et al., 2016).
- The objectives of a sample and monitoring plan could include:
 - Delineation of the area(s) affected by the spill,
 - Identification of background and incident-specific contributions of oil,
 - Description of any variations in oil character, concentration, and mode of occurrence in space and time,
 - Evaluation of the variability of oil concentrations in water samples or oil penetration depth in ice, snow or sediments,
 - Generation of data to help forecast the persistence and fate of the oil,
 - Overall assessment of environmental impacts, and
 - Generation of data of potential use to understand oiling effects on resource use.

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 in Arctic environments (Owens and Sergy 2004). The method of documentation described in this section has been adopted by IPIECA (2014), the governments of Canada (Environment and Climate Change Canada), the United States (National Oceanographic and Atmospheric Administration) and the European Commission.

The EPPR “*Arctic SCAT Manual*” (Owens and Sergy 2004) and a SINTEF study on shore-ice formation in Norway (Øksenvåg et al. 2009) provide details on field survey methods and terminology, and examples of ice formations that characterize Arctic shorelines. The EPPR “*Guide to Oil Spill Response in Snow and Ice Conditions in the Arctic*” (2015) discusses ice cycles (Annex D) and outlines shoreline assessment strategies and the shoreline treatment decision process (Chapter VI-1).

The shoreline oiling assessment 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. The width group categories should be adjusted to relate to the tidal range for location and for shores without tides (rivers and lakes).

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Width Category	WIDTH OF OILED AREA	
	Small Tidal Range (<2 m), Rivers and Lakes	Large Tide Range (>2 m)
Wide	>2 m	>6
Medium	1 – 2 m	3 – 6 m
Narrow	0.3 – 1 m	0.5 – 3 m
Very Narrow	<0.3 m	<0.5 m

OIL DISTRIBUTION	The oil distribution is the per cent 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.
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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 per cent surface coverage of oil are shown in Figure 6.7. The width and distribution can be combined to provide a simple summary of surface oil cover as shown in Table 6.4. These data can be collected from low-altitude, low-speed aircraft or by ground surveys.

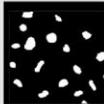
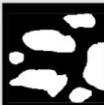
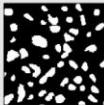
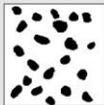
Range	Examples			
continuous (91 - 100%)	95%			
broken (51 - 90%)	70%			
patchy (11 - 50%)	30%			
sporadic (1 - 10%)	5%			

Figure 6.7. Examples of per cent surface oil cover

Table 6.4. Surface oil cover matrix (width category and oil distribution are defined in the tables above)

		OIL WIDTH CATEGORY			
		WIDE	MEDIUM	NARROW	VERY NARROW
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

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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 by digging pits or trenches.

Following pioneering work at SINTEF as part of the JIP program in Svalbard (Brandvik and Buvik 2009, Dickins et al. 2010), further studies with oil detection canines have demonstrated the ability to locate subsurface oil on beaches at depths to at least 1m (API 2016c, OCC 2016, Owens et al. 2016, 2017).

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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 that must be taken to inform others who might be involved.
- 2 A **decision process that** must be implemented to set 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 first 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 would 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 sets in motion a notification sequence that could include:

- a spill response team(s)
- local government agencies
- regional and/or national government agencies
- agencies in neighbouring countries
- the general public

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 on-going 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 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),

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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	<i>Gather and assess information and data.</i> <ul style="list-style-type: none">● Define the regional distribution of the oil on water and on shorelines, e.g., surveillance, tracking and aerial videotape survey (Sections 6.3 and 6.6).● Extract data from sensitivity maps and resource databases.● Obtain local knowledge.● Estimate the spill path, resources at risk and persistence of the oil (Sections 6.1, 6.2 and 6.4).● Identify safety, environmental, ecological, human use, and cultural constraints.
Step 2	<i>Define objectives (Section 7.4).</i> <ul style="list-style-type: none">● Set regional response objectives.● Define regional priorities.● Identify acceptable recovery or treatment levels.● Establish local (site) response objectives and priorities.
Step 3	<i>Develop strategies (Sections 3 and 4).</i> <ul style="list-style-type: none">● Develop regional response strategies to meet the objectives and priorities.● Establish local response strategies to meet local response objectives.
Step 4	<i>Select response options (Section 5).</i> <ul style="list-style-type: none">● Define acceptable and available methods and tactics to achieve the response objectives and strategies.

Step 5	<p><i>Evaluate operational feasibility and safety.</i></p> <ul style="list-style-type: none"> ● Identify environmental (physical), ecological, safety and logistical constraints that might affect the proposed operations. ● Evaluate the Net Environmental Benefit and/or Spill Impact Mitigation options of the proposed actions (Section 7.5). ● 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	<p><i>Prepare operational plans.</i></p> <ul style="list-style-type: none"> ● Develop a long-range regional response plan. ● Prepare individual (site or group) response plans.
Step 7	<p><i>Obtain approvals and permits.</i></p> <ul style="list-style-type: none"> ● Obtain approval of response plans from person in charge or command team. ● Obtain permission for access to private property or restricted areas. ● Secure other permits, e.g., disposal, incineration of materials.
Step 8	<p><i>Conduct response.</i></p> <ul style="list-style-type: none"> ● Implement strategies developed in the response plans for water-, ice- and land-based operations.

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.

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- ✓ Stop and control 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 operational 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.

7.5 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 operational practicality and effectiveness (or feasibility) of the planned activities and the likely environmental effects of proposed actions (the Net Environmental Benefit compared to natural attenuation – can be positive or negative - as discussed in more detail below).

The evaluation of feasibility includes an assessment of the potential

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of proposed actions to achieve the desired 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 (Section 8) and operational 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.
- Similarly, operational constraints due to remoteness and logistics may preclude one or other strategy or technique in favor of another.

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 operational 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? ((Section 8)*

- *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?*
- *Are the potential backshore staging areas in a sensitive tundra environment?*
- *What wastes will be generated and can they be managed without interrupting recovery or treatment?*
- *Are Valued Ecosystem Components (VECs) present that might be adversely affected by response activities?*
- *Are cultural resources present that might be adversely affected by response activities?*

Feasibility

Developing response plans and selecting strategies for any given area where ice is present must take into account:

- First, the logistics capacity to deploy equipment and necessary resources; and
- Second, the available infrastructure to support the continued operation of those strategies in the field.

Having one without the other most likely will result in a response failure. For example, it may be possible to airfreight vast quantities of booms and skimmers into a remote airport but without the marine and shore-based infrastructure (work boats, ports, oily waste storage sites etc.) to support a mechanical recovery system, the response is not viable.

- The issue of operational self-sufficiency requires careful consideration for remote areas where infrastructure is sparse and

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any spill site could be thousands or even tens of thousands of kilometres from a major staging base of oil spill equipment.

Net Environmental Benefit Analysis (NEBA)

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 developed and 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 (NEBA)** (IPIECA/IOGP 2015). The key question in this analysis is:

- *Will the proposed action(s) accelerate or delay natural recovery? Another way of stating this is to consider whether the overall environment will benefit from the response action(s).*

Note: Several current programs use the term **Spill Impact Mitigation Assessment (SIMA)** to expand the focus beyond environmental issues.

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 optimal spill response technique is defined as the one that

minimises the potential adverse effect(s) of a spill and the response methods themselves on the habitat of the region and its biological resources.

- Planners and responders must be mindful that the subsistence lifestyle in the Arctic is inextricably linked to the natural resources as well as to the traditional cultural practices of Arctic residents and that these issues are an integral element of the NEBA/SIMA process.
- NEBA is a process tool that formalises the evaluation and comparison of the expected response effectiveness versus the potential environmental impacts of the oil spill, as well as the response activities (vessels, aircraft, waste disposal etc.). Knowledge of the biology and ecology of the specific region is key to the application of a NEBA in a meaningful and rigorous manner.
- Traditional NEBAs involve the following elements (IPIECA/OGP, 2015) in the process of collecting information on physical characteristics, ecology and human use of environmental and other resources in the area of interest:
 - Review previous spill case histories and experimental results, which are relevant to the area and to response methods which could possibly be used.
 - On the basis of previous experience, predict the likely environmental (and socio-economic outcomes – not directly included as part of NEBA in every national jurisdiction). If the proposed response is used, compared to outcomes if the area is left to natural clean-up and recovery processes.
 - Compare and weigh the advantages and disadvantages of possible responses with those of natural attenuation.

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The generic NEBA framework outlined in IPIECA/OGP 2015 also provides:

- ✓ information for the selection of the best clean-up methods
- ✓ an assessment of the long-term effects on an ecosystem as a whole
- ✓ guidance on the intensity level and operational endpoints for clean-up operations, and
- ✓ estimates of likely recovery rates.

In support of this program, the Arctic Response Technology Joint Industry Program (JIP) recently released a “NEBA Support Tool” to aid oil spill response decision-making (<http://www.arcticresponsetechnology.org/videos/video-new-online-tool-to-aid-oil-spill-decision-making>) (Gardiner et al., (2017)

NEBA in the Selection of Oil Spill Response Strategies and Techniques

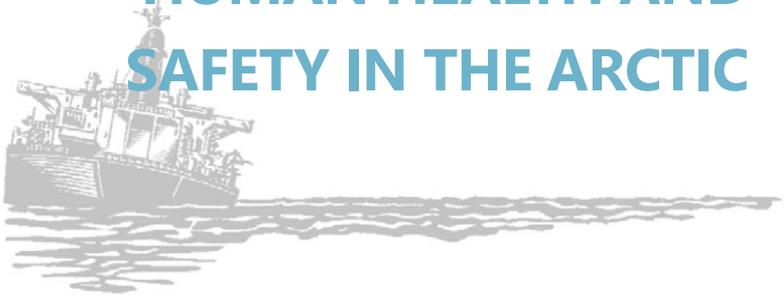
- Planners and responders have a number of clean-up methods available for operations on water (physical recovery, dispersant applications, in situ burning, and monitoring natural recovery) and on shorelines (manual collection of oil, low-pressure flushing, shoreline cleaning agents, pressure-washing, bioremediation, surf-washing, etc.).
- There are clear differences in operational limits for each oil spill response strategy (NRC, 2014). Each response method has certain advantages (e.g., speed, efficiency, simplicity), and disadvantages from operational or environmental perspectives (e.g., soot and residue from in-situ burning; the low encounter rates for containment and recovery in many open water situations, high volumes of waste generation, etc.).

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- The usefulness of each clean-up method in any given situation depends on factors such as type of oil spilled, environmental resources and habitats threatened; weather and sea state conditions, and the availability of logistical and operational support.
- A NEBA or SIMA should take all of these factors into account during the selection of the optimal response strategy.

8

HUMAN HEALTH AND SAFETY IN THE ARCTIC



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8.1 Introduction

- Safety of personnel is always paramount
- Operational and safety challenges posed by long periods of darkness and extreme temperatures are typical in Arctic marine and coastal environments. Addressing risks during response operations in Arctic environments requires specialized knowledge and training for responders, particularly those unfamiliar with or unused to working in Arctic conditions. Hazards encountered by responders may be physical, chemical, ergonomic, biological, and safety hazards, as well as human factors and require a continuous process of risk assessment.
- Job safety assessments for individual activities or specific types of response tasks are an essential element of operational awareness planning (Section 8.9).
- Best practices to address risk is a continuous process of anticipating, recognizing, evaluating, and controlling identified hazards:
 - ANTICIPATION and RECOGNITION includes a review of work practices and potential exposures in advance to identify hazards.
 - EVALUATION includes the development and implementation of an appropriate assessment strategy for potentially hazardous exposures.
 - CONTROL includes actions taken, based on the hierarchy of controls, so that identified hazards are eliminated or reduced through a combination of engineering, administrative, or personal protective equipment (PPE) approaches.

Implementing each step in the process allows the responsible responding organizations to identify, assess, and address the hazards posed to personnel conducting spill response activities

in the Arctic (Section 8.9). The following sections 8.2 through 8.8 can be used as a checklist for training and for a job safety analysis.

8.2 Physical Hazards

Oil spill responders in the Arctic may face a variety of health and safety hazards due to temperature, weather, and seasonal extremes. Although cold air and water temperatures and darkness in winter can contribute many hazards, excessive light and even heat also can be health and safety issues. Weather conditions can deteriorate rapidly, and frequently updated, accurate weather reports are necessary to ensure responder safety.

8.2.1 Cold Stress

Cold stress is one of the most prominent physical hazards of working in the Arctic. The main factors for the potential of injuries due to cold include:

- temperature
- wind chill (a function of air temperature and wind speed)
- wet conditions
- level of physical activity

Arctic oil spill response managers should develop a written response plan for preventing injury, illness, and fatalities as a result of the combination of these exposures. Plans should include:

- Training on the possible hazards associated with working in cold and wet environments, symptoms of cold stress, and procedures for providing first aid;

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- Special consideration for the adequacy of selected PPE to ensure that the performance of such equipment provides appropriate levels of protection for Arctic conditions;
- Access to hydration, as the Arctic can be extremely dry;
- Development and use of a “buddy” system for responders to monitor each other for cold stress symptoms;
- Provision of temporary warming shelters, such as tents or cabins near responder work locations;
- Provision of chemical hot packs for use by responders; and
- Development of work schedules that enable responders to move to warming shelters on a regular basis, limiting the amount of time exposed to cold and wet conditions.

8.2.2 PPE for Cold Weather Conditions

Provision of appropriate PPE for the body, hands, feet, face, ears, and head is important to maintain core body temperatures above 36°C. These PPE include waterproof and insulated boots; and cold-weather gear, such as coats, gloves, and hats. Selection of cold protective clothing should be based on the levels of cold and physical activity that responders will encounter. Outdoor clothing for field operations in cold weather should incorporate a system of three layers (EPPR, 2015):

- inner layer (base layer that that helps to wick moisture away from the skin);
- middle layer (insulating layer; several may be appropriate depending on the conditions; cotton clothing

should not be used a material for insulating since it loses insulating capacities when wet); and

- outer layer (waterproof layer to provide protection from wind, rain, and snow).

Several layers of loose clothing provide improved insulation, but clothing should not be so tight that it reduces blood circulation or restricts needed movement. Extra sets of dry PPE should be available to the responders in case gloves, socks, or other clothes become wet through immersion or from heavy sweating.

8.2.3 Cold Stress Injuries

Responders should be trained to recognize symptoms of cold stress injuries and seek first aid as soon as possible to minimize injury (NIOSH 2016).

Hypothermia

Initial symptoms of hypothermia (core body temperature less than 36°C) include shivering, fatigue, loss of coordination, and confusion/disorientation. Symptoms can then progress to include blue skin, dilated pupils, slowed pulse, slow breathing, and loss of consciousness.

Immersion Hypothermia, Cold Incapacitation, and Cold Shock

Response to oil spills in the Arctic may entail work on and around very cold water. Immersion hypothermia, cold incapacitation, and cold shock may occur if a responder becomes immersed in such water.

Frostbite

Frostbite results from freezing of affected body areas, including the hands, fingers, feet, and toes. Symptoms can include numbness, tingling/stinging, and bluish skin.

Trench foot or Immersion Foot

Blood circulation in the feet shuts down when feet lose heat due to extended periods of exposure to wet and cold conditions; resulting in the death of nerve, muscle, and skin tissue. Symptoms can include reddening of the skin, numbness, swelling, blisters/ulcers, and gangrene.

Chilblains

Damage to the skin capillaries can occur when skin is repeatedly exposed to cold, but above freezing, temperatures, resulting in redness, itching, and inflammation.

8.2.4 Ultraviolet Light and Seasonal Conditions

Reflection of ultraviolet light from snow and ice may lead to excessive exposures, resulting in sunburn as well as pain, reddening, and swelling of the eyes, known as snow blindness (IPIECA/OGP, 2008). Sunblock and appropriate protective glasses or goggles may be appropriate to prevent these potential health impacts.

Long work shifts outdoors in the extended daylight hours of summer may also lead to injuries such as sunburn, heat stroke, heat exhaustion, heat cramps, and heat rashes. Workers should be trained in the prevention of heat-related illnesses and provided hydration, sunblock, and appropriate PPE for conditions.

8.3 Chemical Hazards

Arctic oil spill responders have the potential to come into contact and work with a variety of potentially hazardous chemicals and chemical mixtures. A program to identify and evaluate such exposures is warranted to ensure responders are protected

from adverse health effects as a result of over-exposures. Examples include:

- Hydrocarbons and other petroleum constituents resulting from spilled/released crude oil;
- Dispersants, cleaning chemicals, and related compounds; and
- Combustion by-products.

8.3.1 Hydrocarbon and other petroleum constituents

Crude oil spilled or released into Arctic marine and coastal environments has the potential to contain a complex variety of chemical constituents. These include both aliphatic compounds such as butane, pentane, and hexane, and aromatic compounds such as benzene, toluene, ethyl benzene, and xylenes. Other constituents can include nitrogen, oxygen, and sulfur compounds as well as trace metals. (OSHA 2010). Evaluation of the character of the spilled oil to determine specific constituents of concern is recommended.

Exposures to such compounds may occur through:

1. **Inhalation** - Exposure assessment strategies including air sampling should be developed and undertaken to:
 - a. evaluate the concentrations for the range of airborne compounds;
 - b. compare them against recognized occupational exposure limits (OELs); and
 - c. determine appropriate controls or mitigation actions.
2. **Dermal Contact** - Selection of appropriate PPE, including protective gloves and clothing suitable for the Arctic environment is warranted as contact with oil may present an additional route of exposure and could result in skin irritation and inflammation.

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A key variable in determining the level of exposure is the degree to which the oil is “weathered”. Many of the organic compounds volatilize as the oil weathers to the extent that their concentrations are considerably reduced. However, the weathering process may be slower in the Arctic due to cold climate conditions.

If high rates of hydrocarbon gases and vapors are volatilizing at concentrations reaching the lower explosive limit (LEL), particularly at the source of the spill, explosions and fires may be a hazard. Assessments to determine the presence and concentrations of such gases and vapors is necessary to identify and address these potential risks and prevent responder injury or fatalities.

Shoreline cleaning techniques, such as pressure washing, may result in aerosolization of oil mist and volatilization of hydrocarbons. Respiratory protection may be appropriate based on an exposure assessment.

8.3.2 Dispersants, Cleaning Chemicals, and Related Compounds

Dispersants can be applied in a number of ways: via plane, helicopter, and sea-going vessels such as workboats, tugboats, and barges (Section 5.6). Dispersants can contain a variety of chemical constituents including propylene glycol, 2-butoxyethanol, and petroleum distillates. Exposure assessments should be conducted for workers on vessels applying dispersant, with appropriate controls implemented to reduce exposures. Such controls could include respiratory protection, goggles, and gloves, as well as ensuring responders are at a safe distance away from area in which the dispersant is released.

A range of cleaning chemicals may be used for a number of work activities during oil spills. Improper handling of solvent-based compounds may present respiratory and/or dermal risks. Evaluation of such exposure and provision of appropriate PPE

such as gloves, goggles, or respiratory protection may be necessary.

8.3.3 Combustion By-Products

A number of by-products may be released into the atmosphere from the process of in-situ burning. As in any burn, combustion by-products are produced such as respirable particles, polycyclic aromatic hydrocarbons (PAHs), and gases such as carbon monoxide. Implementing safety practices that ensure prevailing winds direct the plume away from the worker locations minimizes potential worker exposure. Exposure assessments should be conducted for workers on vessels involved in in-situ burning to monitor the levels of exposures experienced and incorporate control strategies as necessary.

Gasoline- and diesel-powered generators typically are used extensively to provide power and heat for responders in the Arctic and pose risks of potential exposures to diesel exhaust, carbon monoxide (CO), or noise. In particular, gasoline-powered generators and running engines can emit large quantities of CO, an odorless, colorless gas which can act as an asphyxiant. If generators are used by responders indoors or in enclosed areas, levels of carbon monoxide can quickly reach lethal concentrations. Generators and running engines should be restricted to outdoor use in the open and away from building openings into which emissions could be entrained to ensure that such exposures do not occur.

8.4 Ergonomic Hazards

Bodily (musculoskeletal) injuries are a concern during any oil spill response activities; such as waste management, shoreline cleaning, wildlife cleaning, and off-shore booming and skimming operations, among others. These types of work activities may include repetitive forceful movements and awkward postures, especially during lifting, pushing, and pulling actions, potentially resulting in responders experiencing musculoskeletal injuries, particularly of the hands, back, and shoulders.

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Ergonomic risk factors include: repetitive and sustained back twisting, squatting, ground-sitting, or kneeling; repetitive upper extremity motions; awkward wrist/forearm twisting; and moderate upper extremity and lower back forces.

Arctic oil spill response managers should proactively plan to ensure that such ergonomic hazards are addressed or avoided through a number of steps:

- evaluate responders' tasks and work practices to identify potential ergonomic hazards and develop corrective or mitigating solutions, such as alternative processes, to reduce the risk of injury;
- provide mechanical lifting equipment where possible and train workers in appropriate lifting techniques if manual handling of equipment is required;
- select or design ergonomically efficient tools and/or machine controls appropriate for Arctic use and specific tasks such as shoreline cleaning; and
- be aware that tools and/or machine controls should be easily used without removing hand protection, and if tools selected are metal, ensure anti-contact gloves are provided to prevent contact frostbite or metal components are covered with thermal insulating materials.

8.5 Biological Hazards

The Arctic environment's indigenous flora and fauna can pose unique risks for responders. Response managers should proactively plan and consult experts as appropriate to ensure that potential biological hazards are addressed or avoided. Awareness training for responders should be provided, including appropriate actions to react to the presence of wildlife in work areas and regular reports of any animal sightings. Potential hazards may include:

- Large, dangerous predators, such as polar bears and walrus, which may put responders at risk of attack, both on land and at sea (e.g. Majors et al. 2014);
- Large animals, such as moose, which may feel threatened and charge responders if approached;
- Birds that may protect nesting areas or young by diving at the heads of anyone who approaches those areas too closely;
- Plants and berries which could irritate skin or be poisonous if ingested;
- Teeth, spines and claws of animals (e.g., anemones, jellyfish, crab); and
- Insect bites (of special consideration in warmer months) and the potential for allergic reactions.

8.6 Safety Hazards

Worker training to focus on potential safety hazards is required to ensure workers are fully knowledgeable about both the potential hazards and effective controls or mitigation actions. Safety checklists and briefings before responders deploy on assignments and the provision of safety equipment as demanded by the operation (such as hardhats, personal flotation, safety boots, emergency locator beacons, safety lines, and medical kits) are all important components of responder safety programs. Each response is different, so that site-specific and season-specific risk assessments and Job Safety Assessments are critical to identifying and mitigating hazards.

Slips, Trips, and Falls

Slips, trips, and falls are one of the most common sources of injury during spill response operations (IPIECA/OGP, 2012). These are often exacerbated by the presence of oil-covered PPE, walking on oil-covered surfaces, such as shoreline bedrock that already may be naturally slippery, and walking on

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snow and ice. Bedrock coastlines may be difficult to access, contributing to a greater risk of slip, trip, and fall hazards. Slipping on an iced or oiled deck into the water is a common hazard in both nearshore and offshore operations. Awareness of these hazards should be raised and appropriate mitigation identified in a job safety assessment.

Transportation Safety

Operations in remote locations, which are typical throughout the Arctic, involve the transportation of responders and equipment by plane, helicopter, all-terrain vehicle, and/or barge/boat. The hazards associated with these modes of transport, include inclement weather (e.g., ice, reduced visibility, wind), ocean conditions (e.g., wave heights, fog, vessel icing), the presence of moving sea ice, rising tides, and the absence of nearby infrastructure. Assessment and response plans that anticipate and manage these risks to the extent possible are vital.

Working on or Near Ice

Work activities and vehicle operations on ice pose inherent safety hazards. Typical safety measures include staying away from ice edges, assessing the bearing capacity of the ice, awareness of ice movement, land ice stress and ice dynamics factors, etc. Sea ice thickness guidelines and working load information are critical to site safety assessments (for example, Tactic L-7 in ACS, 2015).

8.7 Human Factors

Mental and psychosocial stressors can significantly affect responders on oil spills. Heavy work demands, particularly during large and high-profile events, may result in “work pressure” for managers and responders. Symptoms include, worry, stress, depression, feelings of inadequacy, short-temper, or frequent mood changes. Additionally, working in a remote or isolated location away from family and friends for extended periods of

time, coupled with “tent-living” and lack of privacy/time alone may increase stress.

Long work shifts (generally more than 12 hours), particularly performed in cold and wet conditions, with requisite PPE, and during long periods of darkness, can result in considerable levels of mental and physical fatigue, which can impact health and quality of work. Conversely, extended daylight hours in summer may prevent workers from getting adequate sleep, and/or impact their ability to judge a safe shift length, believing that they can work longer hours.

Arctic oil spill response managers should proactively plan to ensure that such mental and physical stressors are addressed or avoided through a number of steps:

- provide temporary living quarters for responders that are not crowded or unsanitary and that provide responders with sufficient personal space and privacy;
- train workers to recognize signs of fatigue;
- schedule rest days for responders allowing for sufficient recuperation from multiple consecutive days/long shifts;
- develop a clear chain of communication to relay important work directives and decisions to responders, avoiding increased confusion, frustration, and stress; and
- acknowledge and address stress that may result from isolation and separation from family and friends for extended periods of time.

8.8 Health Monitoring and Surveillance

Potential safety and health risks exist in all response operations.

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A health monitoring and surveillance system for both managers and responders can effectively protect personnel during all phases of the oil spill response, by:

- identifying exposures and/or symptoms early in the response;
- preventing or mitigating adverse health outcomes;
- ensuring workers can continue to respond to the spill effectively;
- evaluating implemented protective measures; and
- identifying responders who may qualify for medical referral and enrolment in long-term health surveillance as needed.

Specific activities appropriate to different phases of a spill response include:

Pre-Deployment Phase Activities:

- assessment of the training levels and credentials of responders
- baseline health screening
- health and safety training
- data management and information security

Deployment Phase Activities:

- in-processing of onsite responders
- monitoring and surveillance of responders' health during response activities
- integrating exposure assessment and responder activity documentation
- effective communication of exposure and health monitoring and surveillance data

Post-Deployment Phase Activities:

- out-processing assessment of responders
- post-event tracking of responder health/function
- conducting lessons-learned and after-action assessments

8.9 Risk Identification and Mitigation (checklists)

- Risk mitigation and planning explore risk response strategies for the high-risk activities.
- The process identifies and assigns parties, either a manager or individual personnel, to be responsible for each risk response. This process ensures that each risk requiring a response or mitigation has an “owner”.

The major steps in determining the appropriate risk management strategies include the following (NAS 2005):

- Development of risk awareness;
- Project risk identification;
- Qualitative risk assessment;
- Quantitative risk assessment;
- Risk prioritisation;
- Risk mitigation; and
- Active, on-going risk management.

A common tool for risk assessment is a matrix which plots the likelihood (probability) and consequence (impact) outcomes from individual activities, such as working outside or operating equipment on ice. Figure 8.1 is an example that plots relative values to assist in the planning and mitigation process:

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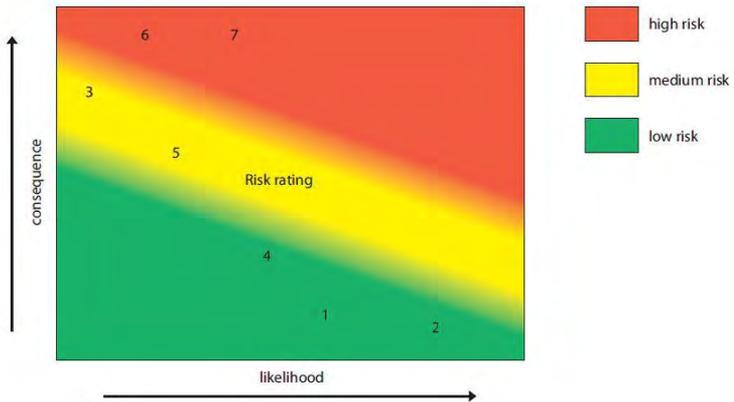


Figure 8.1. Example of a Risk Assessment Matrix (RAM) that might result from an analysis of seven individual tasks or scenarios. *Source: IPIECA/OGP, 2014.*

Mitigation can involve a range of actions (NAS, 2005) such as:

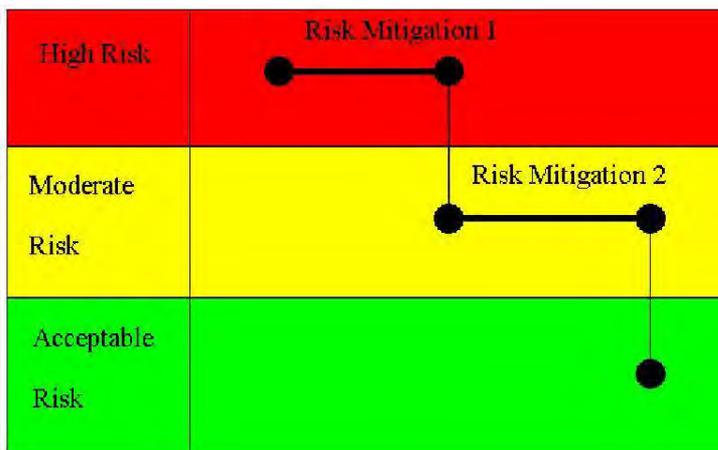
- TRANSFERRING (for example, assignment of a task to a specialist or specially trained team/individual)
- BUFFERING (making something stronger or more durable than would be normal)
- AVOIDING (changing the scope of work or the parameters of a task or activity)
- CONTROLLING (PPE, or early warning systems)

The “waterfall” diagram (Figure 8.2) illustrates the process by which a risk is mitigated so that it changes sequentially from “high” to “moderate” to “low” risk.

- As an example, in extreme cold temperatures the health risks to an individual outside worker can be mitigated by avoidance,

such as delaying the activity until temperatures rise if the consequence is likely to be high (hypothermia, frost bite).

- Similarly, journeys can be rescheduled if an existing or forecast white-out situation or high seas make land or sea conditions risky.
- A moderate risk can be buffered or controlled through the use of appropriate sheltering or clothing (PPE) so that the activity can be conducted with a low likelihood of a health impact (“acceptable risk”).



Waterfall Diagram

Figure 8.2. “Waterfall” diagram that shows the progression of a risk as mitigation actions are applied. *Source: NAS, 2005.*

The first step for site safety is a high level risk assessment that is designed to lead, progressively, to a Job Hazard Analysis (JHA) or a Job Safety Analysis (JSA) which provides each responder with information on potential risks and hazard control methods for a specific operational task (Figure VII-3.1, EPPR 2015).

9

WILDLIFE RESPONSE IN THE ARCTIC



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9.1 Standard Response Options

Wildlife response refers to minimizing the impacts of an oil spill on wildlife by preventing their oiling and by mitigating effects if oiling has occurred.

IPECA (2014) presents an up-to-date summary of good practice guidelines for incident management and emergency response personnel.

Prevent the impacts of oil on wildlife

- Remove oil before it affects wildlife:
 - The implementation of mechanical containment and recovery, protective booming, in situ burning and/or dispersants.
 - The use of detailed seasonal (monthly) sensitivity maps
 - Real-time monitoring to verify the location of wildlife in relation to the oil and to projected oil movements
 - Strategic biological guidance (where/when animals are likely to be moving in relation to oil) by combining real-time monitoring with sensitivity map data and migration patterns
- Remove animals before oil reaches their habitats
 - Hazing/deterrence, by scaring animals away from the oil or from threatened habitats, using propane cannons, bird-scare buoys, etc.
 - Pre-emptive capture/collection in which captured animals are maintained in captivity until they can be released to a clean environment. In addition, nests or eggs

may be collected and relocated elsewhere or, in the case of eggs, artificially hatched.

- Prevent secondary oiling
 - Remove oiled animals from the environment to prevent scavenging and distribution of oil in the food chain; prevent live oiled animals spreading oil into unoiled areas.

Mitigate the effects of oil on wildlife

- Deal with live casualties
 - Rehabilitate casualties by capture, stabilization, cleaning, reconditioning and release. This process is technically demanding and many elements must be in place in order to be successful. Animals are temporarily taken out of their natural environment, treated and released in an improved condition. Post-release survival studies are appropriate to monitor and assess the success of the operations.
 - Euthanise casualties if rehabilitation is not an option; for example, because the animal is too weak, or the capability for rehabilitation is limited. Humane methods minimise the suffering of animals that cannot be rescued. For some methods, animals need to be captured, for others (e.g. shooting) capture is not necessary, but disturbance of other animals may be an issue. Corpses of euthanised animals are collected and disposed. The euthanasia of animals may be controversial in cases where the public expects them to be rescued and rehabilitated.
 - Dealing with stranded marine mammals: the rescue and rehabilitation of a live, stranded animal would be feasible only if a suitable facility that can handle a large animal is located within a reasonable distance, as well as having

suitably qualified persons and equipment for handling and transport. Euthanasia protocols should be defined in cases where an animal cannot be rescued or rehabilitated. If an animal strands alive in an area where the public is able to see or access the area, a communication strategy should be in place to inform the public concerning measures being taken and to create an exclusion zone around the affected animal.

- Assess impacts.
 - Ensure the assessment of oil impacts on populations is based on a scientifically, reliable methodology for collection and analysis (e.g., appropriate documentation for collection, necropsy, biometry, etc.).

9.2 Arctic Limitations

In more southerly geographic regions, a wildlife response can consider many options. These same options can be applied in the Arctic but with the limitations described below (adapted from Nijkamp et al. 2014):

Wildlife in the Arctic is extremely vulnerable to spilled oil and whether or not the more standard options described above can be used at the same level of effectiveness under Arctic circumstances depends on limitations present during significant periods of the year, such as:

- Long periods of extreme cold and frost
- Sea ice coverage and shore ice for weeks to months
- Snowfall and, in places, a persistent, thick snow cover
- Extremely short periods of daylight (several hours)

- Unpredictable and sudden weather changes
- Sensitive soils (e.g., tundra) that could be affected by a response and/or present access constraints.
- Remoteness

Extreme cold reduces the potential for survival of oil-affected wildlife. Animals quickly suffer from severe hypothermia after losing the insulating value of feathers or fur upon contact with oil. This reduces the window of opportunity for responders to capture and stabilise casualties.

Ice and snow can prevent responders from safely reaching oil-affected areas to conduct field activities.

Short working days for field activities or a complete absence of daylight in winter months.

Quickly-changing weather conditions, e.g., polar low-pressure systems and Arctic mist or fog can reduce visibility and create transportation safety problems.

Ice, snow, sensitive soils and other conditions that do not allow or constrain responders to approach and deal with individual animal casualties (e.g., animals that spread out or hide in inaccessible areas or sensitive tundra).

Extreme environmental conditions can affect the health and safety of responders (extreme cold, working in/near ice, lack of medical facilities, etc. - See Section 8)

Remoteness, more specifically the absence of any support facilities.

Dangerous and/or large predators that may put responders at risk (e.g., polar bear, walrus)

- Basic resource requirements:
 - Trained work forces for wildlife response and their equipment
 - Animal care facilities (large spaces to protect animals and people from harsh weather and climate conditions, where electricity, water are sufficiently and continuously available)
 - Supplies for operations (food and basic life-support necessities for staff/volunteers)
 - Field stations with accommodation and basic amenities for wildlife responders.
 - Reliable infrastructure (roads, airports, harbours) that can be kept ice- and snow-free or controlled, to allow quick and efficient transport of responders and animals between affected areas and facilities.

Compared to non-Arctic conditions, these limitations may lead to a reduced scale wildlife response (e.g., fewer animals that can be prevented from oiling, lower number of live animals rescued and rehabilitated, fewer oil-affected corpses that can be recovered from the environment), or may not be possible at all. This reduced level of effort may not meet the public expectations of a successful Arctic wildlife response.

9.3 Meeting Public Expectations

The Arctic is considered one of the last unaffected wilderness places with its pristine qualities, including wildlife, and the need to safeguard this environment has a high profile. Images of oiled animals on shorelines can be viewed with concern by the public who would expect an effective response to any oil spill. For the incident response organisation, especially during the planning phase, it is

important to be aware of a public expectations and the role of media in affecting public perceptions of the response. The media must be provided with reliable information on reassurances that an Arctic wildlife response is professional and effective, as well as safe.

The use of many wildlife species for subsistence purposes by local communities adds an important and significant dimension to management decisions and response activities.

9.4 Arctic Wildlife Response Preparedness

Figure 9-1 illustrates the challenges of a potentially hostile environment for a wildlife response which considers rehabilitation and euthanasia as potential response strategies. The x-axis is the environmental gradient from north (left) to south (right) latitudes at a global scale for the Arctic. Environmental conditions change from left to right and become more extreme and locations become more remote and potentially more hazardous for humans to work. The y-axis indicates the degree to which three basic options for intervention can be implemented for live oiled animals (maximum = 100%):

- 1 Monitor (blue):** no active intervention; the response is to monitor and leave animals in situ where they potentially would die from oiling
- 2 Intervention - Euthanasia (red) :** active intervention in which oiled animals cannot be rescued and are euthanized
- 3 Intervention - Rehabilitation (green):** active intervention that assumes animals can be rescued and rehabilitated, because the circumstances and logistics allow for a complete chain of capture, transport, stabilisation, washing, water-proofing and release to be successfully completed

Option 3 is the most demanding in terms of preparedness and can only occur under ideal conditions. Option 2 can still be implemented under conditions that are not favourable for rehabilitation, but it is limited to places in which responders can work without compromising their health and safety. Even under optimal conditions where rehabilitation can take place, this is not an exclusive response option and always goes hand in hand with euthanasia (ending the suffering of animals that cannot be rescued). The fact that some animals die at sea before they can be rescued also must be considered.

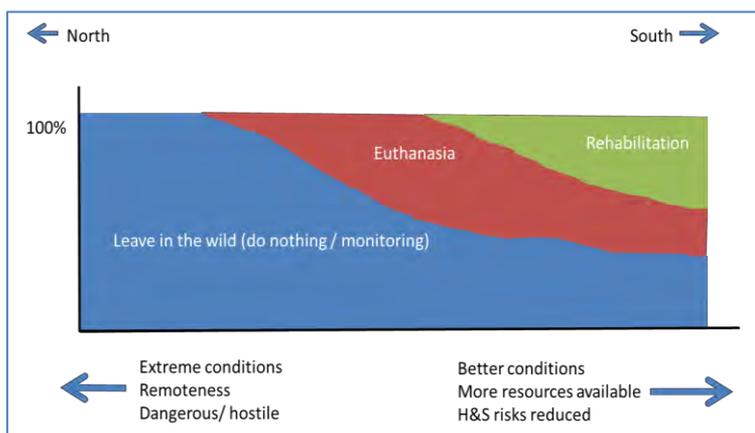


Figure 9.1. Model for dealing with live animals under Arctic conditions. *Source: Nijkamp et al. 2014*

9.5 Challenging Boundaries

Figure 9.1 indicates that the intervention/rehabilitation option is eliminated first as the model moves north. Continuing north, at some point responders can no longer safely approach animals to administer euthanasia. That point determines the absolute limit of

an active wildlife response intervention, and leaves Option 1 (monitoring) as the only practical and safe choice that can be considered. Towards spring and summer, the boundaries may move southward, allowing wildlife response activities in areas that would not be considered during winter.

Theoretically, there are two ways to challenge these boundaries:

- 1** Capturing animals in relatively remote areas and transporting them, often over considerable distances, to a site where rehabilitation can be set up and sustained, and returning rehabilitated animals to their habitat, or transporting them to a suitable, equivalent habitat for release.
- 2** Setting up a self-supporting mobile rehabilitation unit in an area that does not naturally support more permanent facilities. This requires a well organised and planned operation, including comprehensive logistics preparations.

9.6 Wildlife Response Planning

Implementing the three options involves country- or region-specific oiled wildlife response plans. The strategic planning process is key for a response in the Arctic (EPPR 2015) and begins with mapping the sensitivities (geographical, seasonal distribution of vulnerable species) and assessing the risk of oiling.

An assessment of local preparedness (expertise, trained work forces, equipment, facilities, etc.), and determination of the legal and policy requirements for a response (through the local authorities) provides further direction for developing the objectives and strategy of the plan. The geographical and physical limits of the different response options can be defined by determining how these options can be realised by local and/or international resources, taking into account seasons, local topography/geography, available infrastructure, and other relevant logistics and

safety variables.

Offshore, nearshore and onshore aspects of planning

The potential source of a spill and its distance to the shoreline are important factors to consider in wildlife response planning. Potentially large volumes of oil may be released from a well into the environment until it is capped. The Macondo accident in 2010 led to specific Arctic developments to reduce blowout volumes, e.g., drilling capping systems, relief wells.

In open-water areas, wildlife that becomes affected by oil at sea while still alive may not necessarily stay in the slick. Debilitated birds may swim away from the oil and might reach a nearby coast. If distances are too far, however, and/or winds are blowing offshore, oiled animals may die before reaching the coast and may never be found on the coastline. Animals oiled far offshore may not reach the nearest coast, even if prevailing winds blow onshore. In nearshore spills, many live animals might arrive on the coast, especially if prevailing winds blow them there.

Arctic conditions can either complicate or simplify the response required to deal with oiled wildlife and must be assessed on a case-by-case basis. In colder water, spilled oil may be below the pour point and become semi-solid. In ice conditions, the behaviour of spilled oil depends heavily on the timing of the spill and the type of ice which is present (Section 6). Oil can be contained by ice, or if spilled under a solid sheet of ice, can spread laterally and may re-surface at some distance from the original spill site or during the next melt period.

A terrestrial oil spill (e.g., pipeline rupture) can result in surface oiling of only a limited geographical area. This type of situation allows hazing and deterrence to be considered as more useful and effective wildlife response options, and can result in relatively

fewer casualties in a confined search and rescue area. The diversity of terrestrial species affected may however be larger, potentially challenging the rehabilitation process as species may be admitted into a rehabilitation centre for which no protocols have been developed. The sensitivity of many Arctic soils, such as tundra or wetlands, must be considered when devising deterrence strategies.

9.7 Transboundary Issues

There are two main areas in which customs and border crossings would be considered in a wildlife response:

- 1 The entry of responders and/or equipment into a country.
- 2 The transport of oiled wildlife across borders.

In some cases, permits may be required to transport wildlife to and from a country. When permits are necessary, the Requesting Party is responsible for ensuring that all permits are secured prior to any wildlife being transported.

9.8 Wildlife Response Capability Requirements for Arctic Conditions

Arctic environments are extremely vulnerable in the event of an oil spill and the threats to birds and mammals are considerable. The capability of trained and experienced oiled wildlife responders to deploy in the Arctic is generally limited, but has been established in some areas. In many parts of the world, responders are well trained and experienced to deal with oiled wildlife casualties in warmer climates; however, their training and exercises may not include Arctic modules.

A dedicated capability for Arctic wildlife response that includes specialized equipment kits and land- or sea-based mobile facility

modules is not available in most regions. Overcoming the limitations of Arctic wildlife response would involve addressing the following requirements:

- Training programmes for wildlife responders to work under Arctic conditions
- Specialised Arctic:
 - PPE and wildlife response equipment
 - mobile equipment units and facility design/logistics guidelines
 - transport equipment for wildlife field monitoring and response activities.
- The development of strategies for:
 - Setting up a well-equipped response base that can operate in Arctic extremes
 - Transporting captured animals to locations where their rehabilitation can be undertaken
 - Euthanizing animals in the field, if their rescue and rehabilitation cannot be achieved
 - Communicating with the public on the limitations of Arctic wildlife response, e.g. through a pre-incident developed website that can be activated at the time of a mobilised incident response
- Where appropriate, monitoring programmes to provide better baseline data on distribution and behaviour of arctic marine wildlife species at risk of becoming oiled

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- A high level oiled wildlife response plan for the Arctic region, specifying (in terms of seasons, ice, snow and permafrost conditions, offshore nearshore and onshore):
 - The availability and limitations of various response options (rehabilitation, euthanasia, hazing and deterrence)
 - An overview of existing rehabilitation protocols for the most vulnerable species in the region (marine, coastal, terrestrial)
 - An overview of hazing and deterrence methods that can be used in the Arctic
 - Equipment and facility support.

10

COASTAL CHARACTER OF THE ARCTIC REGIONS



CONTENTS

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10.1 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.

An awareness is provided for each country of the geographic character and environmental conditions of neighbouring countries by outlining the physical features of the coasts of the region.

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. For example, 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. 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 10.1 and Figure 10.2, 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) is based on 14 shore types, for which colour photographs are presented in Section 10.9.

COASTAL CHARACTER OF THE ARCTIC REGIONS

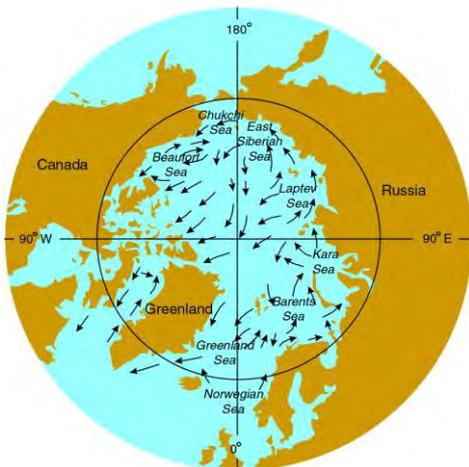


Figure 10.1. Surface currents of the Arctic Ocean

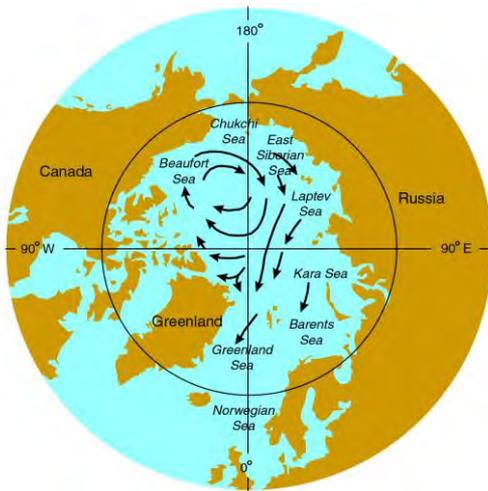


Figure 10.2. Ice drift in the Arctic Ocean

10.2 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 parts per thousand (ppt). 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.

COASTAL CHARACTER OF THE ARCTIC REGIONS

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 10.3. Baltic Sea

Zone 1 Scania Coast



Coastal Zone Character

lowland/coastal plain

- low relief, but thick sediments that often form eroding cliffs
- areas with archipelagos and islands

Shoreline Types

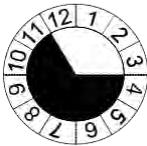
bedrock shores

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

Shoreline Types

bedrock shores

Ice Season



Tidal Range



- low coastal relief
- sediments not abundant
- many archipelagos and islands
- one section of high coastal relief (300m)
- ice-free period usually May to December in northern areas and April to November in the Stockholm
- less than 0.1 m

**Zone 3 Eastern Baltic Coast,
Gulf of Riga**



Coastal Zone Character

lowland/coastal plain
delta
barrier islands/beaches

- lowland coastal plain with abundant sediments
- barrier beaches, lagoons and marshes, with a delta at the mouth of the Daugava River

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
delta
barrier islands/beaches

Shoreline Types

bedrock shores
sand beaches
mixed-sediment beaches
marshes

- lowland coastal plain with abundant sediments
- some cliffed sections and barrier beaches, lagoons and marshes
- Oder and Wisla Rivers drain the north German Plain

Ice Season



- coastal area is ice-free usually April to November

Tidal Range



- less than 0.1 m

10.3 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 (Owens 1994).

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 used to remain close to the Beaufort Sea coast during summer months; in some severe years the open-water areas were only tens of kilometres in length. Over the past thirty years, the aerial extent and volume of multi-year (older than two summers) that typically covered much of the central Arctic basin has diminished greatly. As a result, the so-called “permanent” pack ice edge now tends to reside much further north with a greater expanse of open water along the Arctic Ocean coast and within the archipelago.

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

COASTAL CHARACTER OF THE ARCTIC REGIONS

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 ($41^{\circ} 50'$ 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.

ARCTIC WATERS FIELD GUIDE

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.

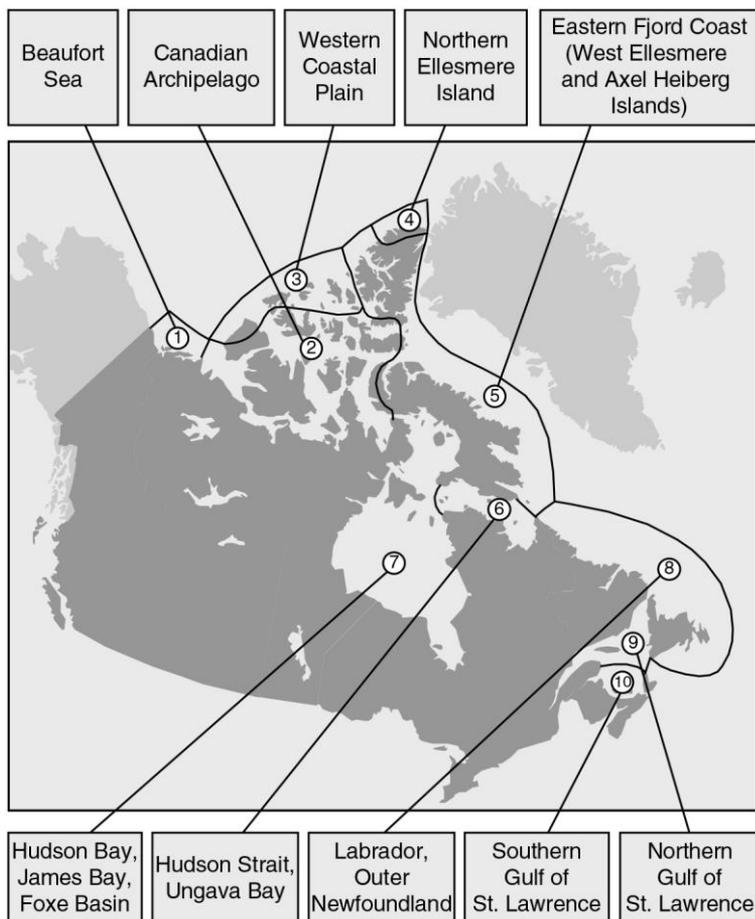
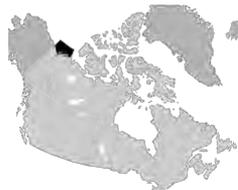


Figure 10.4. Canada

Zone 1 Beaufort Sea



Coastal Zone Character

lowland/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 with a year-round, large freshwater discharge

Ice Season

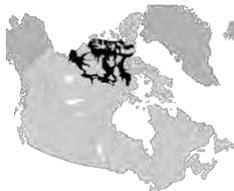


- with climate change, the permanent polar pack is further from shore during the summer and there is a much greater expanse of open water for wave generation
- 1 - 4 months open water (August to October) season
- less than 0.5 m

Tidal Range



Zone 2 Canadian Archipelago



Coastal Zone Character

upland or mountains
lowland or coastal plain

Shoreline Types

bedrock shores
sand beaches
mixed-sediment beaches

- upland coast in most areas, with steep cliffs and coarse-sediment talus slopes
- relief decreases from east to west
- mixed-sediment beaches generally narrow, except in low-lying areas

Ice Season

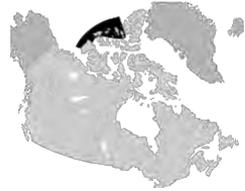


- ice-free 0 - 3 months
- open-water areas small due to size of the channels between the islands

Tidal Range



- 1.0 - 2.0 m



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 small deltas, braided streams and raised beaches

Shoreline Types

bedrock shores
sand beaches
mixed-sediment beaches
pebble/cobble beaches

Ice Season



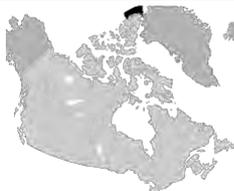
- with climate change, the permanent polar pack is further from shore during the summer and there is a much greater expanse of open water for wave generation
- ice-free period may be as short as 1 month and some years no open water

Tidal Range



- less than 1.0 m
-

Zone 4 Northern Ellesmere Island



Coastal Zone Character

fiord coast
ice shelf

- high-relief, ice shelf coast
- occasional rock cliffs with a few beaches

Shoreline Types

bedrock shores
ice shores

- usually permanent ice foot

Ice Season



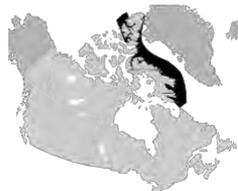
- with climate change, may be ice-free during the summer

Tidal Range



- less than 1.0 m

Zone 5 Eastern Fiord Coast
(includes West Ellesmere Island and Axel Heiberg Island)



Coastal Zone Character

- upland or mountains
- fiord coast
- ice shelf
- deltas

- high-relief fiord coasts with tide-water glaciers in northern areas
- beaches generally narrow or absent

Shoreline Types

- bedrock shores
- ice shores
- mixed-sediment beaches
- sand flats

- deltas or intertidal flats at heads of fiord

Ice Season



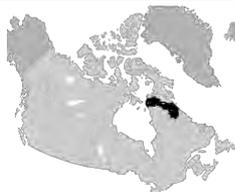
- ice-free less than 1 month in north to 3 months in south
- frequent icebergs move south along the Baffin Isl. Coast

Tidal Range



- 0.5 - 3.0 m

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

Shoreline Types

bedrock shores
mixed-sediment beaches
pebble/cobble beaches
boulder beaches
sand flats
mud flats

- wide tidal flats in Ungava Bay

Ice Season



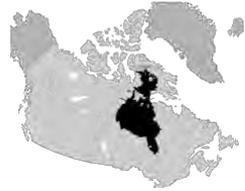
- ice-free 3 - 4 months
- exposed eastern areas subject to occasional storm-wave action

Tidal Range



- 3.0 - 8.0 m
- Ungava Bay to 15 m

**Zone 7 Hudson Bay, James Bay,
Foxe Basin**



Coastal Zone Character

lowland or coastal plain
tidal flats

- low muskeg coast and wide tidal flats in southwest Hudson Bay
- elsewhere, lowland coasts with narrow pebble/cobble beaches and mud flats common

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
-

Zone 8 Labrador, Outer Newfoundland



Coastal Zone Character

lowland 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
- rapidly southerly moving band of rough pack ice including old ice and icebergs
- 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

Shoreline Types

bedrock shores
 mixed-sediment beaches
 mud flats
 marshes

- 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

Ice Season



- enclosed sea, fetch up to 700 km energy levels increase NW to SE
- rough first-year ice in central part
- icebergs can move in through Strait of Belle Isle
- 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
marshes

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

10.4 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. The Environmental Oil Spill Sensitivity Atlas for the West Greenland Coastal Zone provides detailed digital maps of coastal morphology from an oil spill perspective (Danish Energy Agency and BMP, 2001; Boertmann, 1994; and Boertmann et al. 1994).

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, as well as other areas.

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 to 2 months (August - September) in northeastern sections, and 3 to 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.

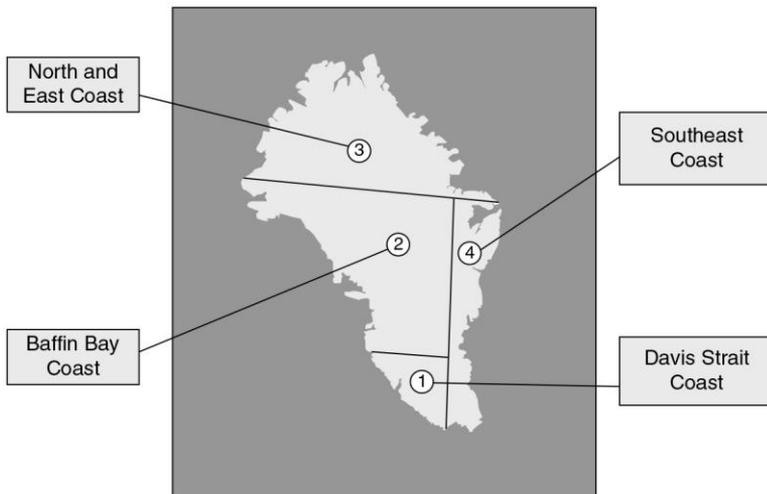


Figure 10.5. Greenland



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

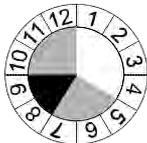
Shoreline Types

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, some areas have year round open water, others only have sea ice for short periods in late winter (February - March)
- ice and icebergs from the east coast can move into Davis Strait
- some years multi-year ice is found in the south in April – June
- first-year ice (thickness normally less than 1.0 metre)

Tidal Range



Zone 2 Baffin Bay Coast



Coastal Zone Character

fiord coast

- high-relief coast with cliffs and fiords
- numerous calving glaciers particularly in Melville Bay

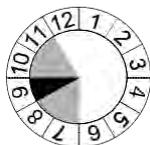
Shoreline Types

bedrock shores

ice shores

- sand beaches on Disko and Nuussavaq

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) increasing to the northwest
- predominantly first-year ice mixed with low percentages of multi-year ice; high iceberg densities.

Tidal Range

2.0 - 2.8 m





Zone 3 North and East Coast

Coastal Zone Character

fiord coast
ice shelf

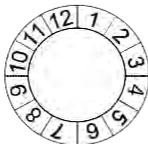
- high-relief coast with cliffs and fiords
- the ice shelf forms the coast in many sections

Shoreline Types

bedrock shores
mixed-sediment beaches
ice shores

- numerous glacier outlets with floating ice shelves

Ice Season



- no ice-free season in many years
- dominated by a dynamic belt of multi-year ice continually drifting out of the Arctic Basin through Fram Strait (thickness 3 - 4 metres)
- navigation possible some years on the east coast in August and September

Tidal Range



- less than 2.8 m
-



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

10.5 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 Beidafjörður 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.

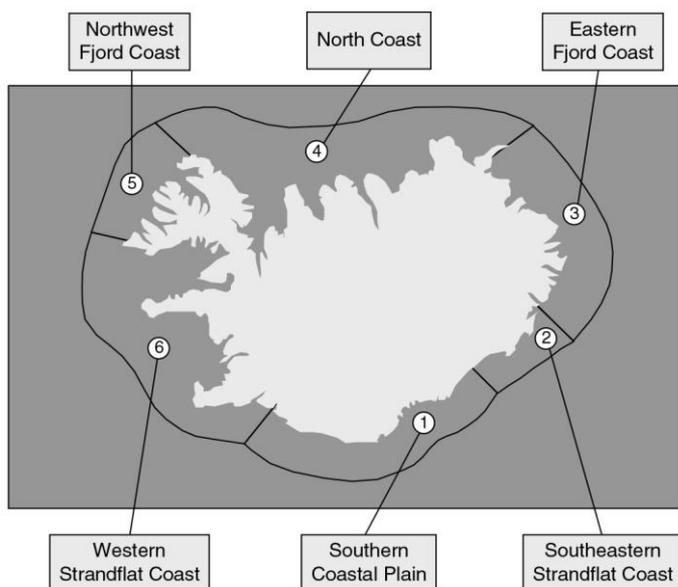


Figure 10.6. Iceland

Zone 1 Southeast Coastal Plain



Coastal Zone Character

barrier islands
lowland/coastal plain

- 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

Shoreline Types

sand beaches
mixed-sediment beaches

- 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

Zone 2 Southeastern Strandflat Coast



Coastal Zone Character

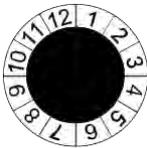
lowland/coastal plain
deltas
barrier islands

- alternating bedrock headlands and pocket barrier beaches
- beaches cut by tidal inlets and backed by tidal flats and salt marshes

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

upland or mountains
fiord coast

- high-relief fiord coast
- beaches cut by tidal inlets and backed by tidal flats and salt marshes

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
-

Zone 4 North Coast



Coastal Zone Character

upland or mountains
fiord coast

- high-relief coast with cliffs and some fiords (Hróútfjörður and Eyjafjörður)
- broad beach systems at Hérardsflói, Axarfjörður, Skagafjörður and Húnaflói

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



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

Shoreline Types

bedrock shores
 sand beaches
 pebble/cobble beaches

- high-relief coast with cliffs and fiords
- two major volcanic headlands separate Beidafjörður and Faxaflói
- embayments have many bedrock islands, shoals, and skerries
- extensive sand barrier beaches in northern Faxaflói
- coarse-sediment beaches on headlands
- open water on outer coast with some local ice in sheltered bays and fiords

Ice Season



Tidal Range



- generally less than 2 m but up to 5 m in Beidafjörður and Faxaflói

10.6 Arctic Norway

The coasts of Norway that are north of the Arctic Circle include the islands of Svalbard, Bjørnøya and Jan Mayen Island. With the exception of Bjørnøya, 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 Bjørnøya 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 Bjørnøya, 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, Bjørnøya and Jan Mayen Island.

ARCTIC WATERS FIELD GUIDE

Arctic Norway has been divided into six regions, as shown below. Each region is described in terms of coastal zone character, shore-line type, wave exposure and ice season, and tidal range.

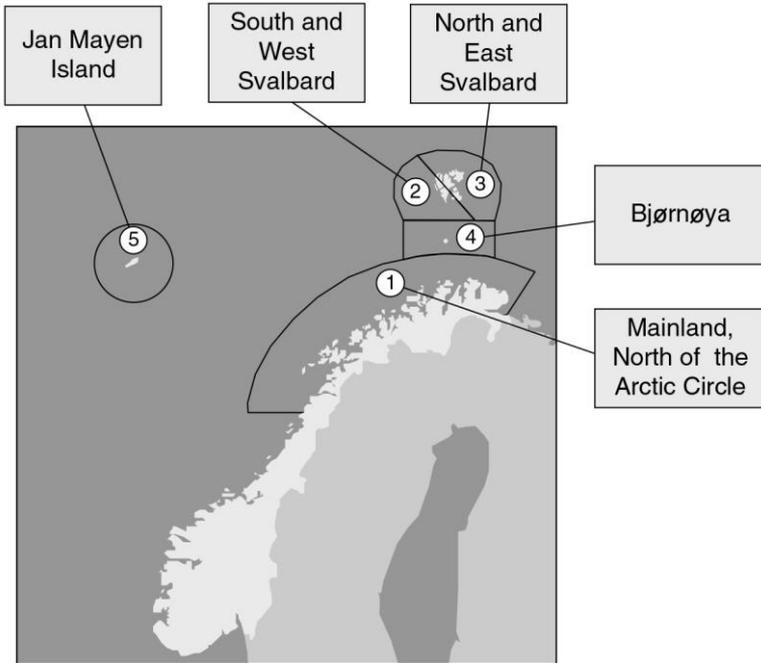


Figure 10.7. Norway

Zone 1 Mainland, north of the Arctic Circle



Coastal Zone Character

upland or mountains
fiord coast

- upland cliffed coasts with many steep-sided fiords and a complex coastline
- coarse-grained beaches in some sections

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
-

Zone 2 *South and West Svalbard*



Coastal Zone Character

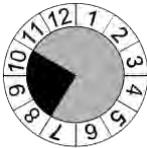
upland or mountains
fiord coast
ice shelf

- 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

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 typically 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 4 *Bjønøya*



Coastal Zone Character

cliffs
lowland or coastal plain

Shoreline Types

bedrock shores
mixed-sediment beaches

- lowland cliffed coasts
- narrow coarse-grained beaches in some sections

Ice Season



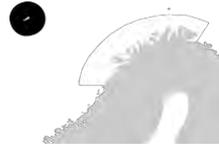
- exposed to the Atlantic Ocean, unlimited fetch
- near the edge of the polar pack during winter - outer west-facing coast usually has open water all year
- the eastern coast may be ice-bound from October through May

Tidal Range



- 1.0 - 2.0 m

Zone 5 Jan Mayen Island



Coastal Zone Character

upland or mountains

- lowland cliffed coast with narrow coarse-grained beaches in some sections

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

10.7 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 Peninsula; at times limiting the Northeast Passage 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.

COASTAL CHARACTER OF THE ARCTIC REGIONS

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.

ARCTIC WATERS FIELD GUIDE

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.

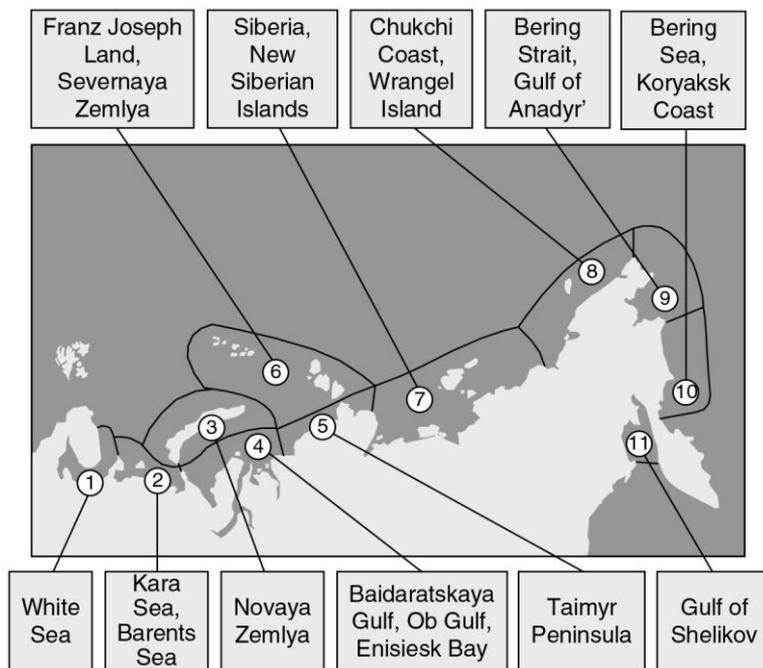


Figure 10.8. Russia

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

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.

Shoreline Types

sand beaches
marshes
low tundra shores
tundra cliff shores

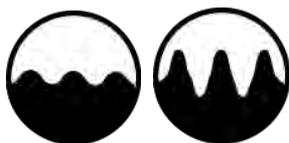
- large delta at the mouth of the Pechora River

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

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

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

uplands or mountains
fiord coast
ice shelf

- high-relief coast with calving glaciers

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)

Shoreline Types

bedrock shores
 sand beaches
 mud flats
 low tundra shores
 tundra cliff shores

- shallow nearshore waters

Ice Season



- low wave-energy coast
- permanent polar pack ice may stay close to shore all year, with limited areas for wave generation
- 2 months (August to September) open-water season

Tidal Range



- less than 1.0 m
- wind surges are common and can flood inland several kilometres
- up to 3.0 m at the head of the Khatanga estuary

Zone 8 Chukchi Coast Wrangel Island



Coastal Zone Character

fiord coast
 barrier island/beaches
 delta
 tundra coast

- 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

Shoreline Types

bedrock shores
 sand beaches
 mixed-sediment beaches
 mud flats
 low tundra shores
 tundra cliff shores

- large delta at the mouth of the Kolyma River

Ice Season



- permanent polar pack ice may stay close to shore all year, with limited areas for wave generation
- 3 months (August to October) open-water season
- Wrangel may have no open-water season some years

Tidal Range



- less than 1.0 m

Zone 9 Bering Strait, Gulf of Anadyr'



Coastal Zone Character

fiord coast
barrier island/beaches
tundra coast

- alternating bedrock and lowland eroding tundra cliff coast
- fiords on southeast Chukchi Peninsula

Shoreline Types

bedrock shores
ice shores
sand beaches
pebble/cobble beaches
low tundra shores
tundra cliff shores

- many coarse-grained barriers and spits in the Gulf of Anadyr'

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

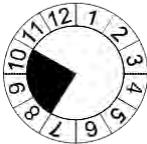
- fjord coast
- barrier island/beaches
- tundra coast

- upland region with small fiords and coarse-grained bay-mouth barriers

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



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

10.8 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 closer to the Beaufort Sea Alaskan coast during summer months than in Canada but the overall trend in the past 30 years is similar: more frequent and more extensive retreats of the polar pack for several months, leaving a much more expansive area of open water. This trend also applies to the North Chukchi Sea described below. Open-water fetch distances increase rapidly moving west and south into the Chukchi and northern Bering Seas and the ice-free season usually is greater than 6 months south of Norton Sound. The open water season in the Chukchi Sea decreases with latitude but generally in the central part (the latitude of Wainwright) extends from early July to mid-November. 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

COASTAL CHARACTER OF THE ARCTIC REGIONS

ice-free all year except in embayments with fresh-water inputs and bergs from calving glaciers.

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.

ARCTIC WATERS FIELD GUIDE

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.

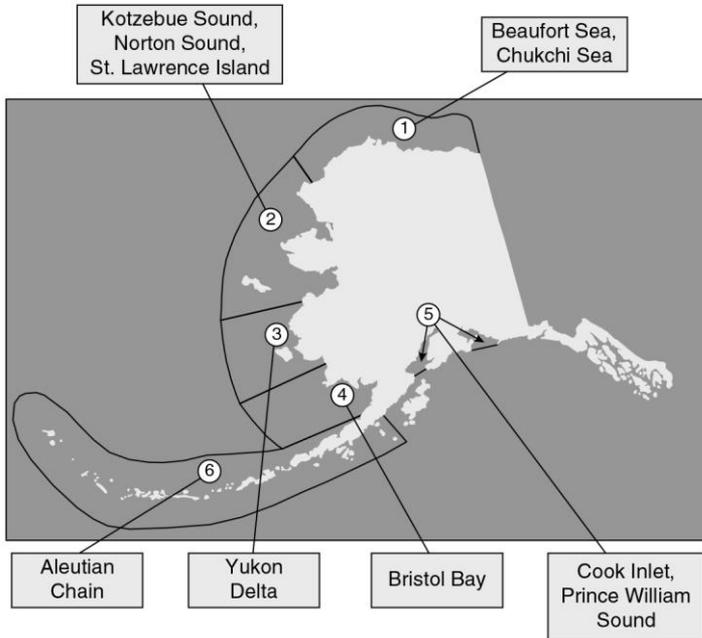


Figure 10.9. Arctic Alaska

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



- ~3 months open-water season in the Beaufort Sea (early August to late October)
- ~4-5 months open-water in the Chukchi Sea (July to November)
- permanent polar pack can still remain close to shore in extreme years but continuing warming through the Arctic Basin has led to much less old ice. The summer open water has expanded in extent and duration, most notably in the Chukchi Sea.

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

- 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

Shoreline Types

bedrock shores
 sand beaches
 mixed-sediment beaches

- St. Matthew and Diomedede 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 beaches
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

Zone 4 Bristol Bay



Coastal Zone Character

lowland/coastal plain
tidal flats

- lowland coastal plain with extensive mud flats
- the Pribilof Islands are predominantly bedrock cliffs with narrow beaches

Shoreline Types

mixed-sediment beaches
sand beaches
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
glaciers
tidal flats

Shoreline Types

bedrock shores
pebble/cobble beaches
sand/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
- the Pribilof Islands are near the southern ice limit; occasional sea ice in March or April
- 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 except for bergs from calving glaciers and some freshwater ice in embayments

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

10.9 Photographs of Shore Types of the Arctic Region

The 14 shore types described in Section 4 are illustrated with colour photographs.

Shoreline Type	Figure(s)
bedrock	10.10
man-made solid structure	10.11
ice or ice-covered shores	10.12, 10.13
sand beach	10.14
mixed-sediment beach	10.15
pebble/cobble beach	10.16
boulder beach	10.17, 10.18
sand flat	10.18
mud flat	10.19
salt marsh	10.20
peat shore	10.21
inundated low-lying tundra	10.22
tundra cliffs	10.23, 10.24
shorelines with snow	10.25

Figures 10.25 to 10.29 depict shorelines in winter conditions. Figures 10.30 to 10.32 illustrate oil in snow and ice.

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Figure 10.10. Bedrock coast, Labrador, Canada



Figure 10.11. Man-made solid structure: dock of pilings and sheet metal, Prudhoe Bay, Alaska

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.12. Ice shelf, southwest Devon Island, Canada



Figure 10.13. Calving glacier, Kongsfjord, Spitzbergen, Norway



Figure 10.14. Sand beach, Sakhalin Island, Sea of Okhotsk, Russia



Figure 10.15. Mixed-sediment beach, Cape Ricketts, Devon Island, Lancaster Sound, Canada

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.16. Pebble beach, Ny Ålesund, Spitzbergen, Norway



Figure 10.17. Boulder beach, Cartwright, Labrador, Canada



Figure 10.18. Sand-mud tidal flat with boulder barricade, Cartwright, Labrador, Canada



Figure 10.19. Mud flat with drying cracks on river bank, Kupiguak Channel, Colville River, Alaska

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.20. 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 10.21. Peat shore, Foggy Island Bay, Beaufort Sea, Alaska



Figure 10.22. Inundated, low-lying tundra near Ikpikuk River, Beaufort Sea, Alaska



Figure 10.23. Ice-rich tundra cliff, Point Brower, Beaufort Sea, Alaska

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.24. Ice-poor tundra cliff, Peard Bay, Chukchi Sea, Alaska



Figure 10.25. Winter shoreline, tundra cliff at Peard Bay, Alaska (same location as 10.24)



Figure 10.26. Shore zone covered with snow, Prince William Sound, Alaska



Figure 10.27. Ice foot forming on a sand beach, Gulf of St. Lawrence, Canada

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.28. Leads that often develop in solid ice where pooled oil can be burned or skimmed



Figure 10.29. The ice-free, lee-side of an artificial island in dynamic, broken ice where the mechanical recovery of oil may be possible



Figure 10.30. Oil widely distributed in small ice forms near shore; no countermeasures approach is practical



Figure 10.31. In-situ burning of pooled oil in an ice lead, Kolva River, Komi Republic, Russia

COASTAL CHARACTER OF THE ARCTIC REGIONS



Figure 10.32. Globules and droplets of oil adhering to a chunk of ice; recovery of this oil would be difficult

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Legend

Bullets					
	mobile floating barriers		stationary barriers		
	subsurface barriers		berms		
	trenches or slots		diversion booming		
	advancing skimmers		stationary skimmers		vacuum systems
	burning oil on water contained in booms		burning oil on ice		burning oil in broken ice
	vessel dispersant application		aerial dispersant application		
Shoreline Treatment Methods					
	natural recovery		flooding		
	low-pressure, ambient-water wash		low-pressure, warm- or hot-water wash		
	high-pressure, ambient-water wash		high-pressure, warm- or hot-water		
	steam cleaning		sandblasting		
	manual removal		vacuum systems		
	mechanical removal		vegetation cutting		
	passive sorbents		sediment mixing		
	sediment relocation		burning		
	dispersants		shoreline cleaners		
	solidifiers and visco-elastic agents		nutrient enrichment/bioremediation		
Oil Viscosity Ranges					
	good/recommended		fair/conditionally recommended		poor/not recommended

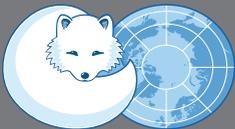
Arctic Region



Arctic Region Map Courtesy of US Central Intelligence Agency
1998 World Fact Book



EMERGENCY PREVENTION,
PREPAREDNESS AND RESPONSE



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