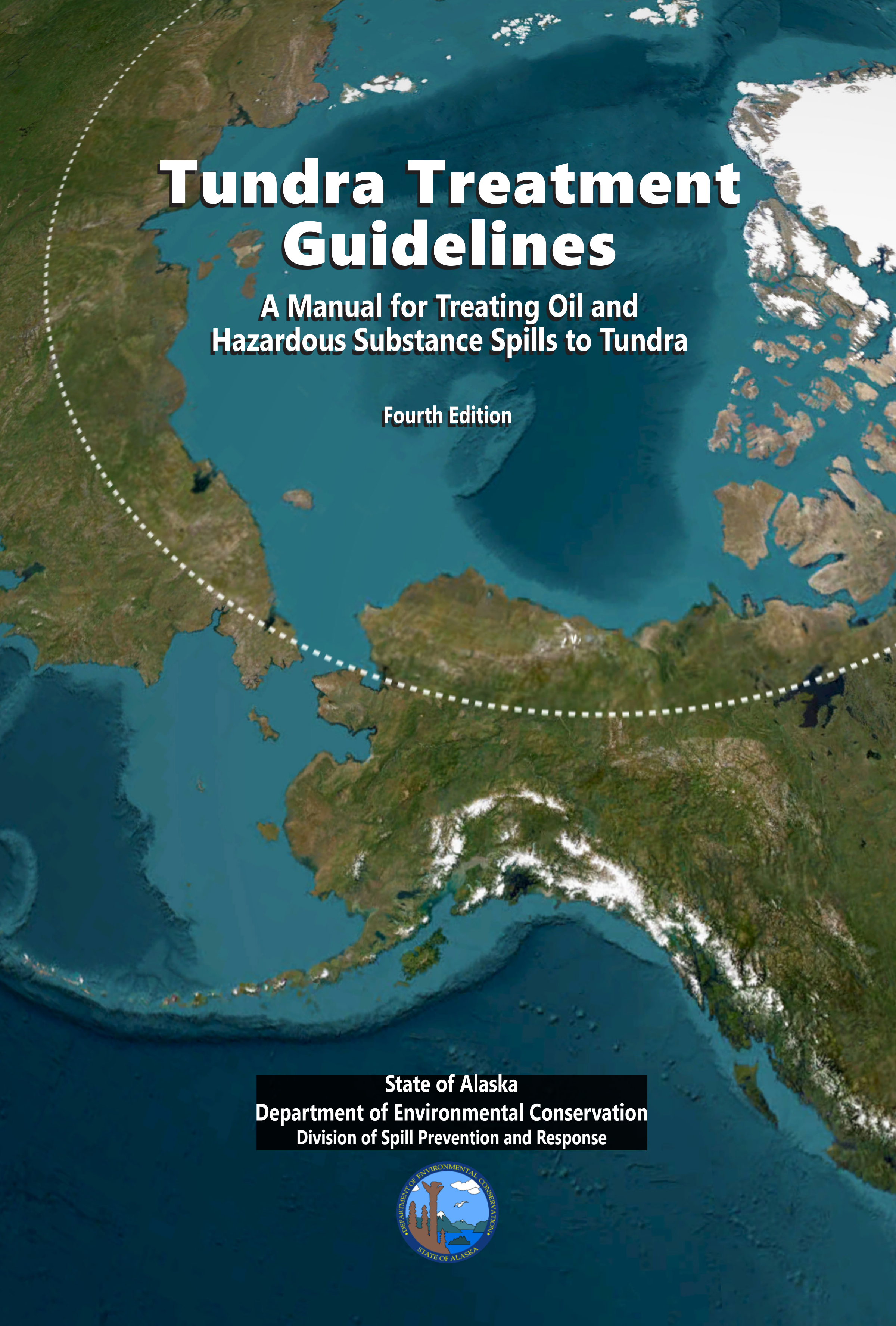


Tundra Treatment Guidelines

A Manual for Treating Oil and Hazardous Substance Spills to Tundra

Fourth Edition

State of Alaska
Department of Environmental Conservation
Division of Spill Prevention and Response

Cover:

Polar view of the Arctic. Image development by Dorte Dissing, PhD, GIS Specialist, ABR

Tundra Treatment Guidelines

A Manual for Treating Oil and Hazardous Substance Spills to Tundra

Fourth Edition

Timothy C. Cater
ABR, Inc.—Environmental Research & Services

State of Alaska
Department of Environmental Conservation
Division of Spill Prevention and Response

The author gratefully acknowledges the contributions of Patrick Athey and Dawn Reeder of OASIS Environmental, Inc., Jim Lukin of Lukin Publications Management, Jay McKendrick of Lazy Mountain Research, Jeffery S. Conn of the Department of Environmental Conservation, and Angela Miller of Shannon & Wilson. *Tundra Treatment Guidelines* is a living document that provides the best available information based on the latest technological and engineering advancements, combined with practical knowledge gained from use of the manual in the field.

Tundra Treatment Guidelines may be copied, in any format, for all uses excluding those for profit. Readers also may visit the DEC website to use the on-line version of this manual or to download a printed version of the manual for free.

The Department of Environmental Conservation welcomes suggestions for improvements that will be considered for future editions. A form is available for submitting corrections, updates, or refinements (see page ix).

4th edition, April 2025, by Timothy C. Cater
ABR, Inc.–Environmental Research & Services
P.O. Box 80410
Fairbanks, AK 99708

3rd edition, September 2010, by Timothy C. Cater.
(Reprinted with minor updates, December 2019)
PO Box 80410
Fairbanks, AK 99708

2d edition, February 2005, by Angela E. Miller.
Shannon & Wilson, Inc.
2355 Hill Road
Fairbanks, AK 99708

1st edition, June 2001, by Patrick Athey,[1] Dawn Reeder,[1] Jim Lukin,[2] Jay McKendrick,[3] Jeffery S. Conn[4]

[1]OASIS Environmental, Inc.
807 G Street, Suite 250
Anchorage, AK 99501

[2]Lukin Publications Management
P.O. Box 241086
Anchorage, AK 99524

[3]Lazy Mountain Research
15705 Shawn Drive East
P.O. Box 902
Palmer, AK 99645

[4]Department of Environmental Conservation
Division of Spill Prevention and Response, Prevention Preparedness and Response
610 University Ave.
Fairbanks, AK 99709

410 Willoughby Ave., Suite 105
Juneau, AK 99801-1795

Cover map by Dorte Dissing, GIS Specialist, ABR.

Production by Pamela Odom, Publications Specialist, ABR.

Printed in the United States of America.

The paper used in this publication meets the minimum requirements of the American National Standard for Information Science—Permanence of Paper for Printed Library Materials, ANSI/NISO Z39.48-1992.

Disclaimer

There are always conditions unique to a site and incident that are beyond the control of persons responding to a spill, and that may affect treatment performance. Accordingly, using this manual will not guarantee specific results. Safety of site workers, the public, and wildlife is the highest priority in all situations and should supersede all other considerations during a response operation. Detailed information about safety requirements and procedures are not provided in this manual. Individuals should consult their company's safety officers to ensure compliance with federal, state, and local regulations.

Some of the information in this manual is adapted from the *Alaska Clean Seas Technical Manual*. Alaska Clean Seas (ACS) believes that the information and procedures contained in the *ACS Technical Manual* are well founded; many of the procedures are based on actual experiences in the environments where these procedures are intended to apply. Nonetheless, ACS and its members expressly disclaim that the procedures provided in the *ACS Technical Manual*, even if followed correctly and competently, will necessarily produce any specific results. Implementation of the recommendations and procedures contained in this manual and the *ACS Technical Manual* is at the sole risk of the user.

The most recent version of the *ACS Technical Manual* can be downloaded for free from the Alaska Clean Seas (ACS) website at https://www.alaskacleanseas.org.

Contents

Foreword

Tundra Treatment Guidelines is a manual published by the State of Alaska's Department of Environmental Conservation (DEC), Division of Spill Prevention and Response, Prevention Preparedness and Response Program. This manual provides standard operating guidelines for responding to spills of oil and other contaminants on Alaska's North Slope. DEC has three main objectives for any tundra cleanup: 1) minimizing damage to the tundra from the spilled material, 2) minimizing damage to the tundra from the response actions, and 3) minimizing the time period for tundra to recover. DEC acknowledges that the ecological damage from the cleanup can be greater than the deleterious effects of the residual contamination. Helping responders strike a balance between these objectives is the primary goal of this manual.

This manual emphasizes strategies that will reduce the toxicity, mobility, and volume of spill residuals in tundra, and that will promote vegetation recovery, control risks to wildlife, aquatic, and human receptors, and protect tundra soils from physical damage and induced thermal effects that can impact permafrost. This manual provides a menu of tactics for spills of crude oil, diesel fuel, gasoline, saline waters and other saline substances, drilling muds and fluids, synthetic fluids, and ore concentrate after initial response efforts have eliminated the threat of large-scale spill migration. Tactics are labeled according to their purpose: P (Planning), CR (Contaminant Recovery), TR (Tundra Rehabilitation), and AM (Assessment and Monitoring). An extensive bibliography of references used to determine the appropriateness and effectiveness of various treatment tactics is included at the end of the manual.

This manual is based on 5 decades of combined industry, university, and government agency experience with tundra spills and field experiments on Alaska's North Slope. New to this fourth edition is the inclusion of mined ore concentrate as one of the contaminants for which this manual is applicable. The physical and chemical properties of ore concentrate are fundamentally different from the other contaminants, however, rendering all of the water-based tactics in this manual as unsuitable for recovering ore concentrate. Also new to this edition is the recommendation to discontinue the use of commercial mixtures of grass seed at many sites.

This manual is a living document that is under constant review and revised as additional information from research and future spill events becomes available. The first edition of the manual was published in 2001. The on-line version of the manual was revised in 2005. The printed and on-line versions were revised in the 3rd edition, published in 2010. The fourth edition of this manual is available on-line from the DEC website. A printed version of the manual also is available to download for free.

Recommended citation:

Cater, Timothy C. 2025. Tundra treatment guidelines: a manual for treating oil and hazardous substance spills to tundra, 4th edition. Department of Environmental Conservation, Juneau, Alaska. 190 pp.

Revision Form

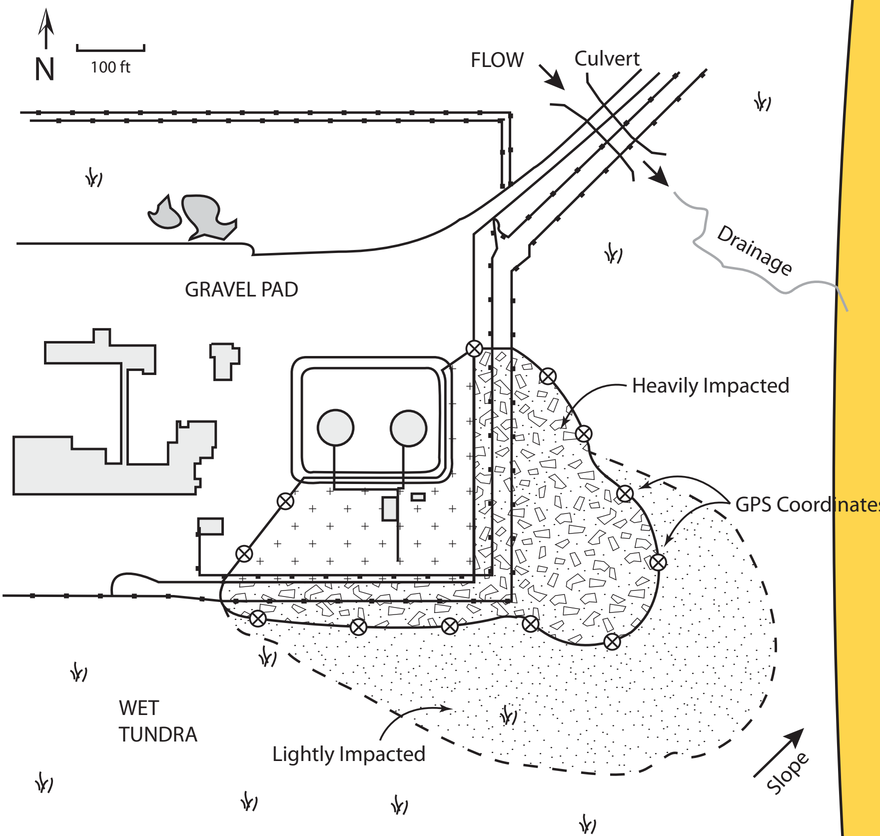
The Department of Environmental Conservation (DEC) requests that users of this manual provide notification of any errors or suggest revisions for use in future updates. If you would like to submit information, include the following information:

Tactic:
Change:
Source of Information for Change:
Name of Person Submitting Change:
Organization:
Telephone:
Date:

Thank you for helping DEC maintain its technical manual and keep it up-to-date!

UPDATED: JUNE 2025

Planning Tactics



P-1 Developing Treatment Goals and Strategies

Step 1: Consult with Government Agencies

Coordinate with appropriate agencies before initiating a treatment strategy. All plans for site characterization and assessment, analytical sampling, treatment, and monitoring must be approved by the Department of Environmental Conservation (DEC) and landowners. Always work with agencies to establish site-specific, short- and long term goals.

Step 2: Characterize Site

In order to set treatment goals and identify an appropriate treatment strategy, consider the spill characteristics (Tactic P-3), how site drainage and layout (e.g., topography, distance from road) will affect the potential for offsite movement of contaminants, and the type of tundra affected (Tactic P-2). Assess the risks to humans and wildlife according to agency requirements. In general, all tundra types are more sensitive to both chemical and physical damage when the soil is thawed.

Spill Characteristics

Gain a general understanding of how the spilled substance may affect soils, vegetation, wildlife, and humans (Tactic P-3). Use field indicators (Tactic AM-2) to assess the apparent damage caused by the spilled substance and by response tactics. If appropriate, use revegetation test plots (Tactic AM-6) to determine whether soil treatments are needed. Agencies may also require sampling and laboratory analyses of the soil and water to establish baseline conditions before treatment (Tactic AM-4).

Site Drainage

The initial selection of tactics must focus on limiting the potential for offsite movement of contaminants. Consider how water is likely to move across the site. Sloping sites and sites with networks of low-lying troughs present particular challenges for controlling movement of contaminants.

Steps	Considerations
Consult with Government Agencies	• Coordinate with government agencies to set site-specific treatment goals and strategies during the treatment and monitoring process. • All site characterization/assessment plans, sampling plans, and monitoring plans must be approved by the Department of Environmental Conservation (DEC).
↓	
Characterize Site	• What spilled? • How did the spill occur? • What season did the spill occur in? • What is the availability of site access? • What is the tundra type? • What are the expected effects of the spill residuals on the soils, hydrology, and vegetation? • What wildlife uses the site? • Do humans use the site?
↓	
Set Treatment Goals	• The treatment goals for all spills are to (a) control risks to humans, wildlife and aquatic receptors by recovering contaminants and (b) promote the recovery of tundra vegetation and a stable thermal regime typical for soil underlain by permafrost. • Set site-specific goals by balancing these general goals, which often conflict because cleanup operations can damage tundra. • The relative importance of these goals varies among spills.
↓	
Select Treatment Tactics	• Select tactics that are consistent with the site-specific treatment goals. • The choice of tactics also depends on factors such as the substance spilled, the size and accessibility of the affected area, and the season when the spill occurred.
↓	
Assemble Tactics into a Strategy	• A variety of tactics may be needed throughout the treatment process, or different tactics may be needed at different locations. • The same tactics may have to be applied more than once. • The sequence of tactics may be important.
↓	
Monitor Treatment and Recovery	• Coordinate with government agencies to select or create acceptable monitoring methods and to determine when treatment goals have been reached.

Where natural drainage patterns cross the site, temporary diversion of water flow may be required. Planning for future events such as spring snowmelt or summer rains also is important.

Site Layout

The topography and layout of the site will help determine which tactics are selected. In particular, consider the availability of road access to the spill site, and limitations to access created by pipelines, other facilities, and natural topographic features. Initially, a simple map of the site layout and topography will be helpful in planning a treatment strategy (Tactic AM-1). As cleanup progresses, in most cases it will be valuable to establish a grid system across the site and into the surrounding tundra, using professional surveying techniques.

Based on this information, determine how the treatment plan can use topographic features, roads and other facilities to help minimize additional disturbance. Identify routes for mobilizing equipment and materials to the site and areas for waste accumulation. Consider ongoing maintenance operations such as snow removal from gravel pads and roads, and how these may affect the treatment and recovery of the tundra.

Tundra Type

The nature and severity of impacts from a spill vary with tundra type, due to differences in hydrology, soils, and vegetation. Tundra types also differ in their sensitivity to the physical impacts that may result from a cleanup operation. These differences are most pronounced when the soil is thawed.

Dry tundra soils are highly susceptible to oil-based substances that adhere to the porous root mat, displacing the air and water needed by plant roots and soil microbes. The dry mineral soils in the active layer have the potential to become saturated with crude oil, fuels, and water-soluble substances. The plant communities on many dry tundra sites are dominated by dwarf shrubs and lichens, which are sensitive to physical damage, slow to recover or colonize after disturbance, and difficult to re-establish by seeding or transplanting.

In contrast, surface water in aquatic and wet tundra can provide some protection from hydrocarbons, which tend to float on the water, and from other spilled substances, which are diluted. In addition, the soil pore spaces are usually filled with water, which slows the infiltration of spilled substances into the rooting zone of the soil. In these tundra types, oiled foliage may be killed, but the rooting systems and other below-ground plant materials often survive and recover if low-impact tactics are used to recover contaminants. Further information about tundra types, including moist tundra, can be found in Tactic P-2.

Step 3: Set Treatment Goals

The objectives of any tundra cleanup are to minimize the potential for migration of contaminants into the surrounding tundra, recover spilled material, minimize damage to the tundra from both the spilled material and the response actions, and minimize the time period for tundra to recover. Using information gained during site characterization, work with the responsible government agencies to establish site-specific treatment goals before implementing treatment tactics. The complexities of tundra spills preclude the use of a single cleanup endpoint. In other words, there are no set criteria for determining: "How clean is clean?" Instead, this manual provides a range of numerical cleanup levels as guidance. These levels should be used to help decide when a cleanup should stop because the benefit of additional treatment will be outweighed by the

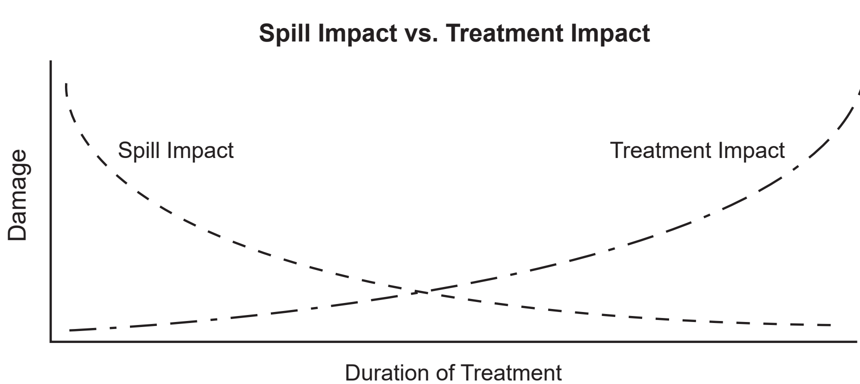


Figure 1. Spill impact vs. treatment impact

additional tundra damage that will be caused by the treatment. Refer to Tactic AM-3 for deciding when to end a cleanup before too much damage occurs.

In addition to the general reasons above, four specific reasons are listed below to help clarify why tundra treatment goals are not necessarily based only on target concentrations of residual contaminants in soil.

1. **Treatments can cause additional tundra damage.** Treatments aimed at reducing soil concentrations of contaminants can cause damage to plants and soil, including disruption of the soil thermal regime (thermokarst). These changes can delay vegetation recovery; in some cases the delay may be indefinite. This concept is illustrated in Figure 1.
2. **Different plant species have varying tolerances to spill residuals in soil**. Some plant species tolerate relatively high concentrations of contaminants, while others may be adversely affected by lower concentrations of the same substance.
3. **Soil properties may influence the toxicity of spill residuals to plants.** For example, organic soils may absorb some of the spilled material, making it less available to plants. For this reason, a given concentration of a contaminant could be much more toxic to plants in a mineral versus an organic soil.
4. **Government agency treatment goals vary.** Agency-determined goals vary on a case-by-case basis, from simply creating conditions capable of supporting some type of vegetation to restoring a site's pre-spill ecological functions and levels of plant species diversity. Factors that may affect the selection of goals include the size of the spill and the importance of the site to wildlife or humans.

Step 4: Select Treatment Tactics

This manual describes the applicability of specific tactics, and the personnel and equipment needed to implement these tactics. If possible, select tactics to recover contaminants to the extent possible, while minimizing physical damage to vegetation and soils. All cleanup and rehabilitation tactics require mobilization of equipment and/or personnel onto the affected tundra surface, which will cause some level of physical

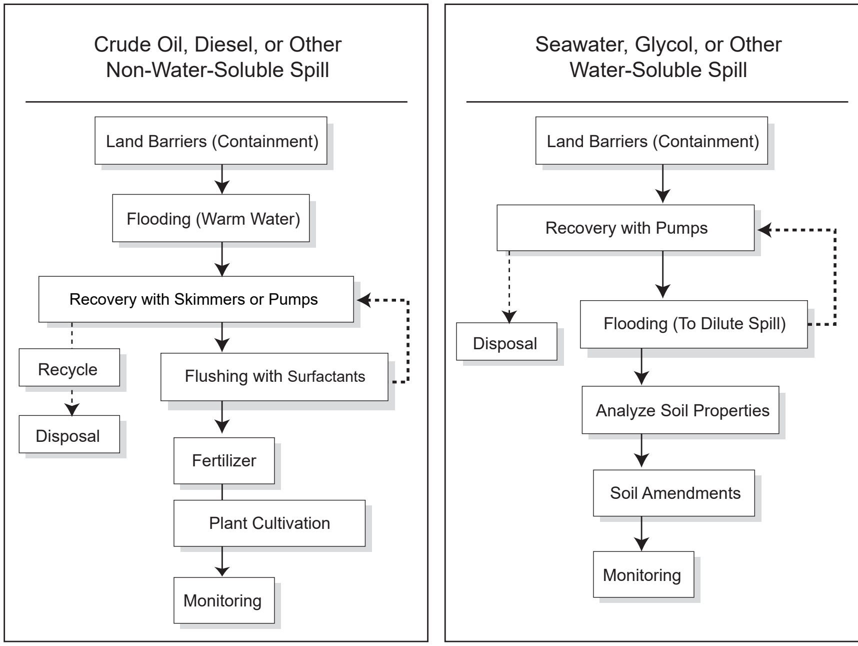


Figure 2. Examples of treatment strategies

damage and may increase the potential for thermokarst. In cases where aggressive tactics are appropriate because of site-specific conditions or goals, design implementation plans to minimize additional impacts to tundra in the vicinity of the affected area.

Step 5: Assemble Tactics Into a Strategy

A tundra treatment strategy consists of a set of tactics implemented sequentially (Fig. 2). In some cases, certain tactics may be repeated until treatment goals have been attained. Review the treatment strategy regularly, considering such questions as: Are the treatment goals attainable with the selected tactics? Can vegetation recovery occur at the desired rate under present site conditions? Will continued treatment cause more damage than benefit?

Each new spill will require the development of an individual site-specific strategy that selects the appropriate tactics. For example, use the generalized decision trees in Figure 3 to help develop a strategy for a

Crude Oil or Diesel Spill

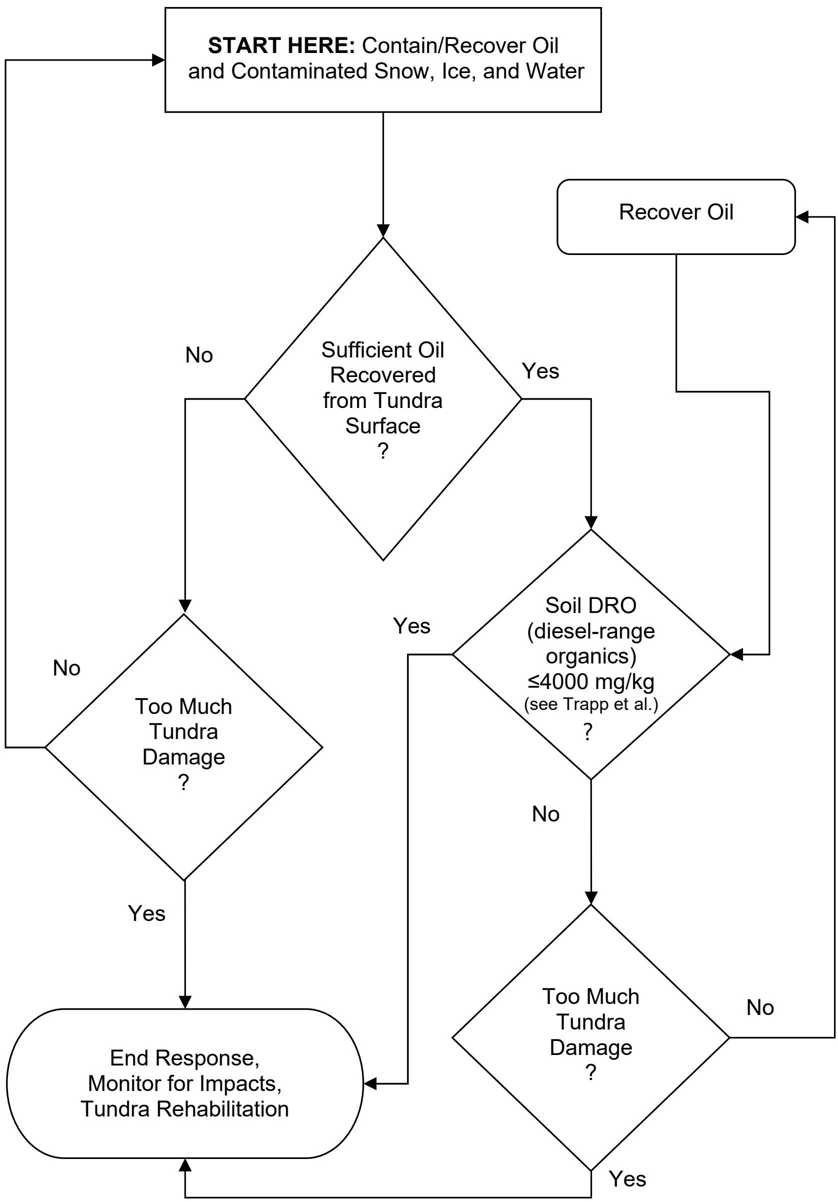


Figure 3a. Generalized example of a decision tree to help develop a site-specific treatment strategy for crude oil or diesel spill.

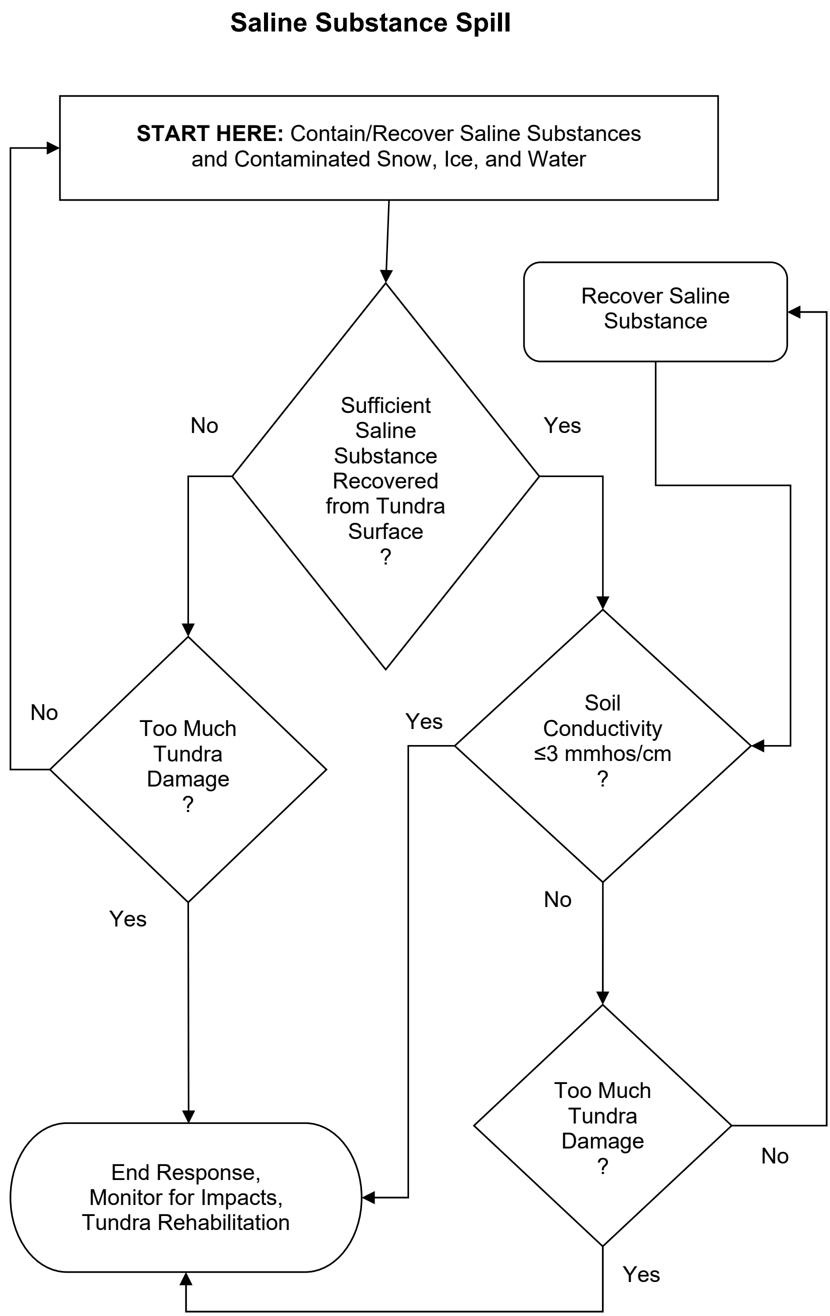


Figure 3b. Generalized example of a decision tree to help develop a site-specific treatment strategy for saline substance spill

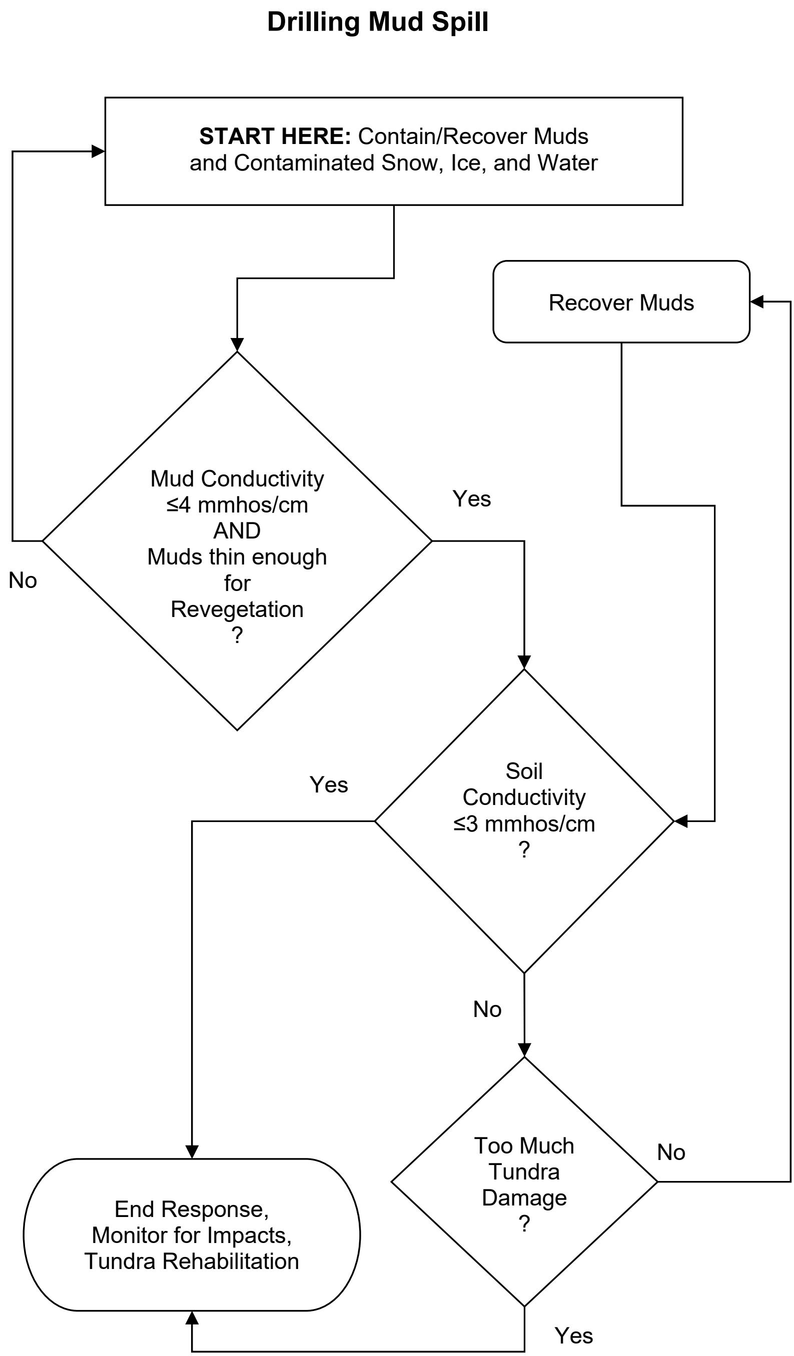


Figure 3c. Generalized example of a decision tree to help develop a site-specific treatment strategy for a drilling mud spill

spill of hydrocarbons (crude oil and diesel), saline substances, or drilling mud. A decision tree for ore concentrate is not included because of complexities associated with the multiple ingredients in the ore and their site specific cleanup levels.

Step 6: Monitor Treatment and Recovery

Coordinate with responsible government agencies (including DEC) to prepare a monitoring program to gauge progress and determine when treatment and recovery goals have been reached. Elements of a monitoring program may include:

- ***Monitoring spill residuals*** during treatment or long-term recovery, based on water and/or soil samples analyzed by a laboratory (Tactic AM-4), field indicators (Tactic AM-2), and/or apparent phytotoxicity (Tactic AM-5 and Tactic AM-6);
- ***Monitoring vegetation recovery*** by measuring vegetation cover, species composition of the plant community, and/or the condition (health) of the vegetation (Tactic AM-6); and
- ***Monitoring physical damage, including thermal effects*** based on visual observation or documentation of the site topography using ground or aerial photographs. The depth of the active layer (thaw depth) within the affected area can be measured and compared to that in an undisturbed (reference) area considered to represent pre-spill conditions.

P-2 Understanding the Tundra Environment

An understanding of the tundra environment is critical when choosing tactics and strategies for treating a spill. Following is an overview of four generalized tundra types and their characteristics. Although this discussion focuses on Alaska's North Slope (arctic tundra), the planning, treatment, and monitoring, tactics in this manual also apply to tundra environments elsewhere in Alaska, including alpine tundra.

What is tundra?

Tundra is a Russian word translated as "treeless plain" (Merriam-Webster definition of tundra) or "marshy plain" (Billings 1974). Tundra in this manual is used to describe ecosystems where the indigenous plant cover consists of low-growing vegetation in places where summers are too cold to allow tree growth. Tundra includes the circumpolar treeless region north (and south) of the latitudinal treeline and the less extensive mountain landscapes above altitudinal treeline (Murray 1978).

Alaska's North Slope stretches from the crest of the Brooks Range north to the Arctic Ocean (Fig. 4). The Arctic Coastal Plain area is flat and wet with abundant oriented thaw lakes. In contrast, the Arctic Foothills Area is a broad expanse of valleys and hills. The climate is characterized by extreme winter cold, strong winds, and brief summers (about 90 days [June–August]) when the air temperature is generally cool and

Figure 4. Boundaries of the arctic coastal plain and arctic foothills on Alaska's North Slope (based on Wahrhaftig 1965)

there is relatively little precipitation. The soil at depth remains perennially frozen (permafrost) but an "active layer" of surface soil, varying in depth from a few inches to a few feet, thaws each summer and refreezes each winter (Fig. 5). The rooting depth of plants and most of the activity of soil microbes are limited by the depth of the active layer (i.e., thaw depth). Although annual precipitation is low, surface water is abundant, because permafrost limits water infiltration and movement. Tundra vegetation consists of low-growing plants including mosses, lichens, grasses, sedges, rushes, forbs, and dwarf shrubs. Compared to most other environments, relatively few plant species have adapted to the extreme conditions of the tundra (Fig. 6). Soils develop slowly in the Arctic, because the cold climate and short growing season limit the decay of dead plant matter.

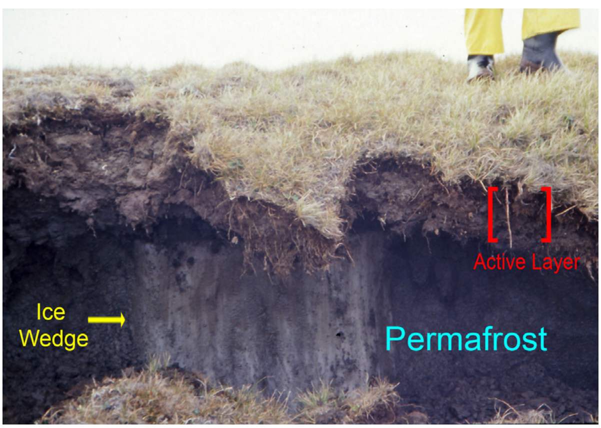


Figure 5. Example of ice wedge (approximately 3-ft wide) and permafrost beneath a thawed layer of soil (active layer)

Figure 6. Aerial photo of polygonal features in tundra. The boundaries between polygons indicate the locations of ice wedges such as the close-up in Figure 5

What are the types of tundra?

This manual classifies tundra into four types: aquatic, wet, moist, and dry (Figs. 7–10). These generalized types are based on a hierarchical tundra vegetation classification

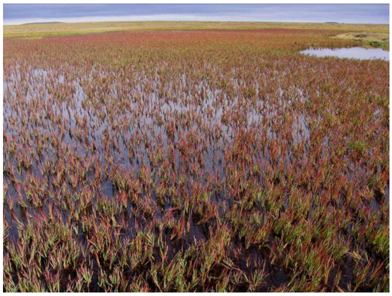


Figure 7. Aquatic tundra

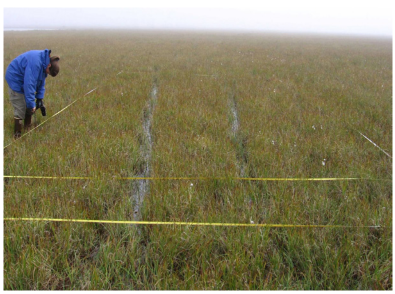


Figure 8. Wet tundra

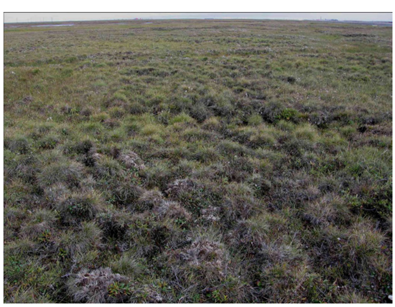


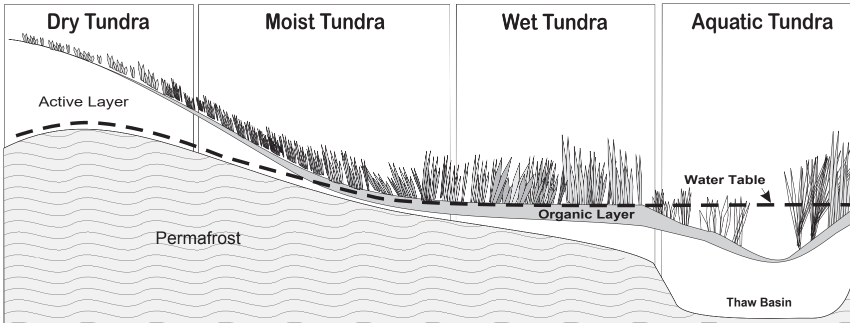
Figure 9. Moist (tussock) tundra

Figure 10. Dry tundra

scheme developed by Walker (1983, 1985). They occur in three major geographic provinces on the North Slope of Alaska: 1) the coastal plain, 2) the foothills, and 3) the mountains of the Brooks Range, as well as on the Seward Peninsula.

Wet tundra is the most common type on the coastal plain, due to the low topographic relief and the presence of a shallow, saturated active layer. Patterned ground features (i.e., polygons bounded by ice wedges, Fig. 6) are abundant. In the foothills province, moist tundra predominates on slopes, wet tundra in low areas, and dry tundra on exposed hilltops and ridges. Patterned ground is less common here. In the Brooks Range and above treeline in other mountain ranges in Alaska, dry tundra predominates. High shrub thickets develop on floodplains, in sheltered areas or where snow accumulates and protects plants from harsh winter winds. In the braided channels of active floodplains, the soil surface is frequently barren.

Figure 11 illustrates topographic features and subsurface conditions associated with a few of the common plant community types on the North Slope.



Dry Tundra	Moist Tundra	Wet Tundra	Aquatic Tundra
Dwarf Shrub Crustose-Lichen Tundra Lichens Mountain-Avens (*Dryas*)	Moist Sedge, Dwarf Shrub Tundra Cotton grass (*Eriophorum*) Sedge (*Carex*) Mountain-Avens (*Dryas*) Grasses (*Poa*, *Arctagrostis*) Moist Tussock Sedge, Dwarf Shrub Tundra Cotton grass (*Eriophorum*) Mountain-Avens (*Dryas*) Willow (*Salix*) Moist Low Shrub Tundra Dwarf Birch (*Betula*) Willow (*Salix*) Blueberry/Cranberry (*Vaccinium*) Labrador-Tea (*Ledum*)	Wet Sedge Tundra Water sedge (*Carex aquatilis*) Arctic pendant grass (*Arctophila fulva*) Other sedges (*Carex*) Cottongrass (*Eriophorum*) Fisher's tundra grass (*Dupontia fisheri*) Wet Saline Graminoid Tundra Creeping alkali grass (*Puccinellia phryganodes*) Hoppner's sedge (*Carex subspathacea*) Scurvy-grass (*Cochlearia officinalis*)	Aquatic Tundra Water sedge (*Carex aquatilis*) Arctic pendant grass (*Arctophila fulva*) Mare's tail (*Hippuris*) Marsh-marigold (*Caltha palustris*) Marsh cinquefoil (*Potentilla palustris*) Buckbean (*Menyanthes trifoliata*)

Figure 11. Characteristic plant communities and associated species are listed for the four tundra types (based on Walker et al. 1980)

Aquatic Tundra

- Occurrence: Frequently forms marshes along the margins of ponds, lakes and streams, and may form a mosaic with wet tundra.
- Common Plants: Arctic pendant grass (*Arctophila fulva*), water sedge (C*arex aquatilis*), and mare's tail (*Hippuris* spp.).
- Soils: Thick layer of aquatic sediments and peat.
- Active Layer: Deep at maximum thaw (late summer). A thaw basin of unfrozen soil may be present in the vicinity of ponds, lakes, and streams.

Wet Tundra

- Occurrence: Where shallow (<1 ft) surface water persists through all or most of the growing season, in troughs, low centers of polygons, and in wet areas within drained lake basins. Wet tundra is the most common tundra type on the coastal plain. May form a mosaic with moist tundra where the soil is saturated but without standing water.
- Common Plants: Water sedge (*Carex aquatilis*), tall cottongrass (*Eriophorum angustifolium*), Fisher's tundra grass (*Dupontia fisheri*), and arctic pendant grass (*Arctophila fulva*).

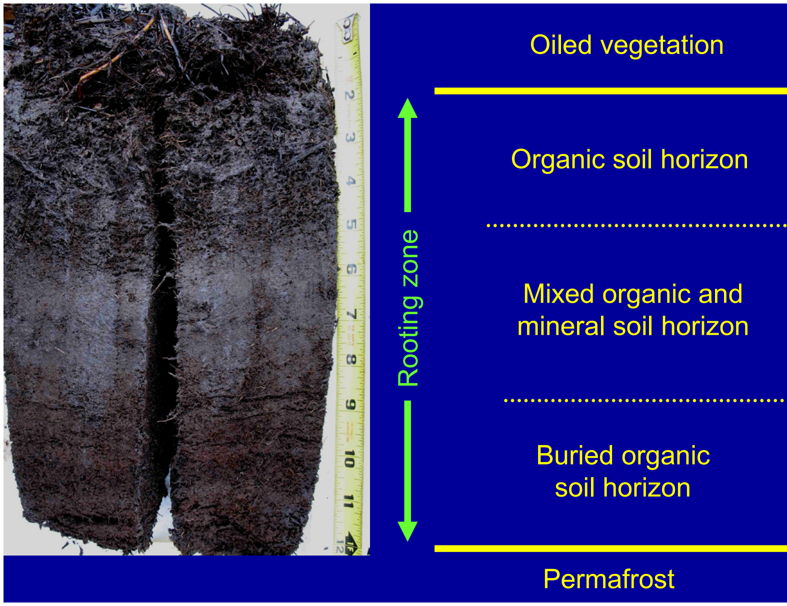


Figure 12. Typical soil profile in wet tundra

- Soils: A mat of roots and organic matter approximately 1 ft thick, underlain by mineral soils. The organic soil layer and rooting zone are thicker in wet tundra than in dry or moist tundra. Ponds and standing water are common within wet tundra areas, and soil pore spaces are saturated with water during the growing season.
- Active Layer: Moderate to deep at maximum thaw. The high thermal conductivity of water may thaw the top of permafrost in the summer despite the insulating effects of the highly organic root mat, especially if the surface has been physically disturbed. This active layer is often about 1 foot (12 inches) in depth (Fig. 12), but it may extend to about 3 feet below the tundra surface.

Moist Tundra

- Occurrence: Usually where the soil is saturated in a portion of the active layer throughout the growing season, but standing water is absent or present for only a part of the growing season. Areas of moist tundra on the North Slope include the slopes of hills, on high-centered polygons, and the rims of low-centered polygons.
- Common Plants: Sedges (*Carex aquatilis* and *C. bigelowii*), cottongrasses (*Eriophorum angustifolium* and *E. scheuchzeri*), and dwarf shrubs including willows (*Salix* spp.), birch (*Betula* spp.) and mountain-avens (*Dryas* spp.). Tussock tundra is a common type

of moist tundra on the North Slope, especially in the foothills. It is dominated by tussock cottongrass (*Eriophorum vaginatum*), dwarf shrubs, mosses, and lichens.

- Soils: A dense, compressed mat of roots and organic matter overlies mineral soils.
- Active Layer: Relatively thin due to the dense insulating organic mat and moderate soil moisture content.

Dry Tundra

- Occurrence: Where good drainage creates relatively dry soil conditions throughout the growing season. On the slopes of mountain ranges, on ridges and hilltops in foothills, stabilized sand dunes, pingos, and other well-drained sites on the coastal plain.
- Common Plants: Dwarf shrubs including birch, willow, mountain-avens, blueberry and cranberry (*Vaccinium* spp.), Labrador tea (*Ledum palustre* ssp. *decumbens*), crowberry (*Empetrum nigrum*), arctic bell-heather (*Cassiope tetragona*), and bearberry (*Arctostaphylos* spp.), along with lichens, mosses, forbs, and grasses.
- Soils: Thin root mat and low organic matter content compared to soils of moist and wet tundra. Ample drainage reduces the ability of the thin root mat to hold moisture.
- Active Layer: The active layer in dry tundra is usually comparable to wet and moist tundra but it can be as deep as 3 feet.

Sensitivity to Disturbance

Tundra environments can be especially sensitive to disturbance for several reasons:

- Permafrost
- Short growing season
- Extreme winter wind and low temperatures

The organic mat and soil insulate the permafrost layer from the sun and warm surface air during the growing season. Actively growing plants cool the soil by drawing water from the soil (evapotranspiration). Surface disturbances can interfere with these processes, causing ice in the soil to melt and resulting in subsidence (thermokarst). Drainage patterns are affected by subsidence, leading to further changes in topography and hydrology. For example, thermokarst in dry or moist tundra can lead to formation of wet or aquatic tundra in areas of pooling water, but thermokarst in wet tundra also can lead to drier conditions if conditions allow water to drain from the area.

Difficulty Treating Spills

Spills on tundra can be difficult to treat for several reasons:

- Short summer season (most treatments are more difficult to implement during winter).
- Low temperatures limit the rate of microbial breakdown of hydrocarbons (biodegradation).
- Remote locations present practical challenges for cleanup efforts.
- Patterned ground features or tussocks make treatment more complicated.
- Soils and vegetation may be physically damaged, which can impede achievement of the treatment goals.

P-3 Understanding the Effects of Spills on the Tundra

This tactic provides a brief description of some potential spill substances and their expected effects on tundra vegetation and soils. This planning tactic focuses on substances that are produced, extracted, or used in the production or extraction of oil and gas in Alaska's arctic oilfields, as well as substances produced by mineral mining operations in northwest Alaska. Substances of concern include crude oil, diesel fuel, gasoline, Therminol™, glycol (ethylene and propylene), methanol, drilling fluids and muds, produced water, seawater, acids, and metal ore concentrate. Spills in industrial settings commonly involve the release of more than one substance; a typical example would be a combined release of produced (saline) water and crude oil.

In tundra outside industrial development areas, spills of diesel, gasoline, and sewage are the main potential concerns. Spills of other substances would typically be small, and they would likely require the development of spill-specific treatment strategies.

In general, a rapid response to a spill will minimize the spread of contaminants across the tundra surface and the vertical migration of contaminants into the soil. Containment and product recovery generally must be completed as soon as possible after the spill. In winter, snow and ice help to contain contaminants and to minimize soil penetration.

Crude Oil

Crude oil contains thousands of organic and a few inorganic compounds, including natural gas, liquefied petroleum oils, resins, and asphaltenes. Hydrocarbons, which are composed only of carbon and hydrogen atoms, are the most abundant components of crude oil. Other components include sulfur, oxygen, nitrogen, and a variety of metals which are bound to organic compounds or exist as inorganic salts.

Crude oil can damage or kill plants in several ways. The light fractions are more volatile and consist of short-chain alkanes (i.e., saturates or paraffins) and aromatic (one or more rings of benzene) hydrocarbons.

Light fractions cause the most severe damage by penetrating and destroying plant tissues. Heavier fractions of crude oil can coat the surface of the leaves and interfere with the exchange of oxygen and carbon dioxide, which is necessary for plant survival.

Crude oil can damage vegetation indirectly by creating hydrophobic (unwettable) soil conditions, thereby reducing the supply of water to plant roots. Crude oil can also displace the air from pore spaces in dry or moist tundra, causing the soil to become anoxic and acutely toxic to plants and soil microbes.

Several factors influence the toxic and physical effects of crude oil on tundra vegetation, including the volume spilled (Table 1), the presence of snow or surface water, weathering, and soil properties. For example, if oil is perched on top of frozen or water-saturated soils, the more toxic aromatic fractions may evaporate without penetrating the soil. This is especially important for sedges and grasses because the buds that sprout new tissue lie below ground and can escape the most damaging components of crude oil if the oil remains on the surface (Walker et al. 1978). In general, shrubs, mosses and forbs have been shown to be more sensitive to crude oil than grasses and sedges (Walker et al. 1978; Jorgenson and Cater 1992a). Dry tundra is considered to be more susceptible to crude oil damage than moist or wet tundra because the aromatic fractions can be carried into the soil before they evaporate, damaging or killing roots and buds.

Diesel Fuel

Diesel fuel, also referred to as "middle distillate," is refined from crude oil and is composed primarily of hydrocarbons with 8 to 21 carbon atoms per molecule. Refined petroleum products, including diesel, are generally more toxic to plants, microbes, and animals than is crude oil. When diesel is spilled, the volatile components (aromatic hydrocarbons such as benzene) often evaporate, changing the chemical composition of the remaining fuel. Diesel will eventually mix with water in the soil or on the tundra surface, allowing it to migrate into the surface soil and root mat. Compounds such as polynuclear aromatic hydrocarbons (PAHs) may adhere to fine particles in tundra soil. Once attached, PAHs may persist for a long time because they are unavailable to soil microbes

*Table 1. Conversion factors for conducting rapid field assessments across 4 levels of oiling.**

Oiling Level	Field measurement of oil thickness on ground surface[a]		Equivalent surface oiling rate[b]				Percent of oil based on volume of soil		Percent of oil based on dry weight of soil[c]		Laboratory result for oil concentration (mg/kg, ppm)[d]	
	mm	Inches	Liters/ m^2	Gallons/ ft^2	Gallons/ acre	bbl/ acre	Oil infiltration depth[e]		Oil infiltration depth[e]		Oil infiltration depth	
							5 cm	10 cm	5 cm	10 cm	5 cm	10 cm
Heavy	10	3/8	10	0.25	11,000	250	20	10	44	22	440,000	220,000
Moderate	5	3/16	5	0.1	6,000	130	10	5	22	11	220,000	110,000
Light	1	1/16	1	0.02	1,000	25	2	1	4.4	2.2	44,000	22,000
Very light	0.1	<1/32	0.1	<0.02	100	3	0.2	0.1	0.44	0.22	4,400	2,200

[a] 1 inch = 25.4 mm = 2.54 cm; 1 cm = 0.4 inch

[b] 1 square meter = 10.76 square feet, 1 square foot = 0.09 square meters, 1 acre =43,560 ft^2, 1 acre = 4,047 m^2; 1 petroleum barrel (bbl) = 42 U.S. gallons, 1 Liter = 0.26 gallons, 1 gallon = 3.79 Liters

[c] Calculations based on soil bulk density of 0.4 g/cm^3 (25 lb/ft^3), which is representative of organic soil typically comprising the tundra surface. Bulk density of mineral soils (e.g., sand, silt, gravel) is > 1.0 g/cm^3

[d] 1 part per million (ppm) = 1 milligram per kilogram (mg/kg)

[e] The distance oil has penetrated the soil beneath the ground surface. Note the volume of spilled oil remains the same for both depths. 1 L = 0.001 m3, 1000 L = 1 m^3, Crude oil bulk density = 0.88 g/cm^3

* *How to use this table: Estimate the surface oiling rate at your site using field measurements of oil thickness on the ground surface. Estimate oil content in soil using field measurements of oil infiltration depth. Conversion factors for infiltration depths of 5 and 10 cm (2 and 4 inches) are provided to demonstrate that the same volume of oil is "diluted" by deeper infiltration. Both field measurements can be converted into oil content in soil based on either volume or dry weight of soil, and into estimates of oil concentrations from laboratory testing. For example, oil infiltration to a depth of 10 cm is equivalent to 1% of the soil volume, 2.2% of the soil weight, and a concentration of 22,000 mg/kg (dry weight basis). Calculations are based on a value of 0.4 g/cm^3 for the bulk density of soil, which is typical for organic tundra soils, and a bulk density of 0.88 g/L for crude oil.*

that degrade hydrocarbons. However, the attachment of PAH molecules by soil particles can reduce phytotoxicity by reducing contact between hydrocarbons and plant roots.

Direct exposure to diesel will kill leaves, and diesel can kill the entire plant if roots and buds are also exposed. As mentioned above (see Crude Oil), spills to dry or moist tundra are potentially more damaging than similar spills to wet tundra. This is partly due to protective effects of water-saturated soil, and partly to characteristics of the dominant plant growth forms in the different tundra types.

Gasoline

Gasoline is a volatile and highly flammable refined petroleum product that spreads rapidly to a thin sheen on water or wet soil. Evaporation rates are very high, as gasoline contains a larger percentage of volatile aromatic compounds than either diesel or crude oil.

Like diesel, gasoline is generally more damaging to vegetation, microbes, and animals than is crude oil. Direct contact of plant leaves, buds or roots with gasoline will often kill the entire plant. In wet tundra, saturated soil may initially provide some protection from gasoline spills, as mentioned above (Crude Oil). However, like diesel, gasoline will eventually mix with water, allowing it to migrate into the surface soil and root mat. Moist and dry tundra are highly susceptible to the effects of gasoline for the same reasons they are readily damaged by diesel spills—rapid penetration of the soil and trapping of the aromatic fractions in the rooting zone, where they can be toxic to vegetation. Many of the harmful aromatic fractions of gasoline, however, may evaporate before penetrating tundra soils. Due to a higher level of benzene, gasoline may result in RCRA waste generated from the cleanup that would need to be properly disposed.

Saline Waters and Substances

Seawater and brine are used on the North Slope as part of enhanced oil recovery processes and are transported by pipeline and truck. Produced water, a byproduct of oil and gas production, is generally separated from the oil stream and reinjected at well heads. The salt in seawater, brine, and produced water consists mainly of sodium chloride, which can negatively affect plant growth and survival at relatively low concentrations. These effects may be persistent since, unlike hydrocarbons, salts are not broken down by chemical or biological processes in soil. Low precipitation and hydrologic gradients typical of the North Slope may prevent salts from being flushed from soils as quickly as they would be in many other areas. Soil amendments (e.g., gypsum) may ameliorate the negative effects of salt spills (Tactic TR-13).

High levels of salts in soil increase the osmotic potential of soil water, making water uptake difficult for most tundra plants. Depending on salt concentrations, salt-affected vegetation may wilt, become discolored, drop leaves, or die within hours or days of contact with foliage or roots (Barker 1985). Jorgenson et al. (1987) found that damage to tundra vegetation was absent at soil salinity levels below 2–3 mmhos/cm, moderate between 2–3 and 6–10 mmhos/cm, and severe above 6–10 mmhos/cm. Conductivity meters usually display results in microSiemens/cm (μS/cm), or in milliSiemens (mS/cm). Another unit, the "mhos" is often used in the United States. Fortunately, 1 mhos = 1 S, and 1 μmhos/cm = 1μS/cm (see Tactic AM-5 for more conversion factors for EC measurements).

Simmons et al. (1983) made controlled releases of seawater to tundra at 8 sites in the Prudhoe Bay, Alaska area. They found that wet tundra was affected much less than moist and dry tundra, reflecting different physiological tolerances of the dominant species, as well as the dilution of salts in soils with high water content. Many spills involve mixtures of crude oil and saline water, and initial cleanup efforts usually emphasize recovery of the crude oil. However, salts can also be harmful to vegetation at relatively low concentrations, and the effects are usually longer lasting since salts are not broken down in soil. Some recent spill responses have focused on the simultaneous recovery of both contaminants.

Drilling Mud and Fluids

Drilling muds and fluids are generally variable and complex mixtures designed to meet oil-well drilling needs. Many current mixtures are water-based, and often contain bentonite clay (barium sulfate), and saline substances (e.g., potassium chloride). Mixtures may also be oil-based, which often include denatured diesel fuel (i.e., mineral oil). Drilling mud spills often include varying amounts of crude oil and saline water. Drilling muds and fluids can affect tundra plants by changing soil salinity and alkalinity, as well as smothering due to burial.

Synthetic Fluids

Methanol. Also known as wood alcohol or methyl alcohol, methanol is a highly flammable, volatile solvent used in oilfield operations. Methanol is a clear, colorless liquid with a pungent odor, and is completely soluble in water. Methanol evaporates quickly from soil and water when exposed to air. This chemical is highly toxic to wildlife, but its toxicity to plants is not well known.

Glycols. Ethylene and propylene glycol are synthetic liquids that mix with water. They are used as antifreeze for vehicles, in heating systems, and in industrial applications. Glycols are clear, odorless liquids that mix completely with water and have low vapor pressures. Abiotic transformations in soil or water are not significant except that glycols are subject to photo-oxidation by the sun. Little information is available on the toxicity of glycols to plants. Ethylene glycol is highly toxic to animals, so initial responses to spills of this compound should focus on containment and wildlife protection, followed by recovery.

Therminol. An insoluble organic liquid commonly used as a heat transfer fluid for pump stations and well houses. In its raw form, it is a clear yellow liquid with a mild hydrocarbon odor and is viscous even at below-freezing temperatures. Little is known about the environmental toxicity of therminol, but test results suggest that it is resistant to biodegradation (Solutia SDS).

Ore Concentrate

Ore concentrate is a powder-like substance produced from the mining and milling of ore containing metals (e.g., lead sulfide, zinc sulfide, and cadmium). Spills of ore concentrate typically occur when a haul truck accidentally leaves the road and ore concentrate is deposited on the tundra surface. The water-based tactics in this manual should not be used at an ore concentrate spill because this substance is 5 times denser than water and does not float. Therefore, water-based tactics have the potential to spread the contamination. All the other tactics in this manual except TR-3 (bioremediation) are applicable to ore concentrate spills.

Ore concentrate can damage or kill plants by deep burial, and high concentrations of metals in the ore concentrate can be toxic to vegetation and wildlife. For all ore concentrate spills to date, vacuum removal was typically done first, but sometimes achieving DEC cleanup standards has required the removal of contaminated soil. As with any spill, removing soil to recover contamination should be limited when possible because it removes live plant materials (e.g., roots) that could revegetate the site.

P-4 Minimizing Physical Damage to Tundra

Cleanup of a spill on tundra almost inevitably results in some degree of physical damage, caused by one or more of the following:

- Repeatedly walking over the same area when the active layer of soil is thawed.
- Driving vehicles or heavy equipment on tundra when the active layer of soil is thawed.
- Repeatedly driving vehicles or heavy equipment over the same area at any time.
- Excavating (Tactic CR-13), trimming (Tactic CR-12) or trenching (Tactic CR-9).
- Using high-pressure or hot water to flood (Tactic CR-7) or flush (Tactic CR-8).
- Injuring the root mat while burning (Tactic CR-10) or scraping (Tactic CR-12), especially when the soil is very dry.

Vehicle and foot traffic over thawed tundra can destroy vegetation and permanently compress organic soils. These ruts or compressed areas may change site drainage patterns, causing drying of some areas and inundation of others. Damage to vegetation and compression or removal of organic soils may reduce their insulating effects on the tundra surface, which can cause underlying permafrost to thaw and the soil to subside (thermokarst). Thermokarst can change dry or moist tundra to wet or aquatic tundra by creating depressions that fill with water. Once the thermal regime and drainage of an area are disturbed, the changes may be essentially permanent.

Traffic on wet tundra during summer can result in a disturbance that is highly visible, because vegetation and soil are compressed and the tracks fill with water. However, the wetland sedges that dominate wet tundra vegetation often recover rapidly from mild to moderate disturbance. The main concern with summer travel on wet tundra is the relatively high potential for vehicles to become stuck, which may result in more substantial damage that requires treatment. Traffic on dry tundra may appear to cause less damage because there are fewer plants and no standing water, but the physical effects are likely to persist for longer than in wet tundra.

In order to minimize physical damage to tundra during spill cleanup:

- Limit foot and vehicle travel on tundra as much as possible.
- Avoid following the same path repeatedly (enter and exit the site from different paths, if possible).
- Use existing roads (gravel, peat, or snow) as much as possible.
- Use snow ramps to access tundra from gravel roads and pads.
- Use existing gravel and ice pads for staging where possible.
- Use plywood or interconnecting rig mats as boardwalks or working platforms for light equipment (Fig. 13).
- Use snowshoes when repeated trips on foot cannot be avoided.
- Limit use of invasive treatment tactics (e.g., soil trimming) as much as possible.
- Replace displaced tundra sod back into original divot, or transplant tundra sod (Tactic TR-10) to replace soil and vegetation that have been removed.
- Restore natural contours and drainage by filling excavations.

Figure 13. Using plywood to avoid trampling

Considerations and Limitations

- Boardwalks should be light enough to be moved manually, so they can be easily moved around the site as needed (Fig. 14).
- If treatment tactics require heavy equipment, tundra travel permits, proper road construction, or use of rig mats may be required (Tactic P-5).

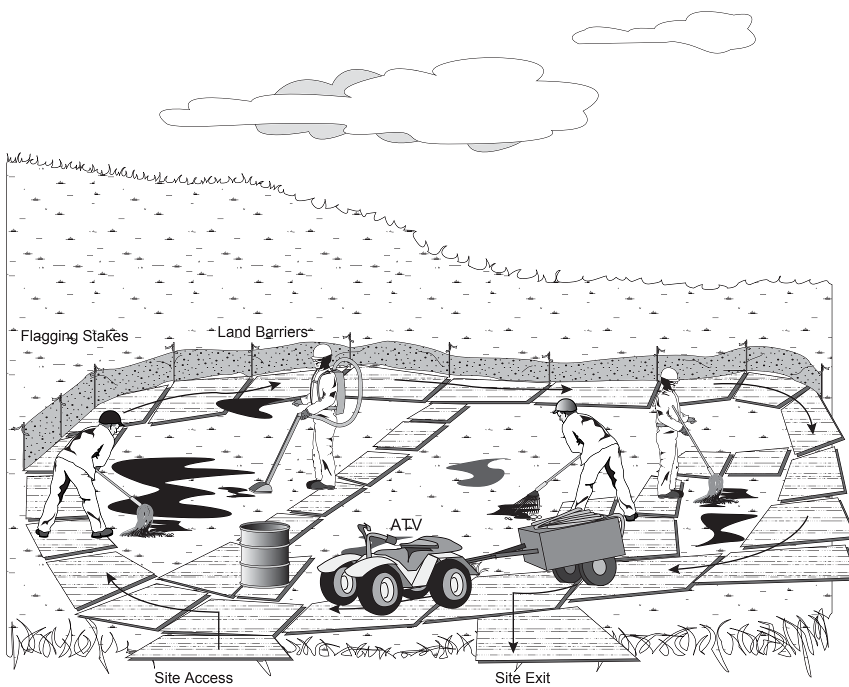


Figure 14. Typical layout of plywood and equipment

P-5 Tundra Travel

Tundra travel permits may be required for vehicles traveling off-road in many areas. Industry operators often have tundra travel permits in place. If no permits are in place, work through the Unified Command and/or contact the appropriate landowners and agencies to identify the plans or permits that are required.

For state-owned land on the North Slope, the Alaska Department of Natural Resources, Division of Mining, Land and Water (DNR) requires a permit for any vehicle traveling on tundra during any season (https://dnr.alaska.gov/mlw/tundra-travel/). Permits are issued for either summer tundra travel (July 15 until freeze-up), winter tundra travel (freeze-up until breakup), or both. No off-road travel is permitted during the period from breakup until July 15 except for true emergencies.

Winter Tundra Travel

Spill responders should follow the guidelines provided by DNR for tundra travel. Because cleanup efforts may require the use of heavy equipment when these conditions are not met, this manual provides additional information to help responders minimize tundra damage (see Tactic P-4 and Tactic AM-3).

In Alaska, tundra is generally open to off-road travel when the ground is frozen to a depth of 12 inches and when there is at least 6 inches of snow on the ground. DNR has developed recommendations for winter tundra travel based on experimental data that separate tundra into two distinct geographical areas (Coastal and Foothill Areas, see Figure 4 in (Tactic P-2). The regulations may be changed to allow travel on tundra when soil temperatures are colder than or equal to –5 degrees C (23.1 degrees F) at a depth of 12 inches (30 cm) below the surface, and when at least 6 inches (15 cm) of snow is present in the Coastal Area and at least 9 inches (23 cm) of cover snow is present in the Foothills Area. The date of tundra opening on the North Slope has ranged from as early as November 4 to as late as January 25. Once the tundra has been opened for winter travel, there are no restrictions on the types of vehicles that may operate on the tundra. In years of limited snowfall, tundra travel may be opened conditionally, with the stipulation that vehicles are restricted to areas where sufficient snow has drifted to prevent damage to the tundra vegetation.

Winter tundra travel on the North Slope is closed when it appears that the snowpack is no longer sufficient to allow travel without damaging vegetation. Operators must move vehicles and other equipment off the tundra within 72 hours after winter tundra travel is closed.

Summer Tundra Travel

See DNR guidelines for complete listing of travel requirements. A variety of vehicles have been tested and approved by DNR for summer tundra travel. Some of these vehicles are listed below. Consult the DNR website for a complete listing of approved vehicles.

- Argo 8 I/C with smooth tracks
- Roller-driven vehicles equipped with large, bag-type tires (e.g., Rolligon or Rimpull)
- Haggland Bearcat with smooth track configuration
- Tucker-Terra Sno-Cat model 1600 with smooth track configuration

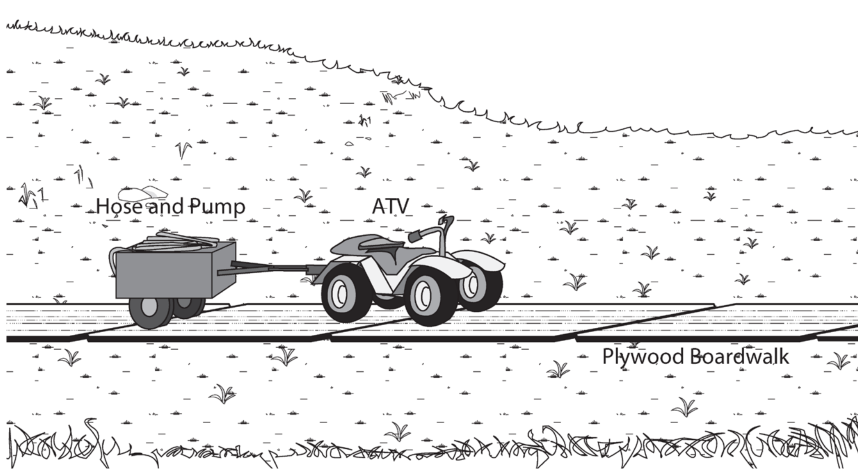


Figure 15. Using 4-wheel all-terrain vehicle on plywood

- Polaris Ranger 800 with 6×6 configuration and smooth tires
- Airboats (for use in spill drills and exercises only)

In addition, DNR can issue a permit approving summer use of 4-wheel all-terrain vehicles on boardwalks placed on the tundra (Fig.15) (Tactic P-4). Use of heavy equipment or airboats to respond to a spill on tundra during summer months is permitted on a case-by-case basis.

Vehicles are tested to determine whether they can operate on the tundra during summer without causing extensive tundra damage (Fig.16). Approvals are only for the configuration tested; for example, a vehicle tested with a payload of 1,000 pounds is limited to that payload when operating on the tundra. A vehicle tested and approved with smooth tracks would require retesting before it could be operated with cleats or wheels.

The following stipulations apply to all summer tundra vehicles operating on state land:

- Operations are restricted to drier areas whenever possible.
- Crossing deep water or vegetation with more than 2–3 inches of standing water shall be avoided if possible.
- Crossing ponds, lakes, or the wetlands immediately bordering these areas is not authorized.

Figure 16. Vehicle designed for tundra travel in summer

- Minimum-radius turns with sharp articulations shall be avoided where possible.
- Multiple passes over the same area shall be kept to a minimum.
- All operators shall be made familiar with tundra vegetation types to ensure compliance with these stipulations.
- The state reserves the right to limit, restrict, or require retesting of vehicles at any time.
- Incidents of damage to the vegetative mat and follow-up corrective actions that have occurred shall be reported to the DNR Northern Region Lands Office within 72 hours of occurrence.
- Vehicles cannot carry more payload than was carried during the certification test.

Considerations and Limitations

- Other regulations or required permissions may apply for travel on lands managed or owned by local government organizations (e.g., North Slope Borough), federal agencies (e.g., Bureau of Land Management or National Park Service), or private landowners.

Contaminant Recovery Tactics

CR-1 Sorbents

Sorbents can be used to pick up spill residuals from tundra and to prevent movement of hydrocarbons into clean areas. Use sorbents if water is not available for flooding or flushing, or if the topography of the site prevents the effective use of booms to contain flooding or flushing water. The choice of which sorbent material to use depends on the substance spilled, season, and availability. The use of sorbents can be labor-intensive compared to other cleanup techniques. Deploying and recovering sorbent material can result in physical damage to tundra; this risk must be carefully weighed against the benefits of removing the residuals. Some examples of sorbent materials include:

- Polypropylene sorbents (pads and boom material) (Figs. 17, 18, and 19)
- Snow (Figs. 20 and 21)
- Granular sorbents (e.g., sawdust or commercially available products)
- Straw
- Pom Poms

Use polypropylene sorbents on crude oil or oil-based substances directly on the tundra surface, or on heavy sheen on standing water in wet or moist tundra or impoundments. A polypropylene sorbent boom can be fixed in position with stakes or fencing to collect floating product in aquatic or wet tundra, or to prevent floating product from moving off site. Sorbent wringers can be used to extend the life of fibrous polypropylene sorbents.

Snow is an effective and readily available sorbent for recovering residues from the tundra surface in winter. Apply snow, recover the snow/residue mixture using hand tools or heavy equipment (Tactic CR-3) and remove for disposal. Other adsorptive materials like granular sorbents or straw may be used if snow is not available.

Considerations and Limitations

- Polypropylene sorbents are not effective for non-hydrocarbon spills (e.g., drilling muds or produced water), and are much less effective after surfactants (Tactic CR-8) have been applied.

Figure 17. Sausage booms for containing floating oil

Figure 18. Sorbent sheets used to recover oil

Figure 19. Sorbent used to prevent spread of contaminants

Figure 20. Snow after being used as a sorbent

Figure 21. Using snow as a sorbent

- Polypropylene sorbents work well on fresh crude, light refined oils, and thick petroleum sheens, but are only partially effective on solidified or weathered oil, highly viscous oil, very thin sheens, or emulsified oil.
- Snow, granular sorbents, and straw are not effective for spill residue floating on water.
- The use of sorbents generates a large amount of waste that requires proper disposal.
- Prolonged use of sorbents on dry tundra may be counterproductive if it requires repeated foot traffic across the site, which can permanently compress organic soils and destroy vegetation (see Tactic P-4).
- This tactic has been adapted from Tactics R-2, R-8, and R-9 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

NOTE: Personnel typically work in pairs for sorbent deployment and recovery.

- *Appropriate sorbent material* – to collect spill residue.
- *Stakes or fencing* – to secure sorbent boom to create a sorbent fence.
- *Shovels, rakes, pitchforks* – for application and removal of sorbents.
- *Plastic bags or disposal drums* – for collection of saturated sorbents.
- *Vehicle approved for tundra travel (optional)* – to collect and transport saturated sorbent materials.

CR-2 Manual Removal

Manual removal of spill residue may include collecting spilled substances or contaminated debris with rakes, mops, pitchforks, trowels, shovels (Fig. 22), buckets, portable vacuum systems (Figs. 23 and 24), and/or sorbent materials (Tactic CR-1). Contaminated material can be placed directly in plastic bags or drums for transfer. If the containers are to be carried to temporary storage areas, their weight should be limited to what one person can safely carry.

A rubber squeegee (or similar tool) can be used to gently compress and agitate the tundra surface, to squeeze contaminants out of pore spaces of the organic layer. Compression and agitation may be used in conjunction with flooding (Tactic CR-7) or flushing (Tactic CR-8) to enhance recovery of spill residue.

During manual removal activities, avoid damaging plant roots and uncontaminated vegetation. The potential for physical damage to the tundra must be carefully weighed against the benefits of removing additional spill residuals. Workers should be provided with clear

Figure 22. Shoveling contaminated gravel

Figure 23. Vacuuming liquid contaminant

guidelines that will allow them to decide when to discontinue manual removal.

Considerations and Limitations

- Take proper precautions to protect tundra from foot and vehicle traffic (Tactic P-4).
- Manual removal is not useful for some non-hydrocarbon spills such as seawater.
- This tactic has been adapted from Tactics R-2 and SH-2 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Rake* (1 per worker) – recovery.
- *Mop* (1 per worker) – recovery.
- *Squeegee* (1 per worker) – agitation.
- *Portable vacuum system* (1 operator) – to recover spilled material.
- *Portable generator* (1 operator) – to power vacuum system.

Figure 24. Vacuuming drilling mud

CR-3 Snow Management

Moving snow onto or off a site may be useful for a variety of reasons:

- Snow can be used as a sorbent to recover spill residue (Tactic CR-1).
- Snow can be placed on a site to reduce desiccation during winter (i.e., freeze-drying), prevent early sprouting in spring, and/or hydrate plants during the growing season (Tactic TR-4).
- Snow can be removed from a site so that contaminated vegetation and soil may be scraped (Tactic CR-12).
- Snow can be removed from a site in spring to allow an earlier start to the growing season (Tactic TR-2).

Snow can be handled with heavy equipment or by hand. Snow can be scraped into piles by a dozer (Figs. 25 and 26) and transferred to dump trucks using a front-end loader. A loader with an extension (e.g., push blade in Fig. 27) may be needed to push snow beneath pipes. Manual handling of snow is recommended when working in congested areas, on uneven ground where heavy equipment is likely to scrape high spots, or when there is insufficient snow cover to prevent heavy equipment from damaging the tundra. If the snow is contaminated with spill residue, it must be stored in an approved containment area and proper disposal must be arranged. If the snow is not contaminated, it may be stockpiled

Figure 25. Removing snow in spring

Figure 26. Snow removed to excavate contaminated soil

nearby or used to build a snow berm to isolate the site during spring snow melt (Tactic CR-3).

Move the snow into piles or windrows using brooms, shovels, or heavy equipment. Transfer the piles to garbage cans, totes, or similar containers. Once a container is full, use a snow machine or Argo to transfer it to a stockpile or a truck on a pad or road (Fig. 28).

Considerations and Limitations

- Avoid stockpiling clean snow on contaminated areas because the snow could persist into the growing season and inhibit vegetation recovery.
- Avoid stockpiling contaminated snow on clean areas to prevent spread of contamination.
- Use of vehicles on tundra must comply with applicable tundra travel policies (Tactic P-5).
- Topographic relief (e.g., tussocks, patterned ground) may preclude use of heavy equipment, because high spots are easily scraped.
- Install a snow fence to prevent snow from accumulating on the site. Alternatively, a snow fence can be installed to promote the accumulation of snow on the site. The effect of the snow fence will be dependent on location, proximity to the site, and the direction of prevailing winds.
- Maintain sufficient snow coverage around the site to prevent damage by supporting operations.

Figure 27. Loader extension pushing material

Figure 28. Removing snow piles

- This tactic has been adapted from Tactics R-2 and R-3 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Snow shovels and brooms (1 worker per tool)* – for manual snow removal.
- *Garbage cans or totes (1 or more workers per container, depending on weight of container)* – to carry snow to trailer.
- *Snowmachine or Argo with trailer (1 operator)* – to transport collected snow or containers.
- *Challenger (1 operator)* – to scrape snow into piles for removal.
- *Front-end loader with bucket (1 operator)* – to transfer snow to dump truck.
- *Push blade attachment for loader (1 operator)* – to allow heavy equipment to push snow beneath above-ground pipes.
- *Dump truck (1 operator)* – to transport snow for storage or disposal.
- *Use a spotter for each piece of heavy equipment* – when working in areas with above-ground infrastructure or other obstacles.

CR-4 Drainage Protection

Drainage protection is used to keep contaminants from moving off site. It may be needed during spring breakup and summer when contaminants are mobilized and water is flowing through culverts, or while using treatment tactics such as flooding (Tactic CR-7) or flushing (Tactic CR-8).

A culvert can be blocked using sheet metal, plywood barriers, inflatable culvert plugs, or adjustable weirs (Fig. 29). Plywood or sandbags can also be used as culvert blocks but they require more labor to install. Place blocking materials over the upstream end of the culvert. Plastic sheeting over the outside of the block will decrease the likelihood of water leaking through the block. Block water flow through a culvert only if the impounded water will not threaten the road or raise water levels sufficiently so that additional tundra becomes contaminated.

If blocking a culvert is likely to damage a road or flood uncontaminated areas, a boom may be deployed in a chevron or diversionary configuration, allowing water to flow while deflecting oil from the mouth of the culvert to collection sites along the road (Fig. 30). This technique is especially useful when there is sheet flow of water across the frozen tundra. Boom systems will not provide drainage protection from water-soluble contaminants.

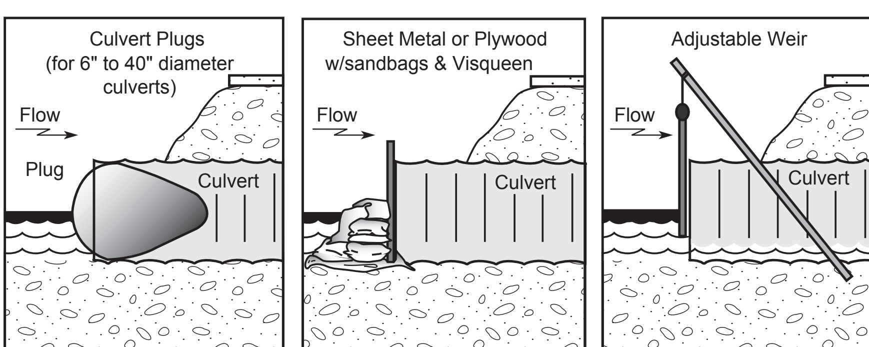


Figure 29. Blocking of culverts

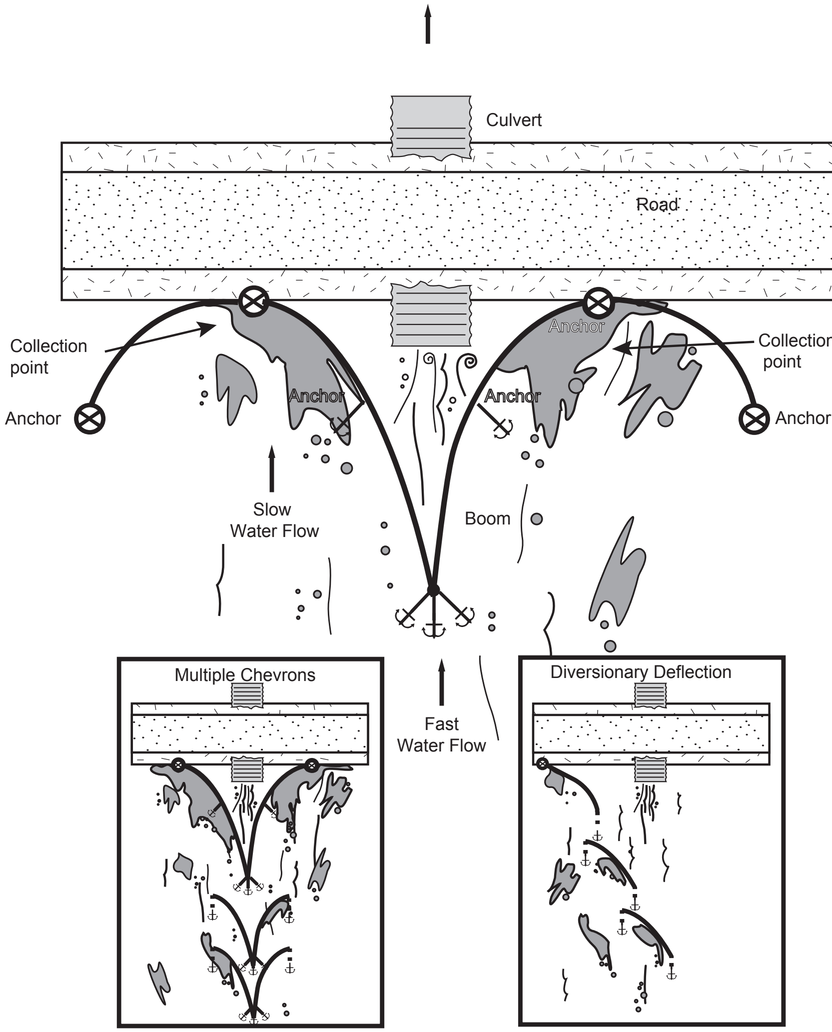


Figure 30. Boom deployed upstream of culvert

Considerations and Limitations

- Culverts should be unblocked when spill response is complete, to avoid impounding water and possibly washing out the road.
- This tactic has been adapted from Tactics C-2 and C-3 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Boom* (2 workers) – to deflect floating contaminants from culvert.
- *Anchor system* (2 workers) – to secure boom system.
- *Visqueen* (2 workers) – to prevent seepage through permeable culvert blocks.
- *Inflatable culvert plug* (2 workers) – to block culvert.
- *Air compressor* (1 worker) – to inflate culvert plug.
- *Sheet metal or plywood barriers* (2 workers) – to block culvert.
- *Sandbags* (2 workers) – to block culvert.
- *Flatbed truck* (1 worker) – to transport sandbags.
- *Front-end loader* (1 worker) – to unload sandbags.

CR-5 Land Barriers

Land barriers can be used for the following purposes:

- Contain and limit further spreading of contaminants (Tactic CR-4).
- Contain water used during flooding (Tactic CR-7) or flushing (Tactic CR-8).
- Augment a natural depression or a trench to act as a containment area for recovery (Tactic CR-9).
- Prevent water from flowing onto a site during draining (Tactic TR-1).

Land barriers can be constructed using sand bags (Fig. 31), shore sealing boom (Fig. 32), large diameter hoses filled with water, sheet piling (Fig. 33), and mixtures of snow and ice (Fig. 34). Berms of tundra soil and gravel may also be used, but these are less desirable because they create additional disturbances. The type of barrier chosen depends on the site topography, tundra type, and treatment strategy. When flooding an area, it must be enclosed completely so that the water level can be raised above the ground surface and the floating hydrocarbons recovered. When using a barrier to prevent contaminants from spreading, form the barrier materials into a horseshoe shape to collect contaminants downslope of the flow. To capture flooding or flushing water for recovery, use barriers to augment a natural depression or a trench and to direct water toward the containment area.

Water-soluble substances can infiltrate soil and move horizontally below the surface in all tundra types, thus subsurface barriers (e.g., sheet piling) may be needed to prevent subsurface movement (Fig. 33).

Figure 31. Sand bags

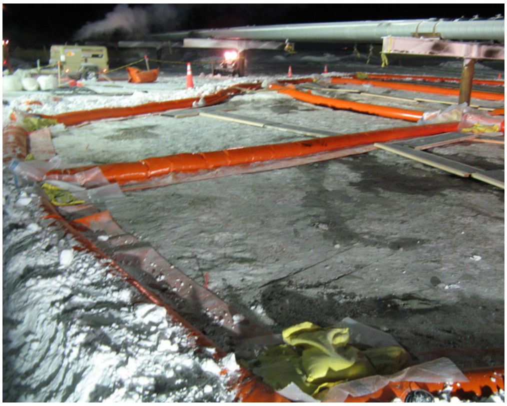


Figure 32. Shore sealing boom

Figure 33. Sheet piling

Figure 34. Constructing a snow and ice berm

Considerations and Limitations

- Hydrocarbons will tend to float on wet and moist tundra but will infiltrate soil in dry tundra.
- Use of vehicles on tundra must comply with applicable tundra travel policies (Tactic P-5).
- Proper disposal of the materials used to construct barriers should be considered during the planning phase.
- Shore seal boom is effective if frozen in place, but reinforcement with sandbags or ice berms is needed on both sides where the boom crosses troughs or other low spots.
- Limit foot traffic to land barriers when possible, to avoid damaging tundra.
- All land barrier techniques (except sheet piling) described in this tactic have been adapted from Tactic C-4 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Appropriate boom material* (2 to 5 workers, depending on site) – to construct land barriers.
- *Dump truck* (1 operator) – to transport clean, approved backfill material to spill site (Tactic TR-12).
- *Backhoe* (1 operator) – to build gravel or tundra berm.
- *Bobcat loader* (1 operator) – to push snow into berm.
- *Water source (1 operator)* – to turn snow berms into ice berms.
- *Front-end loader with bucket* (1 operator) – *t*o move gravel or sand bags.
- *Floating pump and blower* (2 operators) – to fill shore seal boom with air/water.
- *Visqueen or similar heavy plastic sheeting* – to line gravel or tundra berms.
- *Sledge hammer* – to install sheet piling.

CR-6 Recovery with Skimmers and Pumps

Use skimmers (Figs. 35–37) to recover hydrocarbons floating on the water surface. A variety of skimmers are available that are designed for different situations. The choice of skimmer to use is dependent on factors such as the thickness of the floating hydrocarbon layer, the depth of water, the degree of weathering of the hydrocarbon, and whether it has been treated with surfactant. Skimmers are most effective when the floating hydrocarbon is concentrated in a thick layer. Position the skimmer in the area of heaviest concentration of spill residue. A skimmer requires a power pack; a pump with suction and discharge hoses and fittings; and a storage container or portable tank for recovered product.

At a spill site adjacent to a road or pad, a vacuum truck can be used to drain an area (Tactic TR-1) or to recover pooled spills (Figs. 38–39), flood water (Tactic CR-7) or flush water (Tactic CR-8) from natural depressions, land barrier containment (Tactic CR-5), or trenches (Tactic CR-9). The effective range of a vacuum truck is approximately 200 feet when removing viscous liquids such as crude oil, and 400 feet when removing diesel or water. A Super Sucker can be used for direct suction to remove liquids combined with solids (e.g., gravel and ore concentrate) that vacuum trucks cannot process (Fig. 40).

Figure 35. Skimming floating oil with slurper skimmer. Inset: Close-up view of slurper skimmer

Figure 36. Manta ray skimmer in use and close-up view (inset)

Figure 37. Rope mop in wet sedge tundra

Figure 38. Vacuum hose recovering oil from low spot

Figure 39. Super sucker

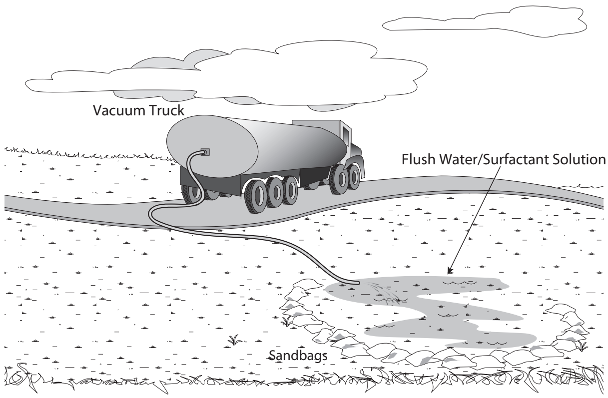


Figure 40. Vacuum truck

Submersible pumps or trash pumps can be used to pump areas that are not accessible by vacuum truck or Super Sucker. Submerge the pump or intake hose in the deepest area of an impoundment. Make sure the pump intake or hose end is fitted with a screen to prevent vegetation from clogging the intake hose.

Considerations and Limitations

- Identify the disposal method or facility to be used and estimate the volume of liquid requiring disposal before skimming or pumping fluids from a spill site.
- Identify the flash points of fluids being recovered.
- Consider ambient temperature during winter when selecting length and diameter of hoses to minimize the risk of fluids freezing in the hoses.
- This tactic has been adapted from Tactics R-6 and R-8 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Any shallow draft skimmer* (e.g., rope mop or Manta ray) (usually 2 operators to deploy and maintain) – to remove floating product.
- *Manta ray skimmer* (1 or 2 operators to deploy and maintain) – to remove floating product.
- *Power pack* – to provide a power source for skimmer.
- *Pumps and hose* (2 operators to deploy and maintain) – to suction product from site.
- *Portable tank, tanker truck or storage container* – for recovered fluids (1 operator).

CR-7 Flooding

The use of flooding with clean water depends on the nature of the spilled substance:

- *Crude Oil and Diesel:* Flooding raises or maintains the water level on the tundra surface, reducing the contact of oil with vegetation and making the use of skimmers (Tactic CR-6) or sorbents (Tactic CR-1) more effective (Fig. 41). In dry tundra, flooding also fills pore spaces in the root mat or soil with water, reducing the amount of oil that can infiltrate. Repeated flooding, followed by removal of the floating oil, can greatly increase recovery of hydrocarbons.
- *Water-Soluble Substances (salts, methanol, glycol):* Flooding reduces toxicity by diluting the contaminants. The diluted contaminants can then be recovered by pumping (Tactic CR-6). This process can be repeated as needed.
- *Flooding should not be used for ore concentrate spills because ore concentrate does not float.* The density of ore concentrate is approximately 5 times that of water, rendering flooding ineffective.

Flooding and flushing (Tactic CR-8) are similar approaches. The potential for erosion is the primary factor to assess when choosing which of these two tactics to use. Use flooding when the potential for erosion is moderate or higher and use flushing when the potential for erosion is low.

Most sites should be divided into several cells that are small enough to manage efficiently (Fig. 42). Water pressure and flow rate should

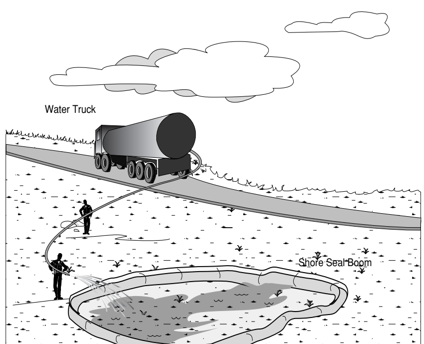


Figure 41. Typical site layout

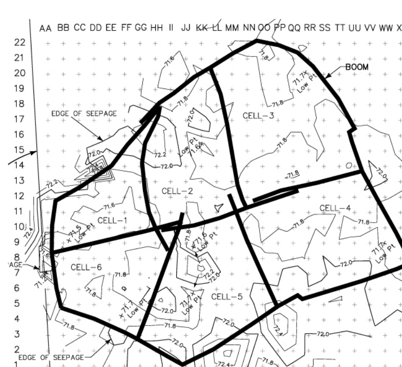


Figure 42. Treatment cells, grid layout, topography

Figure 43. Manta ray skimmer used as inlet hose to prevent erosion

be kept low to minimize erosion; using a velocity dissipation device to diffuse the input of water works well (Fig. 43). Move the input hose periodically to prevent erosion. Water may be pumped from a nearby lake, pond, or creek, or water can be transported to the site using trucks with clean tanks. Do not use seawater or produced water to flood tundra vegetation. Land barriers (Tactic CR-5) are needed to contain water on site (Fig. 44), especially during snowmelt (Fig. 45). In summer, flood with cold or warm water. Hotter water will be needed during winter to allow recovery before the water freezes. Snow melters can generate very hot water (up to 180°F) and may be the best choice during winter at remote sites with no road access if the volume of water produced is sufficient. In winter, water can be hauled to the site in heated or insulated tanks.

Surfactants reduce adhesion of crude oil and fuels to vegetation by increasing the ability of water to mix with hydrocarbons. The use of

Figure 44. Flooding tundra in winter

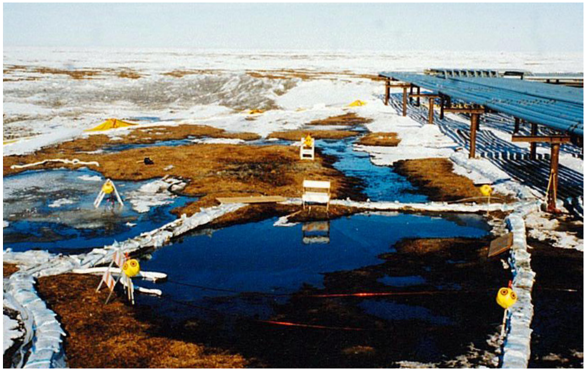


Figure 45. Land barriers to contain snow melt within cells

surfactants is not an expectation, is considered on a case-by-case basis, and is only applied with the proper approvals in place. Flooding with surfactants is appropriate for final cleanup of hydrocarbon spills after most of the spilled product has been removed (Fig. 44). Surfactants can be mixed with water in tanks or added to the stream of water flowing out of the input hoses. Dawn™ detergent is the recommended surfactant because it is not toxic to soil microbes at concentrations used during flushing (Jorgenson and Cater 1992a); it is commonly used for cleaning oiled wildlife because of its effectiveness and low toxicity (Hemenway 1990); and it is readily available. Apply Dawn™ at a 0.1% (by volume) concentration. Surfactants also decrease the ability of sorbent pads, booms, and skimmers to recover hydrocarbons, and should only be used after these methods are no longer needed.

Avoid thawing of frozen soil to the extent possible, to minimize infiltration of contaminants into the rooting zone, and exposure of dormant vegetation to freeze-thaw cycles.

Considerations and Limitations

- The flooding tactic should not be used for ore concentrate spills because ore concentrate does not float, rendering flooding ineffective.
- Maintaining a constant water level is important to prevent exposure of previously unaffected vegetation on higher areas (e.g., polygon rims) to floating or dissolved contaminants, as well as preventing repeated contact of oil with vegetation within the flooded area.

- Create a current in flood water or set-up petroleum collection downwind to remove floating hydrocarbons immediately.
- Surfactants decrease the ability of sorbent pads, booms, and skimmers to recover hydrocarbons, and are generally used during the final flooding, after most of the spilled product has been recovered.
- Surfactants can create enough suds to make operations difficult; add soap carefully.
- Surfactants are not effective for removing substances that mix with water (e.g., salts, glycol).
- Surfactant application is not an expectation. Its use should be considered on a case-by-case basis and applied with the proper approvals in place.
- Insulated water tanks lose heat at the rate of approximately 10°F every 12 hours.
- Ensure that land barriers (Tactic CR-5) are strong enough to contain water in the flooded area, and that the seal with the tundra surface will not leak.
- If ice berms are used as the land barrier, hot water may cause the berm to fail.
- Ensure water is free of hydrocarbons and salts before using it to flood tundra.
- Assess concentrations of contaminants in floodwater periodically using field screening techniques.
- Flood as few times as possible, to minimize physical damage to vegetation.
- Flooding is feasible during winter, but precautions for worker safety are necessary. Flooding may not be practical at extremely low temperatures.
- Protect tundra being flooded by walking on plywood boardwalks, sandbags, rig mats, etc.
- Flooding may also be used to irrigate (Tactic TR-4) a site during the growing season.
- This tactic has been adapted from Tactic R-4 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Water truck or upright tank (1 operator)* – to provide water source.

- *Pumps and suction and discharge hose (1 to 2 operators each)* – to pump water to and from site.
- *Land barriers (Tactic CR-5) (number of people needed is site-dependent)* – to contain water on site and to provide collection points.
- *Clean water* – not seawater or produced water.
- *Plywood, sandbags, or rig mats* – to prevent trampling.
- *Portable tank* – to collect used water.

CR-8 Flushing

Flushing with clean water is used to mobilize oil from ice (Fig. 46), vegetation, and the tundra surface. If necessary, gently agitate and compress the tundra surface with a rubber squeegee (Tactic CR-2) while directing water flow with the discharge hose. Agitation is most useful in wet tundra where the organic mat is relatively thick and resistant to erosion.

Flushing typically adds and removes water continuously. Keep water pressure and flow rate low enough to minimize erosion. Flush toward a collection area, such as a natural depression or a trench (Tactic CR-9) lined with plastic sheeting, where the oil can be recovered with direct suction (Tactic CR-6) or sorbents (Tactic CR-1). A land barrier (Tactic CR-5) is typically needed to contain fluids.

Flushing and flooding (Tactic CR-7) are similar approaches. The potential for erosion is the primary factor to assess when choosing which of these two tactics to use. Use flushing when the potential for erosion is low; use flooding when the potential for erosion is moderate or higher. Flushing should not be used for ore concentrate spills because ore concentrate does not float. The density of ore concentrate is approximately 5 times that of water, rendering flushing ineffective.

Figure 46. Flushing ice to mobilize oil

Water may be obtained from a nearby tundra pond or creek, or it can be transported to the site in trucks with clean tanks. Do not use seawater or produced water to flush tundra vegetation. Flushing water must be contained using land barriers (Tactic CR-5). In summer, flush with cold or warm water. Hotter water will be needed during winter to allow recovery before the water freezes. In winter, water can be hauled to the site in heated or insulated tanks. Snow melters can generate very hot water (up to 180°F) and may be the best choice during winter at remote sites with no road access, if the volume of water produced is sufficient.

Surfactants reduce adhesion of crude oil and fuels to vegetation by increasing the ability of water to mix with hydrocarbons. The use of surfactants is not an expectation and is to be considered on a case-by-case basis, applied only with proper approvals in place. Flushing with surfactants is appropriate for final cleanup of hydrocarbon spills after most of the spilled product has been removed (Fig. 47). Dawn™ detergent is the recommended surfactant because it is not toxic to soil microbes at concentrations used during flushing (Jorgenson and Cater 1992a); it is commonly used for cleaning oiled wildlife because of its effectiveness and low toxicity (Hemenway 1990); and it is readily

Figure 47. Flushing tundra with surfactants

available. Apply Dawn™ at a 0.1% (by volume) concentration. Surfactants also decrease the ability of sorbent pads, booms, and skimmers to recover hydrocarbons, and should only be used after these methods are no longer needed.

Surfactants can be mixed with water in tanks or added to the stream of water flowing out of the input hoses. Most sites should be divided into several cells that are small enough to manage efficiently (Fig. 48).

Avoid thawing of frozen soil to the extent possible, to minimize infiltration of contaminants into the rooting zone, and exposure of dormant vegetation to freeze-thaw cycles.

Considerations and Limitations

- Flushing should not be used for ore concentrate spills because ore concentrate does not float, rendering flushing ineffective.
- Accessing water from a near-by tundra pond or creek may require an authorization from Alaska Department of Natural Resources Division of Mining, Land, and Water
- Flush as few times as possible, to minimize physical damage to vegetation.
- Move the input hose periodically to minimize erosion.
- Surfactants are not effective for removing substances that mix with water (e.g., salts, glycol).
- Surfactant application is not an expectation. Its use should be considered on a case-by-case basis and applied with the proper approvals in place.
- Insulated water tanks lose heat at the rate of approximately 10°F every 12 hours.
- Ensure that land barriers (Tactic CR-5) are strong enough to contain water in the area being flushed, and that the seal with the tundra surface will not leak.
- If ice berms are used as the land barrier, hot water may cause the berm to fail.
- Skimmers and sorbents will not be effective after surfactants have been applied to the site.
- Protect tundra being flushed by walking on plywood boardwalks, sandbags, rig mats, etc.
- Ensure water is free of hydrocarbons and salts before using it to flush tundra.

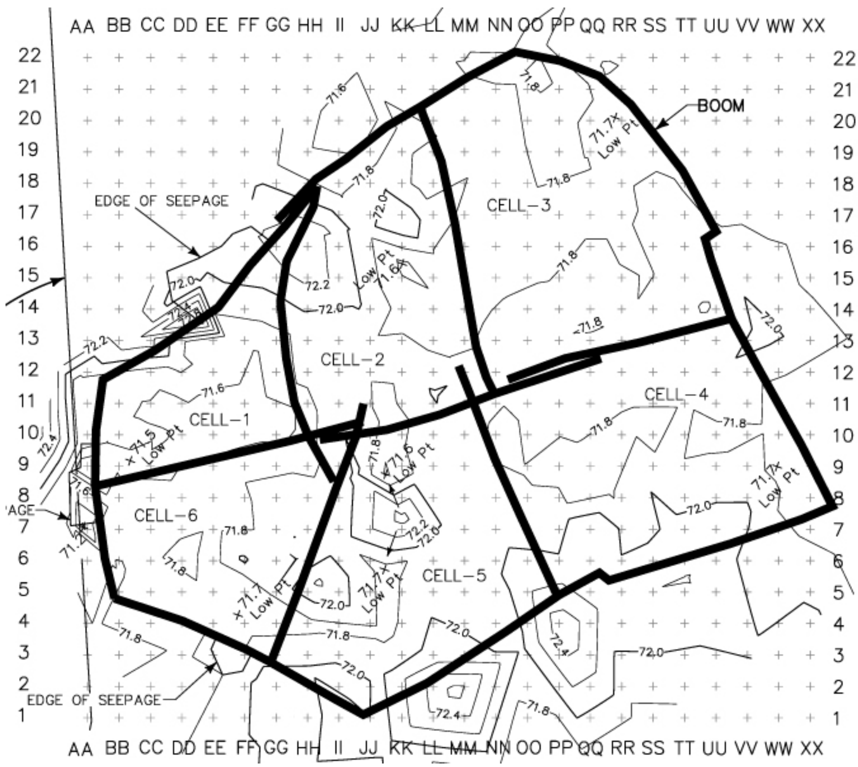


Figure 48. Site divided into 6 cells for treatment

- Flushing is feasible during winter, but precautions for worker safety are necessary. Flushing may not be practical at extremely low temperatures.
- This tactic has been adapted from Tactic R-4 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Water truck* (1 operator), tank, tundra pond or stream – to provide water source.
- *Clean water (not seawater or produced water)*
- *Surfactant* (Dawn™ detergent) – to enhance recovery of spill residue.
- *Trash pump* (1 to 2 operators each) – to pump water to and from site.
- *Suction hose* (1 operator) – to take up water from water source.

- *Discharge hose* (3- to 6-inch) with adjustable valve (1 operator) – to discharge water on site.
- *Mop, squeegee (1 operator)* – to agitate and gently compress tundra mat to release spill residue.
- *Land barriers (Tactic CR-5) (number of people needed is site-dependent)* – to contain water on site and to provide collection point.
- *Plywood, sandbags, or rig mats* – to prevent trampling.
- *Portable tank* – to capture used water.

CR-9 Trenching

Trenching is used to intercept the flow of a spilled substance, to divert a spilled substance around a sensitive area, or to capture and recover water used during flooding and flushing (Figs. 49 and 50). Examining the sidewall of a trench can help determine if spilled substances are moving below the ground surface (Fig. 51). Dig trenches by hand or using a trencher attached to a skid loader, tractor, or other type of heavy equipment.

Dig a trench or series of trenches at right angles to the flow, angled slightly downhill to avoid excessive pooling. Place the excavated material on the downhill side of the trenches. Line the sides and bottoms of trenches with plastic sheeting. A trench can be flooded with water to inhibit contaminant penetration and to promote flow toward a recovery device.

Digging trenches in tundra should be considered a last resort, if no other tactic is available to divert or capture water or contaminants. Do not excavate trenches in an area where the excavation will cause more damage than benefit. Excavating trenches in permafrost terrain will disrupt the thermal regime and cause thermal erosion (thermokarst). It may be necessary to backfill trenches (Tactic TR-12) to reestablish a stable thermal regime, and revegetation may be needed to meet rehabilitation goals for the site.

Considerations and Limitations

- Vehicle use on tundra must comply with applicable tundra travel policies (Tactic P-5).
- The Bobcat trimmer should be used for trenching only if no other options exist.
- It may be necessary to survey spot elevations before trenching, to ensure that fluids flow into the trenches.
- A permit may be needed from the landowner before trenching.
- Trenching in tundra should be considered a last resort. Trenching may lead to further disturbance if a natural stream, river, or swale intercepts the path of the trench.

Figure 49. Excavating trench in ice

Figure 50. Excavated trench

Figure 51. Oil exposed in sidewall of trench

This tactic has been adapted from Tactics R-7 and C-12 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Shovels* (1 worker per tool) – to hand dig trench.
- *Skid loader, or tractor with trenching attachment* (1 operator) – to dig trench.
- *Visqueen or similar heavy plastic sheeting* – to line trench.

CR-10 Burning Contaminated Vegetation

Burning is used primarily to volatilize and oxidize residual hydrocarbon contaminants from vegetation after other tactics have been used to recover most of the spilled substance. Burning is not an expectation, is considered on a case-by-case basis, and used only with proper permits in place. This tactic is especially useful for light oil coatings on leaves of sedges and grasses that are elevated above the tundra surface (Figs. 52–53). Burning was first tested on the North Slope in the late 1970's (Fig. 54). This tactic is not appropriate for removing pooled product from the ground surface. The relatively large amount of heat required to burn pooled product could 1) cause vertical migration of the substance into the rooting zone and 2) induce thermokarst in the underlying tundra soil.

Typically, one worker uses a metal rake to orient oiled leaves and stems more or less vertically. A second worker uses a weed burner, which consists of a flame nozzle, hosing, and a propane tank. The flame nozzle is held just above the contaminated vegetation until the vegetation is burned down to stubble. Burn residue can be recovered with hand tools, but the benefit of recovery should be carefully weighed against the potential for causing additional physical damage to the tundra.

The risk of damage from burning is relatively modest in moist and wet tundra dominated by sedges. Much of the biomass of these plants, including the buds from which new leaves sprout, is deep enough to be protected from the heat of the fire. Use additional caution in drier tundra where shrubs, mosses and lichens are abundant, as these growth forms have little or no ability to sprout from belowground parts.

Figure 52. Propane torch burning contaminted vegetation

Figure 53. Burning a thin layer of surface contamination

Considerations and Limitations

- Burning vegetation contaminated with weathered oil or fuel may produce an unburned residue that requires additional cleanup.

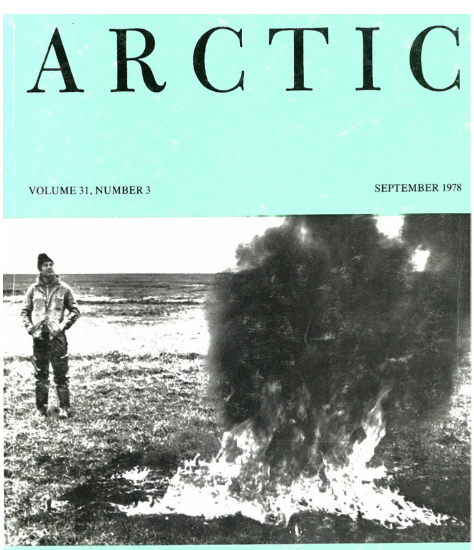


Figure 54. 1979 edition of Arctic

- Permission must be obtained from the DEC, which may require a Burn Plan and/or a DEC Division of Air Quality Black Smoke Permit.
- Permission must be coordinated with the landowner or land manager, who may require a permit.
- Burning as soon as possible after a spill will increase the likelihood of complete combustion because fewer of the volatile components (e.g., benzene) in the

spilled substance will have evaporated.

- Burning should be considered only when there is minimal risk that the fire will spread to unaffected areas. This consideration is especially important when dry sedge and grass leaves (i.e., dead plant litter) are present.
- Burning is not an expectation for a spill-site cleanup. Burning should be considered on a case-by-case basis and applied only after proper approvals are in place.
- Follow proper safety procedures and use personal protective equipment, as required.
- This tactic has been adapted from Tactics B-2 and SH-10 in the *Alaska Clean Seas Technical Manual*.

Equipment, Materials, and Personnel

- *Metal rake* (1 worker) – to orient oily vegetation.
- *Weed burner with propane tank* (1 operator) – to ignite spilled residue and vegetation.
- *Fire extinguisher* (1 operator) – to suppress unwanted fire.
- *Fans* (1 operator) – to increase burning efficiency (optional, if conditions are appropriate).

CR-11 Removing Contaminated Vegetation

Remove contaminated vegetation to prevent remobilization of spill residuals, and to promote recovery of the remaining live plant tissues. Only remove above ground vegetation that is dying or dead (Fig. 55). Avoid damaging plant roots to maximize sprouting of new shoots and leaves. Collect the trimmed material into bags by hand, raking, or shoveling, and remove from the site for proper disposal. Minimize contact between contaminated and uncontaminated vegetation.

Considerations and Limitations

- Place plywood on the ground to minimize trampling and shearing of roots.
- This tactic is less likely to cause physical damage when the ground is frozen, and vegetation is dormant.
- This tactic is labor-intensive and may not be suitable for large sites where site access would cause physical damage to areas unaffected by the spill.

Equipment, Materials, and Personnel

Note: Personnel typically work in pairs when cutting and trimming vegetation.

- *String or line trimmer* (1 operator) – to cut grasses and sedges (non-woody vegetation) on larger sites.
- *Scissors or knives* (1 worker) – to cut vegetation on smaller sites.
- *Hand clippers, pruners, or brush cutter* (1 worker) – to cut woody plant stems.
- *Rakes* (1 worker) – to collect clipped and cut plant materials.
- *Bags* – to collect cut leaves.
- *Cans* – to collect woody plants.

Figure 55. Trimming vegetation

CR-12 Mechanical Removal: Vacuuming, Scraping, Trimming, and Brushing

Use vacuuming, scraping, trimming, and brushing to recover contaminants on the tundra surface while leaving as much soil as possible, to preserve live buds, roots, and rhizomes (Figs. 56–60). Mechanical removal can be used while the ground is frozen or partially thawed. Trimmers are especially effective for breaking up contaminated ice and packed snow. Mechanical removal can also be effective in spring when air temperatures are still well below freezing, but solar heating is sufficient to thaw the surface soil after snow has been removed. Contaminants can be easier to see when soil is partially thawed (Figs. 61 and 62), and a spotter can direct the operator, but the depth of removal must be controlled carefully to minimize tundra damage. This tactic works best for viscous or dense substances, such as crude oil and ore concentrate, which tend to remain on the tundra surface rather than penetrating into the soil. However, the rotating brush should not be used if it will spread contaminants beyond the current spill boundaries.

Damage from scraping and trimming can be severe in moist and dry tundra because the plants' rooting systems are often within 1 inch of the tundra surface. In contrast, much of the rooting systems of plants in wet tundra are deeper than 1 inch below the tundra surface and are more likely to be left in place after mechanical removal.

Use a mechanical brush to clear the area of snow (Tactic CR-3) and expose the tundra surface (Fig. 63). Trimmed ice and snow can be removed with a Super Sucker vacuum truck or by methods described in the snow removal tactic (Tactic CR-3). Adjust the blade or trimmer to remove a thin layer of soil. Transfer contaminated material to dump trucks and transport to appropriate waste disposal facilities.

Considerations and Limitations

- Do not use rotating brushes if they will spread contamination beyond the current spill boundaries.

Figure 56. Scraping soil saturated with oil

Figure 57. Seventy-two-inch trimmer

Figure 58. Forty-two-inch trimmer

Figure 59. Twenty-four-inch trimmer

Figure 60. Rotating brush

Figure 61. Oily spots in scraped tundra

Figure 62. Oily spots in trimmed tundra

Figure 63. Mechanical brush for clearing snow

- Identify the disposal method or facility to be used and estimate the volume requiring disposal before mechanical removal begins.
- Most or all lichens and mosses will be removed by scraping and trimming.
- Scraping and trimming may be impractical for areas with small-scale topographical relief (e.g., tussock tundra, patterned ground).
- Avoid stockpiling contaminated snow on clean areas to prevent spread of contamination.
- Use of vehicles and heavy equipment on tundra must comply with applicable tundra travel policies (Tactic P-5).
- Trimming should be employed as soon as possible following the gross removal of the non-frozen spilled substance, to limit vertical movement of contamination.
- This tactic is not intended to remove pooled product from the ground surface.
- To avoid damage to the root mat, trimming should be limited to the tops of the plant shoots.
- Method of trimming, including equipment, materials and personnel, will be determined by the size and topography of the site.

Equipment, Materials, and Personnel

- *Trimmer (one operator)* – to trim the spill-affected surface ice (size of trimmer will be dependent on size of spill and topography).
- *Grader/Dozer/Bobcat (1 operator)* – to scrape snow and contaminated surface vegetation.
- *Spotter* – to visually identify boundaries where scraping or trimming is needed.
- *Front-end loader and/or Super Sucker (one to two operators)* – to pick up trimmed or scraped ice and snow.
- *Brooms, rakes, and shovels (one worker per tool)* – to sweep up loose ice and snow not picked up by previous methods.
- *Front-end loader (1 operator)* – to transfer scraped or trimmed material into end dumps.
- *Dump truck (1 operator)* – to transfer scraped or trimmed material to disposal site.

CR-13 Excavation for Offsite Disposal

Excavation of tundra soil may be necessary when treatment goals include the rapid and complete removal of spill residuals. Excavation should be considered if contaminant levels are high enough to be toxic to plants, if the entire organic mat is saturated with contaminants, or when other treatment options have been deemed inadequate for achieving the treatment goals.

Dozers, backhoes (Fig. 64), trimmers (Figs. 65–66), and jackhammers (Fig. 67) can be used to excavate the organic mat and underlying mineral soils. Contaminated soil is typically removed from the site for treatment or disposal.

The depth of infiltration by contaminants determines the depth of soil that should be removed. It may be feasible to remove only the organic mat before the spilled material infiltrates down to mineral soil. Minimize the volume of soil excavated by using a spotter to direct the operator to contaminated areas. For example, at many sites, contaminants tend to

Figure 64. Backhoe excavating contaminated soil

Figure 65. Trimmer excavating contaminated soil

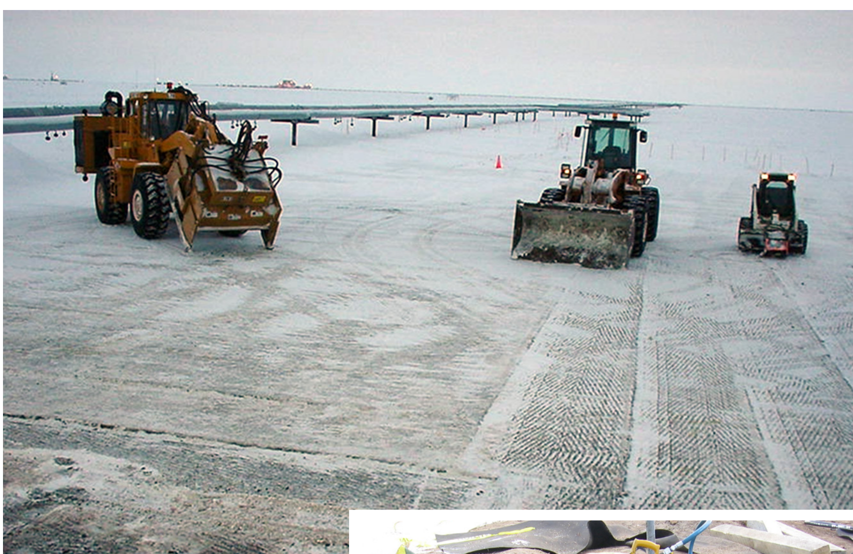


Figure 66. Site after excavation with trimmer

Figure 67. Excavating frozen soil with jackhammer

flow into a network of polygon troughs, leaving higher areas relatively unaffected. However, soil testing (Tactic AM-4) is often needed to identify areas to excavate, because even highly visible substances (e.g., crude oil) are difficult to see under certain conditions, especially during winter with artificial lighting. Consider removing only "hot spots" and leaving as much tundra as possible intact to prevent excessive damage to the tundra (see Tactic AM-3).

In most cases the excavated area must be backfilled (Tactic TR-12) to minimize the risk of thermokarst (Fig. 68). Therefore, a source of approved replacement fill material must be identified before excavation begins. Backfilling may not be necessary if creation of aquatic habitat is an acceptable rehabilitation option.

Considerations and Limitations

- Remove soil only to the depth to which contaminants have infiltrated.
- Identify a source of approved fill material before beginning excavation.
- Ensure backfill has suitable properties (e.g., particle size, relative amounts of gravel, sand, and silt). If possible, the properties of the replacement fill material should be similar to the properties of the excavated soil.
- Allow for settling after backfilling in order to maintain proper surface grade relative to the surrounding tundra.
- Monitoring surface elevation over time may be necessary to document site stability.

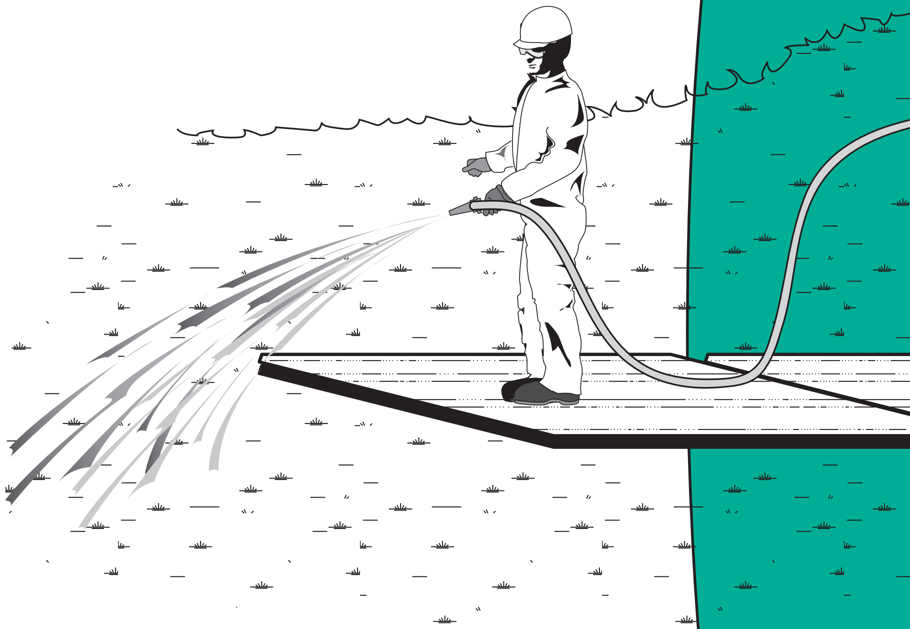
Figure 68. Edge of backfilled area

- Consider disposal options and required approvals before using this tactic.
- On-site field-screening of contaminated soil can expedite the excavation process.

Equipment, Materials, and Personnel

- *Backhoe or trimmer* (1 operator) – to excavate contaminated soil or ice.
- *Front-end loader* (1 operator per loader) – to transport excavated material.
- *Dump truck* (1 operator) – to transport contaminated material to disposal site.
- *Polyethylene sheeting* – lining for stockpiles.
- *Spotter* – to guide excavation of visibly contaminated soil.

Tundra Rehabilitation Tactics



TR-1 Draining and Dewatering

Flooded tundra soils are generally anoxic (lacking oxygen) because the soil pore spaces are full of water. Use draining and dewatering to aerate the soil by lowering the water table and promoting the infiltration of oxygen (Fig. 69). Aeration enhances the ability of soil microbes to degrade residual hydrocarbons (Tactic TR-5). Use this tactic after spill residuals have been removed to the chosen extent.

Drain the site by blocking incoming water with land barriers (Tactic CR-5) and pumping water from the area (Tactic CR-4). Use or enhance topographical relief to create collecting points for pumps or vacuum trucks (Tactic CR-6). Trenches or sumps (Tactic CR-9) may also be needed.

Draining is not recommended when floating product is present; product may be introduced into soil pore spaces or contact vegetation when water level is drawn down. It will usually be unnecessary and impractical to drain aquatic tundra, except for small water bodies. Do not completely dewater tundra if the technique will result in contaminants contacting sediments.

Place suction hoses in all low areas where water collects (Fig. 70); suction may be required at numerous locations within a site. If the site cannot be reached by vacuum truck and hose, all-terrain vehicles

Figure 69. Vacuum truck dewatering site

Figure 70. Natural low spot used for dewatering

(ATVs) may be used to bring in small tanks or drums to collect the water (appropriate tundra travel permits required). It may be necessary to test the collected water for contamination before draining. Proper approvals must be obtained for discharge or disposal of contaminated water from spill sites.

Considerations and Limitations

- Test water for contamination and consider disposal options and required approvals before using this tactic.
- Tundra must be thawed to dewater soil pore spaces.

Equipment, Materials, and Personnel

- *Water truck* (optional) (1 operator).
- *Pumps* (1 operator).
- *Hoses* (1 to 2 operators) – common sizes are 2- and 3-inch diameter.
- *Land barriers* (Tactic CR-5).

TR-2 Extending the Growing Season

Extending the period during which soil is thawed increases the amount of microbial degradation of hydrocarbons that can occur in a given year. Extending the growing season can also enhance plant growth, but plant mortality can result if sprouting begins too early in the spring while air temperatures are still well below freezing.

The following techniques can be used to extend the growing season:

Early spring snow removal to degrade hydrocarbons: Scraping snow off the tundra surface (Tactic CR-3) in April or May will initiate soil thawing and promote the onset of microbial activity 30 to 60 days earlier than under natural conditions (Figs. 71–72). Also, solar radiation levels in the Arctic typically are highest during this period, and exposure to sunlight will promote the photochemical degradation of hydrocarbons remaining on the ground surface. Snow can be removed by hand from small areas or with heavy equipment if the ground is frozen. Leave enough snow in place to prevent physical damage to the tundra surface.

Early spring snow removal to enhance vegetation growth: Scraping most of the snow off the tundra surface (Tactic CR-3) will speed soil thawing and promote vegetation growth (Fig. 73). If snow is removed too early, however, plants will sprout while air temperatures are still well below freezing, which will likely result in plant mortality. Snow removal is most beneficial to plants at sites covered by large drifts or by snow piles resulting from routine snow removal. If not removed, these areas of deep snow can delay soil thawing until late June or July, strongly limiting plant growth. Snow can be removed by hand from small areas or with heavy equipment as long as the ground is frozen. Leave enough snow in place to prevent physical damage to the tundra surface.

Snow fencing: Snow fencing will keep snowdrifts off sites and speed spring thawing, thus promoting soil microbial activity and plant growth (Figs. 74 and 75). Snow fencing should be approximately 4–8 feet high, and it must be placed perpendicular

Figure 71. Clearing snow from site

Figure 72. Site after snow removal

Figure 73. Deep snow cleared from site in spring

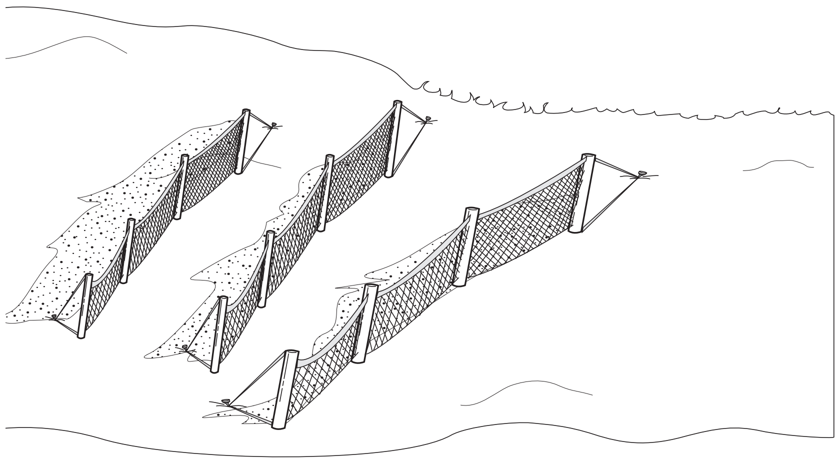


Figure 74. Tiered snow fencing

Figure 75. Snow drift on site not protected by snow fencing

to the prevailing winds and secured with guy wires. Place one fence within several feet of the site, and stagger 2 or 3 additional rows of fencing behind it at 30- to 50-foot intervals. The length of the fences depends on the size of the site.

Tenting: A tent can be constructed to create a snow-free, heated environment to enhance microbial activity (Fig. 76). Tenting is not necessary for enhancing plant growth. This tactic can be

Figure 76. Heated tent to thaw soil

used during spring, summer, and fall. A low tent made with clear polyethylene sheeting and lumber or metal frame can be inflated, heated, and ventilated with a forced-air heater unit.

Considerations and Limitations

- When enhancing microbial activity and plant growth are dual goals, consider the trade-off between promoting early onset of microbial activity and the risk of plant mortality if sprouting occurs too early in the season.
- Snow removal in early spring may limit the water supply on site early in the growing season. Irrigation (Tactic TR-4) may be required during the growing season to compensate.
- Snow fencing left in place for more than a few growing seasons may change the plant communities impacted by the drifts, by repeatedly delaying the onset of the growing season, and by creating wetter conditions resulting from the melting snow.
- Tents and snow fences may require maintenance because of winds.
- Temperature and light levels in tented areas should be similar to natural growing-season conditions.

Equipment, Materials, and Personnel

- *Plastic snow fencing* (available in 4-foot-wide rolls) (2 to 3 people to install) – stretch sheets between steel poles to block snow drifts.
- *Steel poles and means of installation* (2 to 3 workers) – to support plastic snow fencing.
- *Wire and stakes* (2 workers to set up, 1 worker to maintain) – to stabilize snow fences.
- *Polyethylene and metal or lumber frame material* (3 to 6 workers to build, 1 to 2 workers to maintain) – construction materials for tent.
- *Forced-air heater* (2 workers to install, 1 worker to maintain) – to provide heat and ventilation.

TR-3 Fertilization for Hydrocarbon Degradation (Bioremediation)

Fertilizer is applied to enhance the ability of soil microbes to metabolize hydrocarbons (i.e., biodegradation). Biodegradation occurs most rapidly when oxygen (O_2) is available. Applying nitrate (NO_3) fertilizer can enhance biodegradation in the absence of oxygen, because some microbes can use nitrate instead of oxygen. In addition to nitrogen (N), microbes also require phosphorus (P) and potassium (K) for growth and reproduction. Commercially available blended fertilizers supply all three of these essential nutrients. Fertilizer composition varies, and is shown on the bag label as (N-P-K)* followed by the relative percentage of each, e.g., 20-20-10.

Microbes with the ability to degrade hydrocarbons are ubiquitous in the environment, because carbon in organic matter provides the energy that supports many biological processes (Atlas 1985) and because numerous sources of naturally produced hydrocarbons exist (Dragun 1988).

Fertilizer Application

How to Apply

The easiest type of fertilizer to apply is inorganic (mineral) fertilizer, typically packaged in 50-lb. bags of dry pellets. Broadcast fertilizer with a cyclone spreader; these are available in different models that one person on foot can push (Figs. 77–78) or carry (Fig. 79). Larger sites can be treated with a spreader pulled by a 4-wheeler (Fig. 80). Practice and calibration of the spreader are required to distribute fertilizer evenly.

Figure 77. Push spreader

* For historical reasons, the percentage of nitrogen (N) is reported directly, but phosphorus (P) is reported as the fraction of phosphorus oxide (P_2O_5), and potassium (K) as the fraction of potassium oxide (K_2O). This is a standard method used in all fertilizer labeling.

Figure 78. Filling push spreader

Figure 79. Chest spreader

Figure 80. Spreader pulled by 4-wheeler

A good method is to measure and mark off a small area, fill the spreader with the amount of fertilizer appropriate for that area, and move in a grid pattern at a steady pace over the area multiple times until the spreader is empty.

When and How Often to Apply

Fertilizer can be applied at any time if effects on vegetation are not an immediate concern. See Tactic TR-8 for constraints on fertilization if vegetation is present. If possible, apply fertilizer when soil is at least partially thawed and free of snow and water. The rate and frequency of fertilizer application should be based primarily on hydrocarbon concentrations in soil, as well as changes in hydrocarbon concentrations over time. If concentrations of diesel-range organics (DRO) in soil are <4,000 mg/kg, a single fertilizer application is probably sufficient. If DRO concentrations are >4,000 mg/kg, fertilizer should be applied in early summer and fall during two or more successive growing seasons.

What Type to Apply

Ammonium-nitrate fertilizer (e.g., 34-0-0) has the highest concentration of nitrate, making it the most efficient type to apply, but is not always available. Alternatively, a blended fertilizer with a high nitrogen percentage (e.g., 22-4-4) can be used, at a correspondingly higher application rate. A second fertilizer with proportionately more phosphorus and potassium (e.g., 8-32-16) may be applied simultaneously to promote vegetation recovery (Tactic TR-8).

How Much to Apply

In agricultural practice, laboratory analysis of nutrient levels in soil is recommended to calculate the type and amount of fertilizer needed. Levels of major nutrients, however, are low enough in most tundra soils that preliminary measurement of nutrient levels is generally unnecessary. Table 2 provides guidelines for rates of fertilizer application, depending on whether fertilization is also being used to promote vegetation recovery. Different fertilizers can be applied simultaneously, but the total amount of fertilizer should not exceed 800 lbs/acre during a single growing season.

Considerations and Limitations

- Fertilizer will have little effect if contaminant levels are toxic to microbes and vegetation, or if the spilled substance created unsuitable pH or salinity conditions.
- Fertilizer is composed of salts and can result in higher electrical conductivity (EC) in soil. Application may not be beneficial at sites where soil EC is elevated (e.g., seawater spills).
- Fertilizer dissolves in water and nitrogen especially can move off-site in surface water; therefore it is not recommended for aquatic tundra.
- Applying fertilizer without a spreader (i.e., scattering by hand) is not recommended, even for small areas, because the spread will be uneven.

Table 2. Recommended fertilizer application rates

Purpose	Fertilizer to Purchase	Fertilizer Application Rate (lbs/acre)	
		DRO <4,000 mg/kg*	DRO >4,000 mg/kg*
Biodegradation	34-0-0 (use 22-4-4 or similar if 34-0-0 unavailable	100 to 400	400 to 800
Biodegradation and plant growth	22-4-4 and 8-32-16 (use equal amounts of each type)	100 to 400	400 to 800

* DRO = diesel-range organics

- Fertilizer should be stored indoors if possible. Unopened bags can be stored outside for 2–3 weeks in dry weather, but the bags are not airtight and the pellets eventually will absorb water from the atmosphere and stick together in hard clumps, making the fertilizer essentially unusable.

Equipment, Materials, and Personnel

- *Necessary quantity of appropriate fertilizer*.
- *Broadcast spreader* (1 operator) – to spread fertilizer.
- *Vehicle approved for tundra travel* (1 operator) – to pull a broadcast spreader over large sites.
- *Personal protection equipment (PPE)* (e.g., rubber gloves, dust respirator).

TR-4 Irrigation

Irrigation is the application of water to improve growing conditions for plants and the soil microbes to metabolize hydrocarbons. Water is applied by flooding (Tactic CR-7), or by spraying with hoses (Fig. 81) and sprinklers (Fig. 82). Water sprayed on a site will have a relatively high concentration of dissolved oxygen, which will enhance the ability of soil microbes to degrade hydrocarbons. Water can be pumped from a lake or pond near the spill site and sprayed onto the surrounding area repeatedly as the water drains back into the waterbody. This method is commonly referred to as the pump-and-treat method.

Flooding for irrigation can be implemented in the same manner described for flooding to remove contaminants (Tactic CR-7). Irrigation by flooding may require land barriers (Tactic CR-5) to maintain desirable water levels and prevent the spread of contaminants into unaffected tundra. Flooding may be appropriate for rehabilitating wet and moist tundra dewatered during cleanup of contaminants.

To protect plants from exposure to extremely cold air, the site may be covered with snow (Fig. 83) or water, which then freezes.

Figure 81. Watering with hoses

Figure 82. Sprinkler system

Figure 83. Covering site with snow

The snow and ice will provide moisture during the spring, a time when there is typically little rainfall.

Considerations and Limitations

- This tactic is most applicable during dry periods of the growing season.
- Accessing water from a nearby tundra pond or creek may require an authorization from Alaska Department of Natural Resources Division of Mining, Land, and Water
- Verify that water is free of hydrocarbons and salts before using it to irrigate tundra.
- Rainfall events may require modification of the watering schedule.

Equipment, Materials, and Personnel

- *Water truck* (optional) (1 operator).
- *Pumps* (1 operator).
- *Hoses* (1 operator) – common sizes are 2- and 3-inch diameter.
- *Sprinklers* (1 operator).
- *Clean water source* – may be a nearby pond or creek.
- *Power pack* – for pumps.

TR-5 Aeration

The primary purpose of aeration is to increase oxygen levels in subsurface soils to enhance degradation of hydrocarbons by soil microbes. Aeration can also improve growing conditions for plants.

Soils may be aerated manually or mechanically, depending on the size and topography of the affected area. Aerate soils manually by repeatedly driving a pitchfork through the tundra root mat and into the subsurface soil. Aerate soils mechanically by pushing or pulling a rotating barrel fitted with tines over the tundra (Fig. 84). Tines should be long enough to penetrate the root mat and reach the subsurface soil. Tilling (Tactic TR-6) can also be used to aerate soils. Draining water (Tactic TR-1) from low spots will help aerate soils because the removal of subsurface water will allow air to infiltrate into the subsurface soil (Fig. 85).

Considerations and Limitations

- Mechanical aeration (with a rotating barrel) may not be practicable in tussock tundra or in tundra with flooded troughs.
- Use of vehicles on tundra must comply with applicable tundra travel policies (Tactic P-5).

Equipment, Materials, and Personnel

- *Pitchfork* (1 worker) – to punch holes through tundra surface.
- *Rotating barrel with tines* (1 operator) – to punch holes through tundra surface.
- *Vehicle approved for summer tundra travel* (1 operator) – to pull rotating barrel over tundra surface.

Figure 84. Aerating tundra mechanically

Figure 85. Dewatering to aerate soil

TR-6 Tilling

Tilling is used primarily to accelerate volatilization of hydrocarbons and to enhance microbial degradation by increasing oxygen availability in soil. Tilling also restores porosity to compacted soils (e.g., after the removal of a gravel pad), and may facilitate plant establishment by creating favorable microsites that are protected from wind and that accumulate surface water. This technique is most appropriate for sites where persistent contaminants (diesel, crude oil) have penetrated deeply into the soil. Visible surface contamination and contaminated vegetation should be removed prior to tilling.

Small areas can be tilled by one person using a rototiller (Fig. 86). Farm equipment such as disc harrows (Fig. 87) or plows may be needed for larger areas. Earth-moving equipment such as front-end loaders, graders, or bulldozers with scarifying or ripper teeth may also be used. Limit tilling to the depth to which contaminants have penetrated. After tilling, reestablish site contours, using surrounding tundra topography as a guide.

Figure 86. Rototilling contaminated soil

Figure 87. Tilling with disk harrow

Tilling will remove most or all remaining plant cover, and rehabilitation treatments will be needed to restore vegetation. Disruption of the surface increases the likelihood of thermokarst, and backfilling may be necessary to minimize subsidence.

Considerations and Limitations

- This tactic may not be appropriate for sites where the risk of wind or water erosion is appreciable.
- Use of vehicles and heavy equipment on tundra must comply with applicable tundra travel policies (Tactic P-5).

Equipment, Materials, and Personnel

- *Rototiller* (1 operator) – to rework and aerate soil in small areas.
- *Rake* (1 worker) – to contour tilled soil in relatively small areas.
- *Front-end loader or dozer with ripper teeth* (1 operator) – to rework and aerate soil on large sites.
- *Grader with scarifying teeth* (1 operator) – to rework and aerate soil, and to contour large sites.

TR-7 Enhancing Natural Revegetation

Natural revegetation occurs when plants reestablish on a disturbed or spill-affected site without seeding or planting. Enhancing natural revegetation, rather than applying plant cultivation treatments, is appropriate when the effects of the spill and cleanup were minor, so that adequate recovery of surviving vegetation is likely to occur within an acceptable period of time, which will be determined by the landowner(s) and/or regulatory agencies.

Enhancing natural revegetation is generally preferred when the long-term goal is to rehabilitate tundra plant communities with indigenous vegetation. Natural revegetation also increases the probability that the site eventually will resemble the surrounding tundra. Although restoring the ecological functions and plant communities is possible at a spill site, the goal at most sites is rehabilitation. Rehabilitation is the promotion of native tundra vegetation to reestablish a plant community similar to the one that grew there prior to the disturbance (Figs. 88–91).

The following tactics may be used to enhance natural revegetation:

- Apply fertilizer (Tactic TR-8) to the perimeter of a spill site to increase the seed production and vegetative growth of the

Figure 88. Sedges sprouting in dewatered tundra

Figure 89. Sedges sprouting in flooded tundra

Figure 90. Sedges sprouting in moist tundra

Figure 91. Sedges sprouting in wet tundra

surrounding plant community. The wind and wildlife can spread the seeds onto the site.

- Extend the growing season (Tactic TR-2).
- Watering (Tactic TR-4) or dewatering (Tactic TR-1)

Considerations and Limitations

- Analyze soil properties (Tactic AM-5) to evaluate whether natural revegetation is feasible. If the spill residual has created excessively acidic, alkaline, or saline conditions in the soil, plants may not be able to reestablish.
- Concentration of spilled substance in soils cannot be at phytotoxic levels (lethal to plants).
- Monitor the site (Tactic AM-6) for several growing seasons to evaluate revegetation trends.
- Natural revegetation typically requires 10 or more years to rehabilitate the plant cover and diversity to pre-disturbance values. The restoration of the original ecosystem functions and values, if possible, will take much longer.

TR-8 Fertilization for Vegetation Recovery

Fertilizer is applied to ensure an abundant supply of the three main nutrients needed by plants for growth and reproduction: nitrogen (N), phosphorus (P), and potassium (K). Commercially available blends of inorganic (mineral) fertilizer supply all three of these essential nutrients. Fertilizer composition varies and is shown on the bag label as (N-P-K)* followed by the relative percentage of each, e.g., 20-20-10. Fertilizer can also be applied to enhance microbial degradation of hydrocarbons (Tactic TR-3).

Figure 92. Push spreader

How to Apply

The easiest type of fertilizer to apply is mineral fertilizer, typically packaged as 50-lb bags of dry pellets. Broadcast pellets with a cyclone spreader; these are available in different models that one person on foot can push (Figs. 92–93) or carry (Fig. 94). Larger sites can be treated with a spreader pulled by a 4-wheeler (Fig. 95). Practice and calibration of the spreader are required to distribute fertilizer evenly. A good method is to measure and mark off a small area, fill the spreader with the amount of fertilizer appropriate for that area, and move in a grid pattern at a steady pace over the area multiple times until the spreader is empty. Fertilizer may also be applied beyond

Figure 93. Filling push spreader

* For historical reasons, the percentage of nitrogen (N) is reported directly, but P is reported as the fraction of phosphorus oxide (P_2O_5), and K as the fraction of potassium oxide (K_2O). This is a standard method used in all fertilizer labeling.

Figure 94. Chest spreader

Figure 95. Spreader pulled by 4-wheeler

the boundaries of the spill, to enhance seed production in the surrounding tundra and increase seed rain onto the affected area. For transplanted sprigs, cuttings, or plugs of vegetation, larger fertilizer tablets (e.g., 21 g each) are typically placed in the bottom of the hole prepared for each sprig, cutting, or plug.

When and How Often to Apply

Fertilizer should be applied early in the growing season (before 15 July) if possible. Fertilizer can also be applied after the growing season is over (i.e., Fall, approximately 1 September). Fertilizer applied in the Fall is intended to elevate nutrient levels during the following growing season. Applying fertilizer late in the growing season (August) is not recommended because elevated nutrient levels can delay normal plant senescence and result in winter mortality. One application of fertilizer is typically enough to enhance plant growth of indigenous species for several years. If cultivated grass seed is applied (Tactic TR-11), however, fertilizer should be applied at the same time as seeding to maximize germination, and multiple fertilizer applications over one or more growing seasons may be required to maintain productivity.

What Type to Apply

The type of fertilizer to apply will depend on the treatment goals for the site. Use 20-20-10 if vegetation recovery is the primary goal. Other types and rates of fertilizer may be needed if fertilizer is also being applied to enhance microbial degradation of residual hydrocarbons (Tactic TR-3).

How Much to Apply

Tundra soils are typically deficient in all three major nutrients, so soil testing to determine nutrient requirements is usually not needed. The total amount of fertilizer for most sites should not exceed 200 lbs/acre during a single application and 400 lbs/acre during a single growing season. Rates can be higher for sites where microbial degradation of hydrocarbons is the primary goal (Tactic TR-3).

Table 3 provides ranges for rates of fertilizer application to enhance vegetation recovery. See Tactic TR-3 for fertilizer application rates to enhance microbial degradation of residual hydrocarbons.

Table 3. Recommended fertilizer application rate

Purpose	Fertilizer to Purchase	Fertilizer Application Rate (lbs/acre)
Plant Growth	20-20-10	100–200

Considerations and Limitations

- It is easy to apply too much fertilizer, which can cause plant stress, or even kill plants. Weigh fertilizer needed for a given area to prevent the application of too much fertilizer.
- Fertilizer will have little effect if contaminants levels are toxic to microbes and vegetation, or if the spilled substance created unsuitable pH or salinity conditions.
- Fertilizer is composed of salts and can result in higher electrical conductivity (EC) in soil. Application may not be beneficial at sites where soil EC is elevated (e.g., seawater spills).
- Fertilizer dissolves in water and can move off-site in surface water; therefore, it is not recommended for aquatic tundra.
- Fertilizer application rates are not the same as nutrient application rates, although both calculations are based on the relative percentages of the nutrients on the bag label. Nutrient application rates are commonly used in agricultural practice but are not included in this manual.
- Spread fertilizer, seed (Tactic TR-11), and soil amendments (Tactic TR-13) separately, although they can all be applied the same day. Apply fertilizer or soil amendments, and then apply seed. Do not mix fertilizer with seed or soil amendments for application

because the differences in density make proper mixing and spreading with a cyclone spreader difficult.

- Applying fertilizer without a spreader (i.e., scattering by hand) is not recommended, even for small areas, because the spread will be uneven, resulting in patchy growth of plants.
- Fertilizer should be stored indoors if possible. Unopened bags can be stored outside for 2–3 weeks in dry weather, but the bags are not airtight, and the pellets eventually will absorb water from the atmosphere and stick together in hard clumps. The fertilizer will become essentially unusable after these clumps form.
- Spreaders that can be pulled by a vehicle may be needed for large sites.

Equipment, Materials, and Personnel

- *Necessary quantity of appropriate fertilizer*.
- *Broadcast spreader* (1 operator) – to spread fertilizer.
- *Vehicle approved for tundra travel* (1 operator) – to pull a broadcast spreader over large sites.
- *Personal protection equipment* (PPE) for workers (e.g., rubber gloves, dust respirator).

TR-9 Transplanting Vegetation

Use transplanting to introduce indigenous plants to a site where vegetation has been severely damaged by a spill. Harvest and transplant appropriate plants adapted to the growing conditions at the site. For aquatic tundra or for areas that are expected to become aquatic due to subsidence, planting sprigs of pendant grass (*Arctophila fulva*) is appropriate (Figs. 96–98). In moist–wet tundra, transplant sections of tundra sod (tundra plugs) harvested from nearby undisturbed areas (Figs. 99–101). On gravelly areas such as river bars, plant cuttings of willows (*Salix* spp.) (Fig. 102). On sandy areas such as beaches and dunes, transplant sprigs of dunegrass (*Leymus*) (Fig. 103). The above-ground portion of the plant may die back after transplanting, but these plants are adapted to disturbance and should regenerate from below-ground rhizomes and buds.

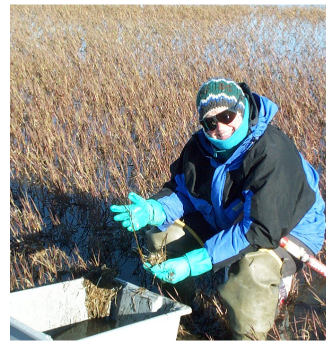


Figure 96. Harvesting pendant grass

Figure 97. Transplanting pendant grass sprigs

Figure 98. Transplanted pendant grass

How to Harvest and Transplant Vegetation

- Harvest pendant grass in aquatic tundra using a shovel with a long blade, such as a drain spade or clam shovel.
- Separate roots from soil and divide clumps into smaller sections or single sprigs for planting (Fig. 104). Keep plants floating in water while this is done, to protect the roots and prevent desiccation.

Figure 99. Transplanted tundra plugs

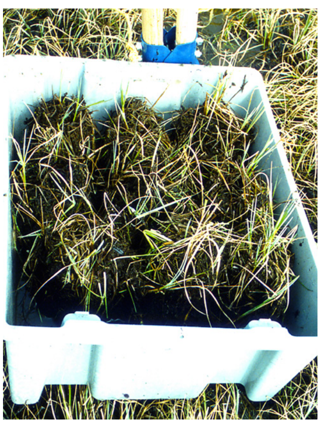


Figure 100. Tundra plugs

Figure 101. Harvesting tundra plugs

- Store the plants in large plastic bags or coolers if they will not be transplanted immediately (i.e., within approximately 2 hours).
- To plant sprigs (singly or in small clumps), one worker uses the shovel to pry open a hole, while the other worker inserts a fertilizer tablet (Tactic TR-8). and the sprig(s) into the hole (Figs. 97 and 103). The soil all around the sprig(s) should be firmly pressed into place (using the feet) to ensure good contact between roots and soil.
- Harvest tundra plugs using the same type of shovel, or a post-hole digger (Fig. 101), to extract a section of sod approximately 8 inches in diameter and extending well into the rooting zone.
- Keep plugs moist if they will not be transplanted immediately (Fig. 100).
- To transplant plugs, dig holes slightly larger and deeper than the plugs, usually 20–40 inches apart depending on site conditions and rehabilitation objectives (Fig. 99).
- Place 2 fertilizer tablets (Tactic TR-8) at the bottom of each hole, then place each plug with its soil surface slightly below surrounding surface. Replace

Figure 102. Transplanted willow

Figure 103. Transplanting dunegrass

soil as needed to fill in holes and press plugs into place as for grass sprigs.

- Willow cuttings can be harvested from natural stands before the plants break dormancy in the spring.
- If necessary, cuttings can be stored frozen until the soil is thawed enough for planting.
- Cuttings should be approximately 15–20 inches long and 0.25–0.5 inch in diameter.
- Cuttings can be planted using a long-bladed shovel (as described above for grass sprigs) or a specialized planting tool (dibble), depending on soil conditions.
- Place 1 or 2 fertilizer tablets (Tactic TR-8) in each planting hole.
- To reduce moisture loss, plant cuttings so that only the top 2–4 inches of the cutting is above the ground surface.

Figure 104. Dunegrass sprigs

Considerations and Limitations

- Check with landowners before collecting plants from nearby areas. For example, a land use permit from Alaska Department of Natural Resources Division of Mining, Land and Water is required for collecting plants on State of Alaska lands. Some special use state lands, such as state parks, may prohibit the collection of plants.
- Refer to *Streambank Revegetation and Protection* (Walter et al. 2005) for additional details for transplanting vegetation.
- If the site is near the coast or saline substances were spilled, test the soil salt level (Tactic AM-5) to help determine which species, if any, are appropriate to transplant.
- Not all species can tolerate transplanting. For example, a species with a single tap root (an underground structure which cannot be divided without killing the plant) is less likely to survive transplanting than is a species with a fibrous root system (Table 4).

Table 4. Examples of plants suitable for transplanting on the North Slope

Tundra Type	Common Name	Scientific Name	Comments
Aquatic and Wet	Pendant grass	*Arctophila fulva*	Salt tolerant
Wet and Moist	Tall cottongrass	*Eriophorum angustifolium*	Somewhat salt tolerant
	Water sedge	*Carex aquatilis*	Somewhat salt tolerant
	Tundra grass	*Dupontia fisheri*	Salt tolerant
Moist and Dry	American dunegrass	*Leymus mollis*	Salt tolerant, adapted to sandy soils
	Feltleaf willow	*Salix alaxensis*	Typically used for biotechnical stabilization of gravel side slopes
	Richardson’s willow	*Salix lanata*	Generally lower survival than *S. alaxensis*

- The advantages of transplanting over seeding are that transplants are usually readily available, and transplanting can produce plant cover more quickly than seeding; however, transplanting over large areas is more labor-intensive.
- At some sites, tundra sodding (Tactic TR-10) may be more appropriate than transplanting sprigs or tundra plugs.

Equipment, Materials, and Personnel

- *Large plastic bags, coolers, or 5-gallon buckets* – to carry and store collected plants and soil.
- *Drain spade or similar* (1 operator, 1 planter) – to open holes in the ground to place sprigs or cuttings.
- *Drain spade or post-hole digger* (1 worker per tool) – to collect tundra plugs.
- *Drain spade or similar* (1 worker per tool) – to dig planting holes for tundra plugs.
- *Long knives and/or scissors* – for cutting grass clumps into smaller sections.
- *Fertilizer tablets (1 tablet per sprig, 2 per tundra plug, 1–2 per willow cutting) – 1 tablet typically weighs 21 grams*. Tablets are available with various NPK blends (e.g., 2-2-10 for shrubs and 20-20-10 for other plants).

TR-10 Tundra Sodding

Tundra sodding is the transplanting of intact tundra soil and live plant materials to restore native plants in an area where vegetation and soil have been removed to recover contaminants (Fig. 105). In addition, sodding may reduce heat transfer to permafrost, allowing a disturbed site to reach a stable thermal regime more quickly. Some thermokarst should be expected, however, and transplanted sod should contain species adapted to the hydrologic regime expected in the treated area once it has stabilized. This technique is based on traditional ecological knowledge used to build ice cellar roofs in northern Alaska. To offset the expected thermokarst, backfilling (Tactic TR-12) may be required before tundra sodding so that eventually, the sod is similar to the grade of the surrounding tundra.

Sod can be harvested from a mine site before gravel extraction begins, or from other sites prior to development. If sod must be stored before use, maintaining adequate soil moisture is critical. The best time to harvest sod is when the soil has thawed 6–12 inches. Sod can also be harvested in winter with heavy equipment, but survival will be lower, and the cut pieces will be uneven in size and more difficult to transplant. Sod can be stored temporarily outside on pallets, or directly on a gravel pad or other suitable location for several years before transplanting.

Figure 105. Sodded area

Figure 106. C. Hopson demonstrating sod harvesting

Sod for small sites can be harvested with hand tools (i.e., knives, shovels, reciprocating saws) (Fig. 106). Mechanical harvesting is recommended for larger sites. A 3.5-ft diameter, 0.75-inch steel disc sharpened and mounted on the

Figure 107. Harvesting sod with a "Nuna ulu"

Figure 108. Harvesting sod with a small loader

Figure 109. Intact sod harvested with a large loader

Figure 110. Large pieces of harvested sod stored temporarily before being cut into smaller pieces for planting

bucket of an excavator, similar to an asphalt cutter, has been used successfully to harvest tundra sod in Prudhoe Bay (Fig. 107). The Inupiat term "Nuna ulu" (earth knife) was coined for this rolling cutter. Vertical cuts in the sod are made to a depth of 1–2 feet in perpendicular directions, and sod is removed with the bucket of an excavator or loader. If a cutting disc is not available, sod can be removed with a loader bucket after making vertical cuts with hand knives (Figs. 108 and 109).

Sod pieces should be as large as practicable during harvesting (Fig. 110), but pieces larger than approximately 4-ft^2 are too heavy for one person to carry. If sod must be moved by hand because the site is not accessible to heavy equipment, worker safety can be maximized by using a conveyor belt similar to those used to load airplanes. Non-motorized rails (6–8 ft long) provide a simpler and more mobile alternative (Fig. 111). If the site is road-accessible, an extendable fork lift ("Zoom Boom") can be used to place pieces that are too heavy to move by hand (Fig. 112). Prior to the placement of sod, fertilizer (20:20:10, granular pellets or tablets, Tactic TR-8) should be placed on the soil surface. The pieces of sod should be placed touching each other to maximize soil contact and to prevent

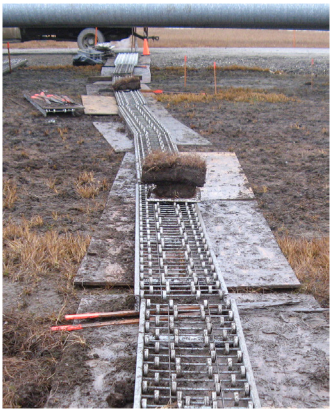


Figure 111. Rails used to move sod onto a site

Figure 112. Moving large sod pieces

loss of moisture between sod pieces, making the treated area as similar as possible to undisturbed tundra.

Considerations and Limitations

- A Material Sales Contract with Alaska Department of Natural Resources Division of Mining, Land & Water is needed to harvest sod from a mine site.
- Sodding success depends on transplanting appropriate plant species that are adapted to the growing conditions after the site has stabilized.
- Using thicker pieces of sod will provide more insulation to minimize heat transfer into the ground, but the addition of backfill material before the placement of sod may still be necessary for the grade of the area treated with sod to eventually be close to the grade of the surrounding tundra (i.e., the site blends in after subsidence and/or settling of backfill material).
- A permit may be needed from the U.S. Army Corps of Engineers if backfill is used.
- Sodding has been used effectively for moist and wet tundra, and may also work for dry tundra, but is not recommended for aquatic tundra.
- Minimize the time between harvesting and transplanting.
- Surface stability may need to be monitored after transplanting for a minimum of 5 years to accurately assess whether sodding affected surface stability.

- Possible locations for long-term storage of sod are unused areas at a mine site, an uncontaminated reserve pit, or a gravel pad.
- A permit may be needed from the landowner before harvesting tundra sod.

Equipment, Materials, and Personnel

- *12-inch serrated knives* (1 worker per tool) – to make vertical cuts.
- *Cutting disc ("Nuna ulu") or asphalt cutter and excavator or backhoe* (1 operator) – to harvest sod.
- *Loader* (1 operator) – to pick up and load sod at harvest site.
- *Flatbed trailer or truck* (1 operator) – to haul sod to transplant site.
- *Portable aluminum rails or motorized conveyor belts* (at least 2 operators) – to move sod beneath pipelines or away from road.

TR-11 Seeding

At sites where recovery of the pre-spill tundra vegetation is not feasible, seeding may be necessary in order to establish plant cover. Seeding is used to help control soil erosion, but only at sites where water velocity is low, improve the appearance of the site, provide habitat for wildlife, and promote the eventual development of a plant community similar to the original tundra. Seeding should not be used with the intent to produce shade and thereby prevent thawing of underlying frozen soil; the insulating properties of intact tundra are due to the surface layer of decaying organic matter, which takes a minimum of multiple decades to develop.

The type of seed to use depends on the tundra type, material spilled, and goals of the seeding effort. Seeding with indigenous (wild) species is strongly recommended over the use of commercially available native-grass seed for a variety of reasons. Although native-grass cultivars have been cultivated from species native to northern Alaska, these species are not dominant in undisturbed tundra communities. At sites where the establishment of more typical tundra plants is a priority, sowing seed of indigenous species is more appropriate. Also, recent changes in climate have increased the risk of introducing non-native, potentially invasive species (weeds) when using grass seed purchased commercially. If the grass seeding tactic is selected, additional work may be needed in the future to remove invasive species. To reduce the likelihood that invasive species removal will be needed, approval for use of the grass seeding tactic should be obtained in advance from the landowner and/or regulatory agencies. Additional details are provided below and in *Considerations and Limitations*, below.

Seeding is more likely to be successful if it is delayed for at least 1 growing season after civil work is complete, although delaying for 2 or 3 growing seasons is preferable. This waiting period allows time for the ground surface to stabilize, which helps to identify areas that are unsuitable for most species because they are likely to become permanently flooded with deep water. Also, seeds float, so seeding should not be used when deep or shallow water is present. If the seedbed is flat and smooth, it may be helpful to scarify the ground surface before sowing to create favorable microsites, or after sowing to improve seed contact with the soil. A rake can be used to scarify small areas; for larger sites mechanized methods are more practical (e.g., drag a section of chain-link fence behind a four-wheeler).

It is generally advisable to sow a mixture of at least two species, especially if conditions vary within the site. The most commonly used wild seed and grass cultivars are listed in Table 5. This table also recommends species and application rates for different tundra types, including those affected by salts. Fertilizer application (Tactic TR-8) is not required when using indigenous seed because these species are adapted to the low nutrient regime typical of arctic soils. Fertilizer application is required when using native grass cultivars, and fertilizer must be reapplied every 3–5 years to maintain the productivity of these grasses.

Seed of indigenous species can sometimes be purchased from the Alaska Plant Materials Center (PMC). Other sources of native plant materials from Alaska are published in the "Directory of Alaska Native Plant Sources" available on the PMC website. The typical rehabilitated spill site requires only a modest number of indigenous seed, so collecting from nearby wild populations can be feasible. Most wild seed used for revegetation purposes ripen in July and August, but some species may be collected in September. Seed of some wild species, primarily sedges, can be harvested using a handheld seed harvester (Prairie Habitats, Inc., Argyle, Manitoba, Canada) (Fig. 113). Seed of other species, including legumes, can be collected by hand (Fig. 114). Collections of wild seed

Figure 113. Collecting seed with a line trimmer and special attachment

Figure 114. Collecting sedge seed by hand

Table 5. Examples of plant species and seeding rates used for North Slope Tundra Revegetation

Site Type	Commercially Available Grass Seed		Locally Collected Indigenous Seed		Notes
	Recommended Species	Application Rate (lbs/acre)	Recommended Species	Application Rate (lbs/acre)	
Wet	*Arctagrostis latifolia* (Alyeska polargrass); *Deschampsia caespitosa* (Nortran tufted hairgrass)	10–20	*Eriophorum angustifolium* (tall cottongrass); *Eriophorum scheuchzeri* (white cottongrass); *Carex aquatilis* (water sedge); *Dupontia fisheri* (Tundra grass)	5	*C. saxatilis* (rock sedge) and *C. membranacea* (fragile sedge) are also suitable, as well as other *Carex* species adapted to wet conditions
Moist	*Arctagrostis latifolia*; *Deschampsia caespitosa* (Nortran tufted hairgrass); *Poa glauca* (Tundra glaucous bluegrass); *P. alpina* (Gruening alpine bluegrass)	20–40	*Eriophorum angustifolium*; *Carex aquatilis*	5–10	*C. bigelowii* may also be used, as well as other *Carex* species adapted to moist conditions
Dry	*Poa glauca* (Tundra glaucous bluegrass); *P. alpina; Trisetum spicatum* (spiked trisetum)	20–40	Legumes (e.g., *Astragalus alpinus* (alpine milkvetch), *Oxytropis viscida* (viscid locoweed); *Artemisia arctica* (boreal sagebrush); *Leymus mollis* (dunegrass)	5–10	–
Salt-affected	*Puccinellia borealis* (arctic alkaligrass)	10–20	*Dupontia fisheri*; *Eriophorum angustifolium; Puccinellia angustata* (narrow alkaligrass); *Leymus mollis* (dunegrass)	5–10	*D. fisheri* for moist-wet sites only

are typically sent to the PMC to have the seed separated from the chaff and tested for viability. Thus, cleaned seed is typically applied at least 1 growing season after collecting. Cleaned seed should be stored frozen in airtight plastic bags for future use. Little information is available about the long-term viability of seed of tundra plants, so long-term storage is not recommended. Wild seed can also be processed minimally in the field and applied immediately, but this approach will not allow results to be evaluated based on the number of viable seeds applied.

Seed of native-grass cultivars is available from commercial vendors in Alaska, which are published in the "Directory of Alaska Native Plant Sources" on the PMC website. Grass seed mixtures have been used since the 1970s for revegetation projects throughout Alaska. Until recently, the small quantities of weed seeds typically contained in these mixtures have not been of concern. Due to recent changes in climate, however, these weedy species are more likely to successfully establish if introduced to the North Slope. The vendor should provide detailed documentation about the seed, to assess the risk of introducing non-native species. For example, grass seed originating from other states (e.g., Washington) or countries (e.g., Canada) may contain a greater diversity of potentially invasive species than seed produced in Alaska.

Fertilizer should be applied before seeding grass cultivars to provide an adequate supply of nutrients for plant establishment and initial growth (Tactic TR-8). Broadcast large amounts of grass seed using a cyclone spreader (Fig. 115). Small volumes of wild seed collected by hand must also be spread by hand (Fig. 116). Both methods are best done when there is a light wind (10–15 miles per hour) to help distribute the seeds. Even distribution of seed will require some practice. One useful method is to measure and mark off a portion of the area to be seeded, and then apply the appropriate amount of seed for that area, moving in a grid pattern at a steady pace over the area multiple times until the seed is gone. Then repeat for the next portion of the area to be treated. A hydroseeder can be used to apply grass cultivar seed to very large areas.

Figure 115. Cyclone spreader

Figure 116. Sowing legume seeds by hand

Considerations and Limitations

- A land use permit from Alaska Department of Natural Resources Division of Mining, Land & Water is required for collecting plant materials, including seeds, on State of Alaska lands. Other permissions may be required from different landowners.
- If the grass seeding tactic is selected, additional work may be needed in the future to remove invasive species.
- To reduce the likelihood that invasive species removal will be needed, approval for use of the grass seeding tactic should be obtained in advance from the landowner and/or regulatory agencies.
- Seeding success depends on soil conditions (nutrient availability, moisture, salinity and contaminant levels). In addition to fertilizer (Tactic TR-8), aeration (Tactic TR-5), irrigation (Tactic TR-4), and tilling (Tactic TR-6) may improve conditions for germination and establishment.
- If the site is near the coast or saline substances were spilled, test the soil for salinity (Tactic AM-5) before seeding, to help determine appropriate species to use.
- Recently seeded sites may be attractive to wildlife, including birds. If this is not desirable (e.g., due to risks from residual contaminants), it may be necessary to use deterrents and/or hazing to keep wildlife away from the site.
- The shade provided by a rapidly-established, dense cover of cultivated grasses, or other vegetation, will offer a nearly negligible (de minimis) amount of protection against thawing of permafrost at a disturbed tundra site. The insulating properties

of intact tundra are due to the thickness of the surface layer of decaying organic matter, which takes a minimum of multiple decades to develop.

- Seeding with native-grass cultivars is not recommended because they typically die back within 3–5 years unless fertilizer is reapplied.
- Seeding with indigenous species does not require the application of fertilizer, which reduces costs for labor and materials.
- Once the fertilizer effect subsides at sites treated with native-grass cultivars, the plant canopy consists mainly of standing dead leaves, which have little value to wildlife and do little to improve the appearance of the site.
- Native-grass cultivars can produce a dense cover of live and dead biomass, which probably inhibits natural colonization of the site by indigenous tundra plants.

Equipment, Materials, and Personnel

- *Necessary quantity of appropriate seed* – either collected from wild populations or purchased from a vendor.
- *Electronic scale (preferably accurate to 0.01 or 0.001 g)* – for weighing out seed for each area of site.
- *Containers* – for weighing and transporting seed.
- *Vehicle approved for tundra travel (1 operator) and chain-link fence – t*o scarify surface at larger sites, if needed.
- *Cyclone spreaders (1 worker per spreader)* – to broadcast large amounts of seed.
- *Line trimmer with collecting bag (1 operator)* – for collecting seed of tundra plants.
- *Pruning shears (1 worker)* – if needed for collecting seed of tundra plants.
- *Metal rakes (1 worker per rake)* – to scarify surface after seeding.
- *Paper and cloth bags* – for collecting seed of tundra plants.

TR-12 Backfilling

Use backfilling to help stabilize the thermal balance at the tundra surface. The addition of backfill can lower the rate of heat transfer into underlying permafrost. Backfill is especially important at excavated sites, and it should be applied as soon as possible after excavation. If the site remains stable, subsidence of the ground surface caused by thermokarst will be mitigated, helping to prevent the impoundment of water and increasing the number of options for revegetation. Backfilling may not be necessary if tundra sod (Tactic TR-10) is added (Fig. 117); sodding is similar to backfilling because relatively thick (6–12 inches) pieces of tundra sod can provide insulation to protect permafrost. Tundra sodding has the added benefit of immediately increasing the plant cover at a site.

Mineral and organic overburden from a mine site often is used as backfill material (Fig. 118). Add enough backfill to allow for settling. Also, the soil may have a high content of ice; add enough backfill material to ensure the volume of soil added will be sufficient after the ice melts. Backfill should be added in lifts. Lifts of backfill should be compacted periodically to minimize settlement.

Figure 117. Sodded area

Considerations and Limitations

- A Material Sales Contract with Alaska Department of Natural Resources Division of Mining, Land & Water, is needed to use overburden from a mine site as backfill.
- Plywood walkways should be set up at the site in order to reduce damage to the adjacent tundra.
- Use of vehicles and heavy equipment on

tundra must comply with applicable tundra travel policies (Tactic P-5).

- Surface water should be removed before backfilling.
- Testing may be necessary to determine backfill material properties such as relative amounts of gravel, sand, and silt.

Equipment, Materials, and Personnel

- *Plywood walkways* (2 workers) – to prevent trampling of tundra.
- *Wheelbarrow* (1 worker) – to haul backfill material.
- *Shovels*.
- *Bobcat or front-end loader* (1 operator) – to collect and transfer soil used for backfilling.
- *Dump truck* (1 operator) – to transfer backfill material to the site for rehabilitation.
- *Wooden lathe* - for staking depth of backfill material needed.

Figure 118. Backfilled area

TR-13 Soil Amendments

Soil amendments are used to promote plant growth by improving soil conditions affected by spilled substances. For example, brine spills may create saline conditions, or metabolism of hydrocarbons by soil microbes may acidify soils. Tundra soils can be naturally acidic or saline, amendments should be applied only if levels of acidity or salinity are substantially higher than those in nearby unaffected tundra. If soil testing (Tactic AM-4 and Tactic AM-5) or active-layer water monitoring shows that soils are strongly acidic or saline, applying an amendment may be appropriate. Periodic monitoring (bi-weekly) of active-layer water (Tactic AM-4) can track changes in soil properties faster than soil testing.

A common technique used to reclaim sodium-affected (sodic) soils is the addition of gypsum or calcium nitrate. These soil amendments displace sodium ions from the soil by replacing them with calcium ions, which adsorb more strongly to soil particles. An adequate water supply is necessary for this chemical exchange to occur, and adequate drainage is necessary to flush the sodium from the affected soil. Chloride ions do not bind strongly to soil and they will be flushed out with the sodium ions. Adding gypsum will not necessarily be effective in all saline soils. Laboratory testing is required to determine if gypsum will improve soil conditions (Table 6).

Apply lime if soils are too acidic, most plants are not adapted for soils with a pH > 8.

Apply soil amendments during the growing season when soils are free of snow and water, if possible.

How Much to Apply

Application rates of soil amendments are site-specific and should be calculated by a soils laboratory. Provide the laboratory with a target pH range (background concentration), and the laboratory will calculate the application rate of a given soil amendment based on results from soil testing. The manufacturer of liquid calcium nitrate will provide information on how much is needed (based on laboratory data) for a certain area to achieve a certain salinity range.

Table 6. Examples of soil amendments used for North Slope tundra

Amendment	Purpose
Lime (calcium carbonate $CaCO_3$)	To buffer overly acidic soil caused by a spill of an acidic substance, or by microbial degradation of hydrocarbons
Gypsum (calcium sulfate and water, $Ca{\bullet}SO_4$ and H_2O)	Calcium source to remove salt (sodium and chloride ions) after a seawater or other type of salt spill
Liquid calcium nitrate	Calcium source to remove salt (sodium and chloride ions) after a seawater or other type of salt spill

How to Apply

Lime and gypsum are available in powder or granular form, typically packaged in 50-lb bags. Broadcast lime or gypsum with a cyclone spreader, which are available in different capacities and models that one person on foot can push (Figs. 119–120) or carry (Fig. 121). Larger sites can be treated with a spreader pulled by a 4-wheeler (Fig. 122). Practice and calibration of the spreader are required to distribute lime or gypsum evenly. A good method is to measure and mark off a small area, fill the spreader with the amount of lime or gypsum appropriate for that area, and move in a grid pattern at a steady pace over the area multiple times until the spreader is empty.

Figure 119. Push spreader

Lime or gypsum may be applied simultaneously with fertilizer (Tactic TR-3 and Tactic TR-8).

Liquid calcium nitrate can be applied to small sites using weed sprayers or watering cans, or to larger sites using a hydroseeder or similar piece of equipment. The distribution method is similar to that

Figure 120. Applying lime

Figure 121. Chest spreader

Figure 122. Spreader pulled by 4-wheeler

for powder or granular amendments. A given amount of product is sprayed methodically over a given area to achieve even distribution at the correct application rate. Calibrate the sprayer before use.

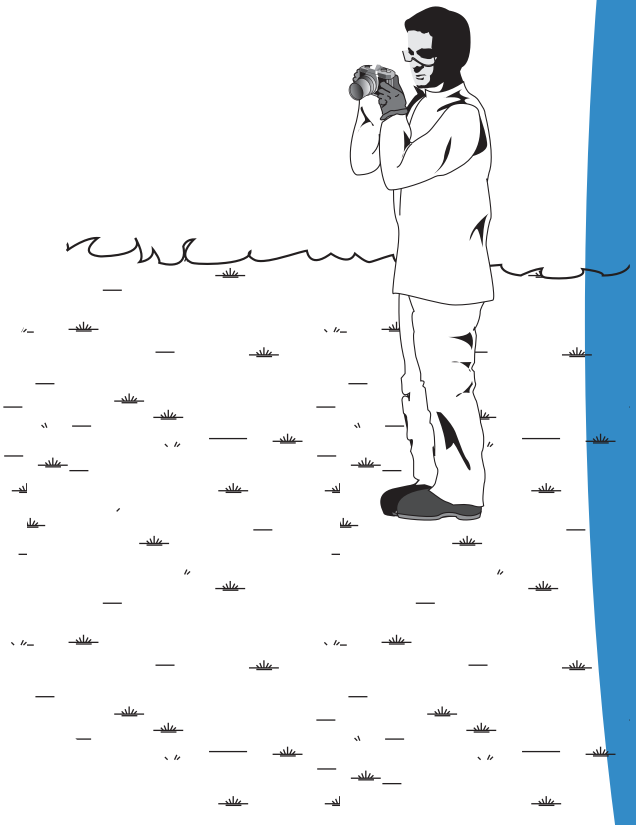
Considerations and Limitations

- To determine the types and amounts of amendments needed, soil samples typically are sent to a soils laboratory that routinely conducts analyses for agricultural purposes. Some analytical laboratories, where soils are analyzed for contaminants, may also be equipped to calculate the need for soil amendments.
- Strongly alkaline (8.5–9.0) tundra soils are not readily correctable with amendments.

Equipment, Materials, and Personnel

- *Necessary quantity of appropriate soil amendment.*
- *Cyclone spreader* (1 operator) – to broadcast powdered soil amendments.
- *Vehicle approved for tundra travel* (1 operator) – to pull a cyclone spreader over larger sites (optional).
- *Weed sprayer or watering can* (1 operator) – to spray liquid soil amendments on small sites.
- *Hydroseeder or similar equipment* (2 operators) – to spray liquid soil amendments on larger sites.
- *Personal protection equipment* (PPE) – to keep workers safe (e.g., rubber gloves, dust respirator).

Assessment and Monitoring Tactics



AM-1 Delineation and Sampling of the Spill Area

It is important to mark the spill area so that its boundaries can be located at a later date, especially if the site is snow covered. Airborne Forward-Looking Infrared (FLIR) photography can be used to identify the spill area even if the site is snow covered (Fig. 123). Delineation should begin as soon as possible after the spill has been contained. Correct the boundary location as needed. The contrast between clean and contaminated snow is especially useful for visually delineating affected areas. Even relatively clear fluids such as diesel, methanol, and produced water, can cause dramatic changes in the color and physical characteristics of snow.

To delineate large spill areas (>1,000 square feet), two workers walk the perimeter of the spill in opposite directions from a common starting point, and place markers every 50 to 100 feet to provide a visible boundary. The two workers should meet midway around the perimeter of the spill area, and then retrace each other's routes to confirm the delineation. While walking, they look for visible impacts, including spilled substance on the ground; discoloration of plants or soil; sheen on standing water or foliage; and dead or damaged vegetation. For smaller spills, a single worker may perform the delineation. Aerial photographs

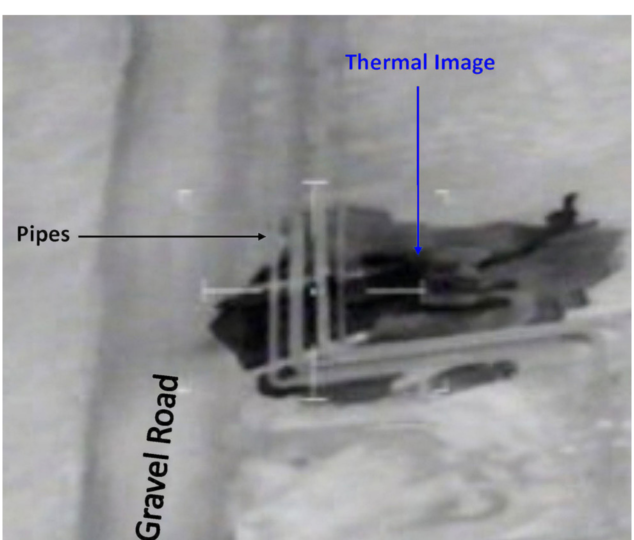


Figure 123. FLIR image of spill area

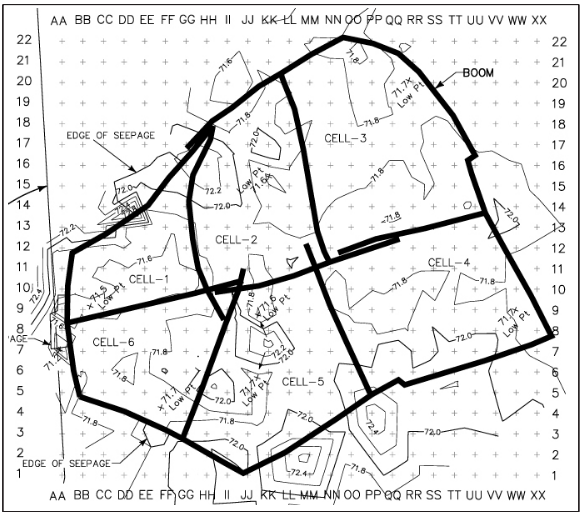


Figure 124. Sampling grid and elevation contours

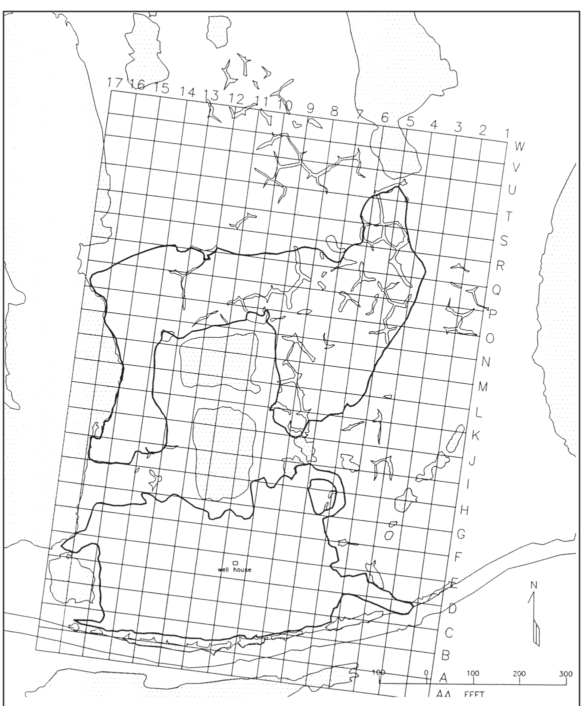


Figure 125. Sampling grid

or other types of remotely sensed data (e.g., infrared reflectance) acquired with unmanned aerial vehicles (i.e., drones), as well as surveys by qualified professionals are of great value for identifying and mapping site features and spill boundaries.

A scaled map of the site probably will be required for planning, monitoring, and reporting purposes and will be most useful if prepared using professional surveying methods (Figs. 124–125). As soon as practical after containment, a sampling system should be implemented, to be used for monitoring (Tactic AM-2 and Tactic AM-4). The preferred method is systematic sampling at nodes on a grid system, which facilitates the unbiased selection of sampling locations (Fig. 126). Depending on the

Figure 126. Wooden lathe showing sampling locations on grid

shape of the affected area, the grid should be a square or rectangle that is large enough to encompass the containment area and some adjacent unaffected (reference) tundra. Vegetation monitoring plots should be located at the same locations where samples were collected..

For affected tundra areas that are ~0.5 acre (~150′ x 150′) in size, a grid with 15-ft spacing would create 100 nodes where lines intersect. Typically, samples are collected at a subset of nodes, chosen using a random selection method. This approach can be used for a site of any size simply by expanding the grid. For larger sites (>1 acre), the distance between nodes can be changed to create a reasonable number of potential sampling locations, or to meet specific sampling objectives. For example, the spill area may be subdivided into areas with high, medium, and low concentrations of contaminants (Fig. 127). If the sampling plan stipulates that 10 samples should be collected from each area, the size of the grid can be adjusted to provide at least 10 potential sampling locations in each area. When the affected tundra includes patterned ground, the grid distances should be less than the average polygon diameter to avoid sampling bias among topographical features (e.g., polygon centers, rims, and troughs).

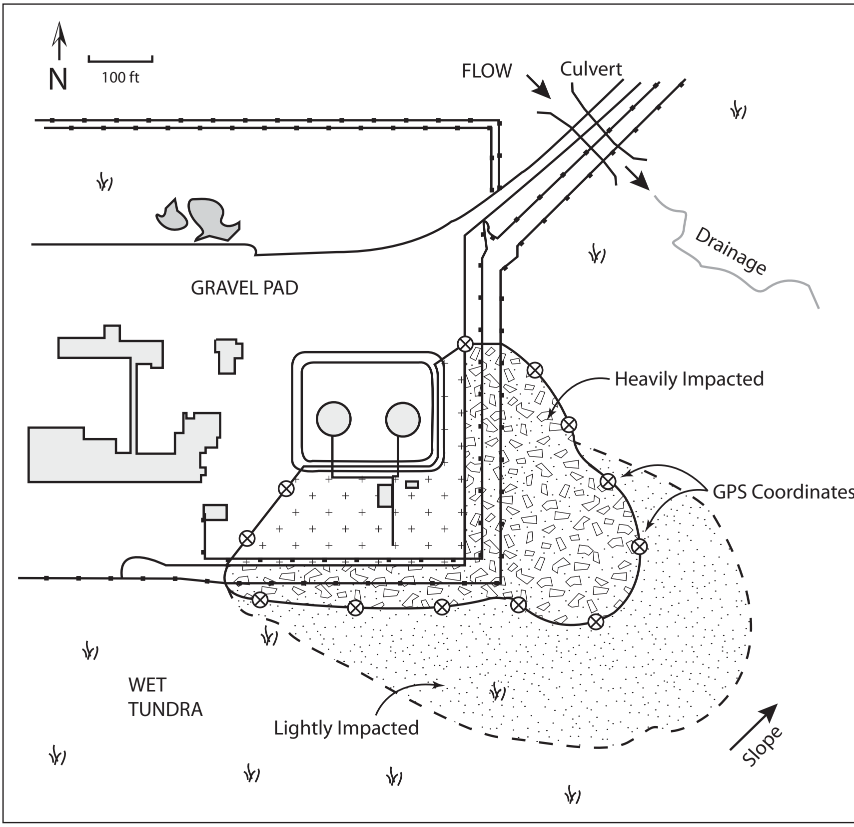


Figure 127. Typical site layout

Two methods exist for establishing the grid system at a site. Importantly, neither method interferes with cleanup operations, because permanent stakes or markers are not needed to locate sampling stations within the spill area. Nevertheless, sample stations can be relocated with good precision. The first method uses permanent markers (e.g., survey nails, wooden stakes, or rebar) that are driven into the ground in two parallel rows on opposite sides of the spill, and that are separated by the appropriate distance between grid nodes. Each marker is labeled with a row number (e.g., 1 through 10), letter (e.g., A, B, C), or distance from a corner of the grid (e.g., 0, 2, 4, 6 for a 2-ft grid). Individual sampling points are then located by stretching a tape between the corresponding end stakes and sampling is done at specified distances along the tape. The second method uses a "virtual grid" created with computer software (e.g., AutoCAD). The coordinates of selected sample stations are then uploaded to a field computer, which is used to navigate to the sample location (Fig. 128). The use of a virtual grid generally requires contracting the services of a professional surveyor, although other personnel with special training and equipment can also establish a virtual grid.

Map Elements

A variety of maps probably will be needed and should include at least the following elements:

- Location of the spill source.
- Boundary of the affected area.
- Areas of low and high concentration of spilled substance.
- Adjacent roads and structures.
- Tundra types within and around the affected area.
- Sensitive areas and habitats (identification may require special training or additional work).
- Nearby drainages or water bodies, most likely direction of water movement, location of culverts in road.
- Slope and topography (e.g., elevation contours).
- Location of monument used to control survey locations and elevations.

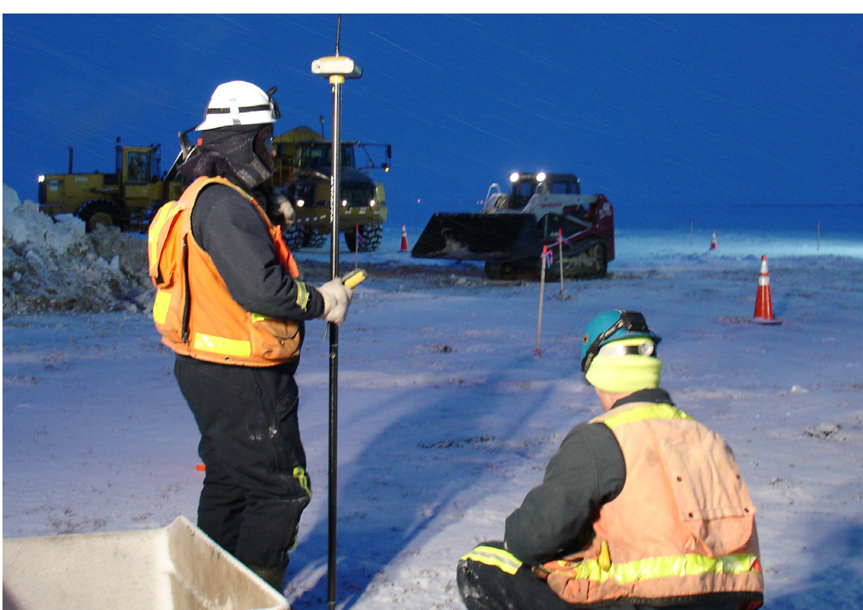


Figure 128. Marking sampling locations

- Sampling grid that can be overlaid on the site map.
- Sampling locations (including background samples), preferably at nodes on sampling grid.
- Vegetation study plots, transects, or photo-plot locations (include direction of photo).
- North arrow, scale and approximate latitude and longitude of the site.

Considerations and Limitations

- Technical literature (e.g., www.EPA.gov) is available to help design a plan for sampling and data collection.
- The area of an uncontained spill will expand with time on all types of tundra.
- The boundaries of spills of saline or water-soluble substances are difficult to delineate visually, especially when snow is absent. These spills tend to spread rapidly except in winter, when the fluids mix with snow and freeze. If salts or other water-soluble compounds are present in high concentrations, the vegetation may die or show signs of stress (wilting, discoloration, loss of foliage) in affected areas.
- Seasonal frost action in the soil may push wooden stakes out of the ground over time (i.e., frost-jacking). Wooden stakes may also be disturbed by winter vehicle traffic in the area. Metal rebar may pose a physical hazard. Survey pins (e.g., 9-inch nails) with bristles are preferred because they do not pose a safety hazard, they are less affected by frost-jacking, and they can be relocated with a metal detector.
- Plywood boardwalks may be needed to protect tundra from trampling by foot traffic.
- Considerations for site assessments used by the Department of Environmental Conservation are found in 18 AAC 78.090.
- This tactic has been adapted from Tactics T-1 and T-2 in the *Alaska Clean Seas Technical Manual*

Equipment, Materials, and Personnel

- *Permanent markers (9-inch nails or wooden lath stakes) (1 or 2 workers)* – to mark spill perimeter and grid system.
- *Handheld GPS unit (1 operator)* – to provide coordinates for initial site delineation.
- *Professional survey equipment and personnel (variable)* – to permanently mark grid layout, sampling locations, and to provide a scaled drawing.

AM-2 Field Indicators

Field indicators are standardized, simple measurements or qualitative observations that can be made periodically at a site to monitor and document contamination, treatment effectiveness, and ecological damage associated with the cleanup operation. Field indicators also provide a context for interpreting chemical analyses of soil samples (Tactic AM-4 and Tactic AM-5) and data on vegetation response (Tactic AM-6). Field indicators are important components of a baseline site assessment or monitoring program.

Four categories of field indicators may be measured or observed:

- *Spill Residue:* Treatment progress may be monitored by visually assessing the degree of contamination on soil and vegetation (Table 7).
- *Soil Conditions*: The rooting zone, where contamination is most harmful to plants, usually extends 1 to 8 inches (2 to 20 centimeters) below the ground surface. Evaluating the infiltration of contaminants into this zone provides a helpful indicator of how vegetation is likely to respond (Table 8).
- *Ecological or Physical Damage*: Cleanup operations can result in physical damage with long-term ecological consequences, including thawing of permafrost (thermokarst). Monitoring physical damage can help determine the point at which intensive treatment should stop. The thickness of the active layer (thaw depth) should be measured periodically (e.g., in Fall), so that thermokarst development can be monitored over time (Table 9).
- *Ecological recovery*: Recovery at a site is indicated by growth of native plants and re-establishment of drainage pathways, and a stable thermal regime typical of permafrost terrain.

Measure and observe field indicators at pre-established sampling points, preferably at discreet points on a sampling grid. The number and locations of sampling points should be established by agreement between the responsible party and regulatory agencies. Field sampling points should represent the entire site, with no bias to either heavily or lightly impacted areas. The number of sampling points that are needed will depend on the degree of contamination and the size of the affected

*Table 7. Field sample coding sheet for visual assessments of oil spills on tundra.**

Parameter	Measurement or Observation
Residue thickness on ground or vegetation	• No visible residue • If sheen is present, thickness is 0.0001 millimeters (mm) • If stain is present, thickness is 0.1 mm • If coating can be scraped with an object, thickness is 1 mm • If thickness is >1 mm, measure with ruler
Residue consistency	• No visible residue • Liquid (flowing) residue • Emulsified crude oil (mousse) • Waxy, gelatinous • Hardened, crystalline, plastic, tar • Crumbly, friable • Sheen
Residue expulsion (residual hydrocarbons can be squeezed out of surface organics or soil with foot pressure)	• No expulsion • Sheen on water • Liquid droplets or thicker film • Pooling on surface • Undetermined: test not done if surface oil present
Residue color	• Silver-gray sheen • Rainbow sheen • Light orange-brown • Dark brown • Blue-black

* Field indicators for other types of residues must be developed on a case-by-case basis. Adapted from Cater and Jorgenson 1999

area. A small site with heavy contamination may require a relatively intensive sampling approach (e.g., 10 field sampling points per 0.1 acres). For larger sites, spread field sampling points out more widely to characterize the entire site (e.g., 1 sample per 0.2 acres). In many cases, it will be appropriate to divide the site into zones of severity (e.g., lightly, moderately, and heavily affected); several samples should be collected in each zone. Field indicators should also be measured in similar tundra types in the surrounding area unaffected by the spill (background or reference areas) for comparison.

Field sampling points preferably should be established at nodes on the surveyed sampling grid (Tactic AM-1). Ideally, the same

Table 8. *Some field indicators of soil conditions.**

Parameter	Measurement or Observation
Organic layer	• Measure thickness of organic layer (includes mosses and peat) • Note any discoloration • Note odor
Mineral soil layer	• Measure depth that mineral layer begins • Note any discoloration • Note odor
Mineral soil texture[a]	• Gravel (gravel, sandy gravel, silty gravel) • Sand (sand, loamy sand, gravelly sand) • Loam (silt, silt loam, sandy loam) • Clay (silty clay, silty clay loam)
Thaw depth	• Use metal probe to measure depth of active layer of soil
Water depth	• Measure depth of water table above (+; surface water) or below (-) ground surface
Containment infiltration	• *Saturation*: soil pores filled with spilled substance • *Coatings*: noticeable coating on mineral or organic particles, void spaces in soil are evident, or substance does not flow out of soil matrix • *Sheen*: sheen is visible when soil squeezed but not evident on particles

* Adapted from Cater and Jorgenson 1999

[a] Classification based on Natural Resources Conservation Service, U.S. Department of Agriculture (Schoeneberger et al. 2002)

measurements and observations should be made at all field sampling points.

If necessary, use survey nails or other permanent markers to physically mark the sampling points and record their locations on a scaled site map (Tactic AM-1) so they can be accurately relocated in the future. If an individual sampling location is not located at a node on the grid, record a waypoint, or the distance and direction of the sample location from a grid node. Most observations of field indicators are specifically related to the tundra surface. When subsurface soil observations are necessary, dig a small test pit and examine the sidewall of the pit, or cut out a soil sample for easier observation.

*Table 9. Some field indicators for physical or ecological damage.**

Parameter	Measurement or Observation
Tundra type	• Aquatic tundra • Wet tundra • Moist tundra • Dry tundra • Bare soil
Vegetation cover (Tactic AM-6)	• Cover estimates (0 to 5%, 6 to 25%, 26 to 50%, 51 to 75%, 76 to 95%, 96 to 100%) for shrubs, graminoids (i.e., grasses and grass-like plants), and other lifeforms (e.g., forbs, horsetails, mosses, and lichens), as well as bare soil or plant litter.
Vegetation damage (Tactic AM-3)	• No apparent damage • Partially crushed (some stems and leaves crushed, but structure mostly intact) • Mostly crushed (stems and leaves recognizable, but mostly laying flat on ground) • Stressed (wilted, dropping leaves, or leaves discolored) • Dead • Roots exposed • 1 to 5 inches of organic layer or soil removed • >5 inches of organic layer or soil removed
Birds and mammals (use data form)	• Species and number observed at the entire site • Condition (healthy, diseased, dead) • Note whether spill residue is visible on animal • Animal dead, probably due to other causes

* Adapted from Cater and Jorgenson 1999

Sample datasheets for recording field indicator data are located at the end of this section.

Considerations and Limitations

- Avoid placing stakes in locations that may interfere with treatment operations.
- Water-soluble spill residues may not be visible on the tundra surface.
- Most observations or measurements of field indicators require a thawed active layer and the absence of snow cover.
- Use plywood walkways to minimize trampling of site.

Equipment, Materials, and Personnel

NOTE: Generally, a team of two workers measures and records observations of field indicators.

- *Ruler or measuring tape* – to measure residue on tundra surface, the depth of infiltration, and thickness of soil horizons.
- *Metal probe – t*o measure depth of thaw, water depth.
- *Shovel* – to dig small test pit to observe soil horizons and depth of infiltration.
- *Large survey nails, wooden laths, or steel "rebar" stakes* – to mark areas where field indicators were measured or observed so they can be relocated easily and accurately during subsequent monitoring events.
- *GPS* – to record sample point locations.
- *Standard data forms* – to record observations.

BIRDS AND MAMMALS OBSERVATIONS FORM

Site:____________ Date:___________ Time:_________ Observer:_______________

Species	No.	Condition	Sample ID	Notes

Condition classes: **N** (present on site but no oiling observed), **L** (lightly oiled, no detrimental effects), **H** (heavily oiled, mobility impaired), **D** (dead due to oil), **O** (dead probably to other causes).

Sample ID: Wildlife handling and collection should only be done by trained personnel. If an animal is collected, assign it an ID number.

For more information, see the A*laska Spill Response Wildlife ID Aid*, available from: https://nrt.org/sites/176/files/AK_Spill_Response_Wildlife_ID_Aid.pdf

VISUAL ASSESSMENT FORM FOR TUNDRA OIL SPILLS

Site:________________________ Date:____________ Time:___________ Observer:______________________________

Grid Location			Photo ID	Oiling (Routine)				Cleanup Method		Tundra Type	Water Depth (cm)	Vegetation Cover Class						Damage Level
Row	Distance	Zone/ Cell		Depth (mm)	Consistency	Expulsion	Color	1	2			Shrub	Graminoid	Forb	Moss	Lichen	Bare Soil	

VEGETATION COVER CLASSES: **0** (none), **1** (0–5%), **2** (6–25%), **3** (26–50%), **4** (51–75%), **5** (76–95%), **6** (96–100%)

OIL CONSISTENCY CLASSES: **L** (liquid), **E** (emulsified, mousse), **W** (waxy, gelatinous), **P** (plastic, tar), **C** (crumbly, friable), **S** (sheen)

OIL EXPULSION CLASSES: **N** (none), **S** (sheen), **L** (liquid droplets or thicker film), **P** (pooling on surface), **U** (undetermined): test not done if surface oil present

CLEANUP METHODS: N (none), I (impoundment), F (flushing), R (raking), C (cutting), S (swabbing, squeegeeing), O (oil skimmers, rope mops), V (vacuum pumping) E (excavation), B (burning), H (heating)

TUNDRA TYPES: A (aquatic), W (wet tundra), M (moist tundra), D (dry tundra), S (bare soil, fill), U (undetermined)

DAMAGE LEVEL: 0 (none), 1 (veg. partially crushed), 2 (veg. mostly crushed), 3 (veg. partially removed), 4 (veg. mostly removed), 5 (veg. all removed, some mosses present), 6 (veg. totally removed, 0–3 cm soil removed), 7 (3–10 cm of soil or moss mat removed), 8 (>10 cm of soil removed).

OIL INFILTRATION SURVEY FORM

Grid Location			Photo ID	Stratigraphy								Water Depth (cm)	Oil Infiltration		
Row	Dist-ance	Zone/Cell		Organic Layer Depth (cm)	Mineral Layer 1			Mineral Layer 2			Thaw Depth (cm)		Satur-ation Depth (cm)	Coated Matrix Depth (cm)	Sheen/Film Depth (cm)
					Text-ure	Top Depth	Bottom Depth	Text-ure	Top Depth	Botttom Depth					

Organic Layer Depth includes fibric, hemic, and sapric horizons.
Soil Texture: **G** (gravel, sandy gravel)**,** **L** (loam, sandy loam, silt loam, silt), **S** (sand, loamy sand, gravelly sand), **C** (clay, silty clay, sandy clay),
Water Depth: record as – when water table is below ground surface, record as + when surface water is present

AM-3 Preventing Damage from Cleanup Activities

The goal of this tactic is to help responders stop cleanup activities before too much tundra damage occurs. There is no precise definition of too much damage, however, site-specific characteristics determine the treatment goals and selection of tactics. Thus, making the key decision during a cleanup response when the risk of physical damage from continued cleanup activity does, or does not, outweigh the benefits of recovering additional spill residuals will depend on many factors.

When field indicators (Tactic AM-2) are used to monitor cleanup effectiveness and tundra damage, responders have access to the most recent information for using the decision trees to guide the cleanup (Tactic P-1). Guidelines are presented here to help determine when cleanup activities should stop. The guidelines rely on simple observations, but some training of observers may be necessary to provide accurate information. For example, damage to soil is often readily visible but disturbance to vegetation often is more difficult to determine, especially in winter. The short growing season in the Arctic often means that a meaningful assessment of vegetation recovery may not be possible until a minimum of 3–5 years after a spill.

The three most likely forms of damage to result from a spill cleanup are the compression of the organic mat, the tearing of belowground plant materials (e.g., roots and rhizomes), and the removal of vegetation and soil. Damage is less likely to occur when soils are frozen, but accurately assessing tundra damage often is not possible until summer. Soil compression is dependent on the depth to which the soil is frozen, the soil type, the amount of water and/or ice in the soil, as well as the weight of equipment, and the number of passes of people or equipment over a specific area. Soils that are wet, or that were frozen when wet, have pore spaces filled with water (or ice), and are less susceptible to compression and shearing forces than drier soils that have air voids. In general, both wet and moist tundra will be less susceptible than dry tundra to compression and shearing forces.

In winter, the first indication that tundra disturbance is possible is the incorporation of dead plant leaves (e.g., plant litter) into the snowpack, which indicates the snowpack is no longer thick enough to provide a protective layer to the tundra surface.

According to the Alaska Department of Natural Resources (DNR), vegetation damage is defined as any visible mechanical alteration of plant anatomy such as broken or abraded branches of shrubs and scuffed or crushed tussocks, while soil damage is defined as any visible depression or displacement of soil resulting in a defined track. Tables 10 and 11 provide additional information that can be used as an overall guideline to assess six levels (from negligible to severe) of physical damage to the spill site (see also Tactic AM-2).

When assessing the level of damage, it is important to compare the spill site with adjacent undisturbed tundra of the same type. For example, undisturbed dry tundra may naturally have areas of exposed soil. This ranking system is intended to be rapid, thus the estimates of cover are subjective and different from the quantitative method used in Tactic AM-6. To rapidly assess the level of damage, an observer visually estimates the proportion of an area (e.g., a treatment cell) according to the damage variables. This rapid assessment method is most useful for describing large differences.

Considerations and Limitations

- If soil samples are collected to assess the depth of penetration/ infiltration by contaminants, the water content and bulk density of the soil also should be estimated to determine the likelihood of soil compression.

Equipment, Materials, and Personnel

- *Grid system* - for sampling (Tactic AM-1).
- *Sample containers, drying oven, and scale* - for calculating water content and bulk density.

Table 10. Classification and description of damage levels for tundra

Damage Level	Description
Negligible 0	No impact to slight scuffing of higher microsites. Disturbance not evident from the air or on air photos.
Low 1	The decrease in vegetation cover is <25% and the amount of exposed soil is <5%. Compression of standing plant litter and slight scuffing of soil is evident in wet, moist or dry tundra; tussocks or hummocks scuffed.
Moderate 2	The decrease in vegetation cover is 25–50%, and/or exposed soil is 5–15%. Compression of mosses and standing plant litter is evident in wet and moist tundra; tussocks or hummocks are crushed; portions of spill site may appear wetter than surrounding area; some tearing of vegetative mat within moist tundra along rivers and in dry tundra.
High 3	The decrease in vegetation cover is >50–75%, and/or exposed soil is >15–25%. Standing water is apparent on spill site that probably was not present before the spill; moist tundra changing to wet tundra; crushed tussocks or hummocks nearly continuous; change in vegetative composition; in moist tundra along rivers and in dry tundra, vegetation mat and ground cover substantially disrupted.
Very high 4	The decrease in vegetation cover is >75–95% and/or exposed soil is >25–90%. Ground depressions common in moist tundra. In wet tundra, thermokarst and ponding may result in a substantial area that is covered by water, especially where extensive areas of vegetation and surface soils have been churned or displaced. Dry tundra appears as barrens with only occasional patches of vegetation remaining.
Severe 5	Vegetation removal is essentially complete (>95%) and exposed soil is nearly continuous (>90%). Some colonizing plants may be present, but vegetation cover is less than 5%.

Table 11. Variables used to rank the damage level for tundra.

Damage Variable	Damage Level 0	1	2	3	4	5
Vegetation Reduction (% cover)	0–4	5–24 or increase	25–50	51–75	76–95	>95
Vegetation Height (% of reference)	90–110	75–89 or >110	50–74	25–49	5–24	<5
Exposed Soil (% cover)	0	1–5	>5–15	>15–25	>25–90	>90
Microrelief (cm) (Depression, Compaction, Thermokarst, Excavation)	0	1–4	5–14	15–24	25–100	>100

AM-4 Testing Soil and Water for Contaminants

Figure 129. Monitoring water in the active layer

Government agencies may require periodic laboratory analysis of soil and water during treatment and rehabilitation of a spill site (Fig. 129). This tactic describes procedures for sampling and analysis to measure contaminants in tundra soil, surface water, and in supra-permafrost water (i.e., subsurface water within the active layer of thawed soil). Sampling and analysis plans must be approved by the Department of Environmental Conservation (DEC). Select laboratory analyses by referring to regulations used by DEC (18 AAC 75.341, 345 and 18 AAC 70.020) to establish chemical-specific screening criteria and cleanup levels for soil and groundwater. Workers must comply with Occupational Safety and Health Administration regulations, which require special training for sampling hazardous substances.

Selection of Sample Sites

To allow testing for a correlation between analytical results and field indicators, collect analytical samples at the same locations where field indicators are monitored (Tactic AM-2) whenever possible. If samples for analytical analysis are collected at new locations, field indicator data should also be collected at these locations. Avoid collecting analytical samples from a location that has been disturbed by monitoring for field indicators.

The number of locations selected for sampling, and the frequency of sampling must be approved by agency representatives. An intensive treatment and monitoring program may require ongoing sampling (weekly to monthly), while a less intense program may require annual monitoring. Sampling is normally performed when the soil is thawed.

Preventing Cross-Contamination

Avoid cross-contamination of samples by using proper sample-handling techniques and decontamination practices. Work in pairs with one person labeling jars and writing field notes without handling contaminated material, while the other person collects samples and handles sampling equipment. Decontaminate sampling equipment before each sampling event to ensure collection of representative samples and to prevent cross-contamination. Use a laboratory-grade detergent and preferably hot potable water to clean sample equipment. Rinse with tap water followed by multiple rinses with de-ionized water.

Soil Sampling Procedures

A typical cross-section of tundra soil has two distinct layers differentiated by color and texture (Tactic P-2). The upper horizon consists of dark organic soils, usually with dense plant roots and is often smooth in texture. The lower, mineral horizon is usually sandy or silty in texture, and the color is often lighter than organic matter, and often gleyed (typically grey to blue in color).

Collect samples separately for the upper (organic) soil horizon and the lower (mineral) horizon. Stainless steel spoons, disposable sample scoops, shovels, and hand augers may be used to collect surface/near-surface samples.

Surface soil samples must be collected from freshly uncovered soil to minimize the loss of any volatile compounds and transferred directly from the freshly uncovered soil to the laboratory-supplied sample container. If a sample is to be collected in a test pit that has been open for longer than one hour, a minimum of 3 inches of surface soil should be removed immediately before collection.

Surface Water Sampling Procedures

Collect samples of surface water by gently immersing a clean sample bottle in the body of water. Avoid disturbing sediments in the immediate vicinity of the collection point before sample collection. Note whether the sample was collected at the water surface to sample contaminants floating on the water surface, or the sample was collected below the water surface to capture contaminants that have dissolved into the water column.

Field measurements of water quality parameters may be recorded after sample collection, including:

- Temperature
- pH
- Specific conductance (SC), which is calculated from electrical conductivity (EC)
- Dissolved oxygen
- Oxidation reduction (Redox) potential

Calibrate the instruments in the field before use.

Testing Surface Water for Salt Content during Flooding or Flushing

When treating a spill of a saline substance by flooding or flushing, use a hand-held field meter to monitor the EC of the water before and after it is applied to the tundra, to provide immediate confirmation that salts are being removed. EC values should decrease with successive flooding treatments as salts become diluted. However, when salts have penetrated into the soil, EC may increase temporarily when these salts are flushed out of the soil. If the soil is frozen, this increase may not occur until the soil thaws sufficiently to allow the salts to become mobile. Calibrate the conductivity meter before collecting data. Because temperature directly affects EC readings, field measurements should be standardized to 25°C (specific conductance) to allow comparison of measurements made at different temperatures. Most newer conductivity meters automatically calculate specific conductance by automatically compensating for temperature. A variety of units are used for recording conductivity in water; the standard international unit is the Siemens (S). Conductivity meters usually display results in microSiemens/cm (µS/cm), or in milliSiemens (mS/cm). Another unit, the "mhos" is often used in the United States. Fortunately, 1 mhos = 1 S, and 1 µmhos/cm = 1µS/cm (see Tactic AM-5 for more conversion factors for EC measurements).

Table 12. Examples of sampling and analysis parameters

Spilled Substances	Analysis	Matrix	EPA/DEC Method	Containers (will vary with lab)	Preservation, Holding Time
Crude Oil, Diesel, Gasoline	Gasoline Range Organics (GRO)	Water	AK 101	40-ml VOA, TLS lid	HCl to pH<2, Cool to 4°C, extract and analyze in 14 days
		Soil	AK 101	4-oz Amber glass, teflon-lined septa (TLS) lid	Methanol, <25°C, extract and analyze in 28 days
	Diesel Range Organics (DRO)	Water	AK 102	2-1L Glass Amber	pH<2 (HCl), 4°±2°C, 7 days to extract, analyze <40 days
		Soil	AK 102	4-oz Amber glass, TLS lid	4°+2°C, 14 days to extract, analyze <40 days
	Residual Range Organics (RRO)	Water	No water method	–	–
		Soil	AK 103	4-oz Amber glass, TLS lid	4°+2°C, 14 days to extract, analyze <40 days
	Total Polynuclear Aromatic Hydrocarbons (PAH)	Water	610, 625, 8021 B, 8260 C	40 ml VOA, TLS lid	pH<2 (HCl), 4°+2°C/14 days
		Soil	8270, 8100, or 8310	4-oz Amber glass, TLS lid	4°+2°C/14 days or per method requirements
	Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX)	Water	8260M (SIM)/602, 624	40-ml VOA, TLS lid	HCl pH<2, cool to 4°C, extract and analyze in 14 days
		Soil	8260M/ 8021 B/ 6240/ AK 101	4-oz Amber glass, TLS lid	4°+2°C, extract and anlyze in 14 days or per method requirements

Table 12. Continued.

Spilled Substances	Analysis	Matrix	EPA/DEC Method	Containers (will vary with lab)	Preservation, Holding Time
Glycol	–	Water	8015 M, 8015 B	40-ml VOA	4°+2°C/7 days or per method requirements
		Soil	8015 M, 8015 B	4-oz jar	4°+2°C/7 days or per method requirements
Therminol	–	Water	8015 M, 8015 B	40-ml VOA	4°+2°C/7 days or per method requirements
		Soil	8015 M, 8015 B	4-oz jar	4°+2°C/7 days or per method requirements
Methanol	–	Soil	8015 M, 8015 B	4-oz jar	4°+2°C/7 days or per method requirements
		Soil	8015 M, 8015 B	4-oz jar	4°+2°C/7 days or per method requirements
Salinity	–	Water	SM-22520B	250-ml plastic	4°+2°C/14 days or per method requirements
		Soil	SM-22520B	4-oz jar	4°+2°C/14 days or per method requirements

Procedures for Sampling Water from the Active Layer of Soil

Collecting samples of water below the tundra surface (i.e., in the active layer of thawed soil or supra-permafrost groundwater) requires the installation of monitoring wells (Fig. 129). Before each sampling event, a minimum of three to five well volumes of water should be purged from the well. This will remove any stagnant water in the well casing and ensure that the sample originates from water that drains into the well from the soil surrounding the well. Use a disposable bailer or a peristaltic pump to purge wells. Collect purged water in drums and dispose of it according to applicable regulatory guidelines. Use a sterile, disposable bailer to collect water samples from wells. Immediately place water into sample containers and preserve as specified by the analytical laboratory.

Laboratory Analysis Plan

The type of substance that was spilled and the sample media dictate the analyses to be used. Laboratories will provide sample containers and specify required sample quantities. Table 12 provides examples of sampling and analysis parameters.

AM-5 Testing Soil and Water for Revegetation

This tactic describes procedures for conducting tests on soil and water to provide information to help select tundra rehabilitation tactics. Some of the procedures and protocols are similar to those used to test soil for contaminants. See DEC's Field Sampling Guidance (2024) for additional details. Sample soils and water in affected and unaffected (i.e., reference) tundra to:

- Determine if salinity is suitable for germination and establishment of plants,
- Determine whether pH conditions are suitable for plant growth and microbial activity,
- Determine baseline conditions (e.g., electrical conductivity) that can be used to compare with conditions in the future, and
- Determine if tundra affected by a spill is substantially different from undisturbed tundra.

Collect at least 3 to 6 soil samples from a site to account for variability. For larger sites, it may be useful to collect 3 to 6 samples from the area with the highest concentration of contaminants, and 3 to 6 samples from areas with moderate or lower contaminant concentrations. In addition, collecting 3 to 6 soil samples from a nearby unaffected area with similar vegetation and soil will allow the affected tundra to be compared with unaffected tundra, which may be important for selecting tundra rehabilitation tactics. For example, tundra near the coast can have naturally saline soils, indicating that salt-tolerant species may be needed to revegetate a site. Tundra soils typically have a surface organic layer overlying a mineral soil layer with very different characteristics, and these differences must be accounted for when using soil characteristics to make decisions.

Collect soil samples from a pit dug using a clean shovel. If necessary, collect samples at different depths to represent the entire active layer (surface to frozen subsurface). Segregate the organic rooting mat, which typically has a high content of plant roots and partially decomposed organic matter, from lower layers of mineral soil. Place each sample in sealable plastic bags (e.g., Ziploc® brand), or in DuPont™Tyvek® bags typically used by geologists. Label each bag with the site name, date, unique sample identification, and the initials of the person collecting the sample. Request that the soils laboratory analyze the organic soil layer separately from the mineral soil layer. Refrigerate soil samples at 4 ± 2°C (36–43°F) until analysis to minimize biological activity which can metabolize some contaminants, resulting in lower concentrations than were present at the time of sampling. Samples should be stored temporarily and delivered for analyses according to laboratory protocols. Many of these analyses allow for drying or freezing of soil samples if it is not possible to keep them refrigerated before delivery to the laboratory. If samples are air dried, ensure they are not exposed to high temperatures. Similar to testing for hydrocarbons, many of the analyses described in this tactic have specific requirements for preservation and/or hold time (e.g., 14 days) for the results to meet laboratory protocols.

Testing for Salinity

The salinity of soil and water is important to tundra plants because high concentrations of salts, such as sodium chloride, can interfere with the absorption of water into the plants, even when a substantial amount of water is present in the soil. Salts may also interfere with the ability of plants to absorb mineral nutrients (e.g., nitrogen and phosphorus). Electrical conductivity (EC) is used as a measure of the concentration of water-soluble salts in soil and water; high EC values indicate high salinity.

Tundra soil is considered saline if EC is greater than 4 dS/m (deciSiemens per meter) which is equivalent to 4 mmhos/cm (millimhos per cm). EC can also be measured in water bodies that may have been affected by a spill. EC in natural tundra water bodies is typically <800 µS/cm (microSiemens/centimeter) which is equivalent to 800 µmhos/cm (micromhos/centimeter). In tundra that is naturally saline (e.g., salt marshes), EC can be much higher. See Table 13 for conversion factors for the most common EC units.

The standard method used by a laboratory to express salinity is to measure EC of a saturated paste extract at 25°C. A soil paste extract is prepared by mixing a known mass of soil with a known volume of deionized water, usually at a 1:1 ratio. The laboratory procedure used

Table 13. Conversion factors for electrical conductivity units

To convert from	To	Multiply by
dS/m	µS/cm	1000
dS/m	µmhos/cm	1
mmhos/cm	µS/cm	1000
µS/cm	mS/cm	0.001
mS/cm	µS/cm	1000
µS/cm	dS/m	0.001
dS/m	µS/cm	1000
dS/m	mS/cm	1

to measure electrical conductivity in soil is described in Soil Survey Investigations Report No. 42, Soil Survey Laboratory Methods Manual, Version 4.0, November 2004, USDA, NRCS. A similar method using a hand-held EC meter can be used in the field to rapidly assess salinity of soil and surface water. Because salinity is affected by temperature, field measurements of EC should be converted to specific conductance, which standardizes EC values to 25°C (Tactic AM-4). Most newer conductivity meters can make this conversion automatically. EC results from a laboratory are reported at 25°C and do not need to be converted.

Field observations can also provide good evidence of salinity. Note the presence of free salt on the soil surface, the presence of bare ground when the surrounding tundra is vegetated, and the presence of salt-tolerant plant species. Using portable EC meters in the field to measure EC in soil and water is often helpful to aid in planning the location and number of samples to be collected for laboratory analysis.

Testing specifically for concentrations of sodium and chloride may be needed. Ion specific probes that are supported by portable field meters are available. Sodic soils have high concentrations of sodium and are a specific type of saline affected soil. If salinity is high and the pH is high (>8.5), the sodium adsorption ratio (SAR) should also be calculated. SAR takes into consideration that the adverse effect of sodium is moderated by the presence of calcium and magnesium ions. The normal range in tundra soil for SAR is <13 (see Brady and Weil 1996, Table 17).

Seeding or transplanting salt-tolerant plants may be appropriate for salt-affected sites if no salt-tolerant plants are growing nearby to revegetate the area (Tactic TR-9). Soil amendments (Tactic TR-13) may be appropriate if the site is too saline for any plant growth (Tables 14 and 15). Flooding (Tactic CR-7) or flushing (Tactic CR-8) also may be appropriate.

Table 14. Electrical conductivity values in tundra surface water and vegetation tolerance

Range of EC in Natural Tundra Water Bodies		Description	Vegetation Tolerance
µS/m, mmhos/cm, and dS/m[1]	**µS/cm**		
<0.8	<800	Freshwater	All plants
0.8 – 2.0	800 – 2000	Brackish	Most plants (some growth limitation)
2.0 – 6.0	2000 – 6000	Saline	Some plants (growth limitation)
>6.0	>6000	Very saline	Salt-tolerant plants only

[1] 1 dS/m = 1000 µS/cm = 1000 µS/cm = 1 mmhos/cm

Table 15. Electrical conductivity ranges in soil for plants

Electrical Conductivity Ranges in Soil for Plants (multiple units presented)		Normal Range in Tundra Soil
Non salt-tolerant	**Salt-tolerant**	
0.3 – 4.0 mmhos/cm	4.0 – 6.0 mmhos/cm	<2 mmhos/cm
300 – 4000 µmhos/cm	4000 – 6000 µmhos/cm	< 2000 µmhos/cm
0.3 – 4.0 dS/m	4.0 – 9.0 dS/m	<2 dS/m

Testing for pH

Use portable meters to measure pH in soil and water rapidly, and to help in the planning of the location and number of samples to be collected for laboratory analysis. Compare results to background levels near the site and to the normal range for tundra on the North Slope. If the pH in soil is above or below normal range (5.2 to 7.8) for tundra, a soil amendment may be appropriate. A pH range of 6.0 to 7.0 is optimal for availability of nutrients in soil. However, other pH values may be normal for that area. If sample results are similar to background levels, soil amendments are not necessary (Table 16).

Table 16. Normal pH in tundra

Normal pH Range in North Slope Tundra	
Soils	Water bodies
5.2 – 7.8	6.5 – 8.5

Testing for Physical and Chemical Characteristics of Soil

Testing for physical and chemical characteristics of soil can provide important information for selecting tundra rehabilitation tactics. The relative amounts of gravel, sand, silt, and clay, and the amount of organic matter are physical characteristics important to plant growth. Laboratories first separate each sample into the coarse earth (particles >2 mm in size) and fine earth fractions (particles <2 mm in size). Gravel typically comprises the coarse earth fraction in tundra soils. The fine earth fraction includes sand, silt, and clay. Most laboratory tests are conducted using only the fine earth fraction. Testing for the amount of organic matter in soil is important because organic matter enhances water and nutrient holding capacity and it improves soil structure. If the soil is analyzed for soil nutrients, the pH of the sample also should be analyzed because plants growing in soil with high (e.g., >8) or low pH (e.g., <5) may not be able to absorb soil nutrients. Compare results from the affected area with undisturbed tundra to determine the relative importance of soil characteristics for vegetation recovery in the affected area (Table 17).

Considerations and Limitations

- Soil sampling is typically done when the active layer is thawed.
- If more than one plant community or soil type is found on a site, additional sampling will be required.
- Comparison of results between different soil horizons and tundra types on a site is not valid. Also, samples must be compared with background results from similar soils and plant communities, to determine the extent to which the area was affected by a spill.
- Mechanical analysis for soil samples may be necessary for backfill material imported to a site.

Equipment and Personnel

- *Shovel (1 worker)* – to collect soil samples.
- *Ziploc® or other plastic bags (1-gallon size) or DuPont™Tyvek® bags* – to store samples.
- *Labels and notebook* – for recording sample identifications bags and soil horizons.
- *Cooler and blue ice* – to store and ship soil samples to the laboratory.

Table 17. Laboratory tests for physical and chemical soil properties.

Soil Property	Normal Range in Tundra Soil[a]
Physical	
Particle Size (%)	
Gravel	15[b]
Sand	18–69
Silt	15–64
Clay	10–39
Organic Matter (%)	5.7–55.5
Chemical	
pH	5.2–7.8
Salinity	
Electrical Conductivity (dS/m)	<2
Sodium Adsorption Ratio	<13[c]
Available Nutrients (mg/kg)	
Nitrogen, Ammonium	8.7–19.5
Nitrogen, Nitrate	5.5–15.2
Phosphorus	0.1–15
Exchangeable Cations (mg/kg)	
Potassium	92–349
Calcium	1399–7381
Magnesium	93–627
Sodium	15–150[b]

[a] Reference values (except where noted) from Walker (1985).
[b] Reference values from unpublished ABR data.
[c] Reference value from Brady and Weil (1996).

AM-6 Monitoring Vegetation

The health, cover, and composition of tundra vegetation are measured before and after treatment, to aid in assessing impacts and monitoring recovery of tundra affected by a spill. The effects of a spill can also be assessed by comparing vegetation in a spill area with vegetation in an area unaffected by the spill. The fastest field techniques for monitoring vegetation use visual observations of plant health, repeat photography (photo-trend plots), or the semiquantitative method of estimating plant cover in plots of a specified size (area method). The preferred method for monitoring vegetation is the point-intercept method because it provides more objective data. The potential for revegetation of a site can be assessed with test plots to determine whether seeds will germinate, and plants can establish and survive under certain conditions. Identification of plant species and implementing some of the monitoring techniques may require special expertise. If appropriate, consult with a plant scientist or other qualified person to develop a monitoring plan or to conduct the vegetation monitoring.

Plant Health

The health and condition of tundra plants growing on the site is evaluated qualitatively based on visual examination. Look for signs of growth, reproduction (flowers, seeds, spreading by roots) and vigor (health) using undisturbed vegetation not affected by the spill near the site as a reference. Signs of poor growing conditions, stress, or toxic effects of contaminants may include dead plants or dead leaves, discoloration such as yellow leaves, stunted plants, lack of reproduction, and slow or no growth. Remain alert to evidence of grazing by animals (e.g., torn leaves, scat, tracks), which may have removed a significant amount of plant parts. Evaluation of the condition of plants often does not require special expertise.

Photo-Trend Plots

Using photographs to monitor permanent plots is a popular and effective technique for monitoring the revegetation of affected tundra over successive growing seasons. This technique is most useful if the same view direction is used each time and is dependent upon being able to relocate the plot. The corners of permanent plots can be marked with metal nails (6 to 9 inches in length) that are commonly used by surveyors, or with wooden or steel "rebar" stakes. A common method used to delineate individual plots in a photograph is to place a 1–meter-square quadrat frame made of white PVC pipe or aluminum flat-bar on the tundra (Fig. 130). A stake is then driven into the tundra soil in opposite corners to mark the location of the quadrat permanently. Prepare a map of the plot locations (Tactic AM-1) so that plots can be easily relocated over multiple years for repeat sampling. If possible, stand in the same location, and use the same camera focal length and exposure settings each time a plot is photographed. It can be very helpful during fieldwork to use a photo of the plot taken previously as a reference when re-taking photographs. Some photo-trend plots of experimental oil spill sites on the North Slope have been documented for over 25 years, providing valuable information about the recovery of the tundra.

Vegetation Cover

Vegetation cover is the vertical projection of vegetation from the ground as viewed from above. Vegetation cover is commonly estimated using either point or area methods (Bonham 1989; NARSC 1999).

Point intercept methods are based on the number of "hits" on vegetation out of the total number of points measured; either the point "hits" a part of the plant (e.g., leaf or stem) or it does not (Fig. 131). The point is defined by shining a pinpoint-beam laser pointer (beam diameter approximately 2 mm) vertically down through the vegetation (i.e., perpendicular to the ground). The plant is hit when the light

Figure 130. 1-m^2 vegetation quadrat

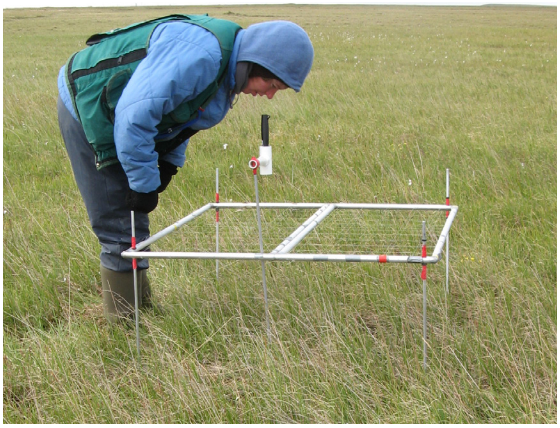


Figure 131. Laser and point-frame

beam is visible as a dot (typically red or green) on a plant part. A second method is based on an observer looking past cross hairs made of thin wire (similar to a gun sight); the plant is hit when it lies beneath the cross hairs. The cross hairs are mounted in a point-frame (Fig. 131). The laser is mounted on a steel rod that is driven into the ground to provide a stable sampling point. Similarly, the stability of a point frame is maintained by driving the four legs in each corner of the frame into the tundra. Many points must be sampled in groups along a line or within a frame to provide useful information. The percent cover of live plants is calculated as the total number of hits on live plants divided by the total number of points sampled. For example, if 50 points are measured and 10 points have "hits" on plants, then the total cover of live plants would be 20%. Tundra vegetation often has multiple layers, or canopies, which can result in a total plant cover that is >100% when using point intercept methods. Sampling specifications may vary due to different sampling goals. For example, only the top hit of vegetation may be of interest, or only the first hit of each new species encountered at a sampling point may be of interest. Counting all layers of vegetation until the laser hits the ground surface will yield the highest total plant cover.

Area methods involve placing a quadrat (a square or circle) of known area on the ground surface, and visually estimating plant cover classes (Fig. 130). Typical examples of classes are 1–5%, 6–25%, 26–50%, 51–75%, and >75%. A 20- by 50-centimeter frame is a popular quadrat size for estimating tundra vegetation cover. Usually a number of quadrats (10–30) are evaluated at a site to reduce the bias inherent in this method. If more than one person is estimating plant cover, the observers should train together and compare estimates within the same quadrats to minimize the amount of error. Although simpler to implement than the point-intercept method, the area method is greatly affected by the biases of each observer. Thus, estimates of vegetation cover using the area method are more difficult to defend as being objective and repeatable.

Vegetation Composition

Tundra vegetation communities typically include a variety of vascular plants, including sedges, grasses, forbs (broad-leaved herbs), and dwarf or prostrate shrubs, as well as nonvascular plants such as mosses, liverworts, and lichens. The number of plant species is a useful gauge of vegetation recovery at a site when compared to similar, unaffected tundra areas. Accurate identification of plants requires some training or special expertise in plant science. An on-line information source for identification of Alaskan tundra plants is available in the PLANTS database (http://www.plants.usda.gov/home) maintained by the U.S. Department of Agriculture. Technical publications and flower guides commonly used to identify tundra plants are provided in Table 18.

Revegetation Test Plots

Before undertaking large-scale treatments such as excavation for offsite disposal (Tactic CR-13), fertilizing (Tactic TR-3 and Tactic TR-8), seeding (Tactic TR-11), or transplanting (Tactic TR-9), it may be desirable to determine if current conditions are toxic to plants. Establish plots to test seed germination or transplant survival. A typical size of a test plot is 5 x 5 m. Germination should be monitored for a minimum of 1 year and survival should be monitored for a minimum of 2 years.

Table 18. Sources used to identify tundra plants

Vascular Plants (Sedges, Grasses, Forbs, Shrubs)	
Flora of Alaska and Neighboring Territories	Hultén 1968
Willows of Interior Alaska	Collet 2004
Field Guide to Alaskan Wildflowers	Pratt 1989
Wetland Sedges of Alaska	Tande and Lipkin 2003
Flowering Plants of the High-Arctic	Threlkeld 1991
Wildflowers of the Yukon and Northwestern Canada, including adjacent Alaska	Trelawny 1983
Alaska Trees and Shrubs	Viereck and Little 2007
The Alaska Vegetation Classification System	Viereck et al. 1992
Nonvascular Plants (Mosses and Lichens)	
American Arctic Lichens	Thomson 1984, 1997
Wetland Indicator Bryophytes of Interior and South Central Alaska	Seppelt et al. 2006
Mosses, Lichens and Ferns of Northwest North America	Vitt et al. 1988

Bibliography

Agosti, J., and T. Agosti. 1973. The oxidation of certain Prudhoe Bay hydrocarbons by microorganisms indigenous to a natural oil seep at Umiat, Alaska. Pages 80–85 *in* Proceeding of the Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Institute of Arctic Biology, Univ. of Alaska, Fairbanks, AK.

Alaska Clean Seas. 2024. Alaska Clean Seas Technical Manual, Volume 1: Tactics Descriptions. Revision 16. https://www.alaskacleanseas.org

Alexander, M. 1995. How toxic are toxic chemicals in the soil? Environmental Science and Technology 29:2713–2717.

Atlas, R. M. 1985. Effects of hydrocarbons on microorganisms and petroleum biodegradation in arctic ecosystems. Pages 63–99 *in* F. R. Engelhardt, ed., Petroleum effects in the arctic environment. Elsevier Applied Science Publishers, New York.

Atlas, R. M., and J. Brown. 1978. Introduction to the workshop on ecological effects of hydrocarbon spills in Alaska. Arctic 31:155–157.

Atlas, R. M., A. Sexstone, P. Gustin, O. Miller, P. Linkins, and K. Everett. 1978. Biodegradation of crude oil by tundra soil microorganisms. Pages 21–28 *in* Biodeterioration, Proceedings of the 4th International Symposium. Berlin, Germany.

Auerbach, N. A., M. D. Walker, and D. A. Walker. 1997. Effects of roadside disturbance on substrate and vegetation properties in arctic tundra. Ecological Applications 7:218–235.

Barker, M. 1985. Two-year study of the effects of a winter brine spill on tussock tundra. Final rep. prepared for ARCO Alaska, Inc., Anchorage, AK. 92 pp.

Barnes, D. L., and D. M. Filler. 2003. Spill evaluation of petroleum products in freezing ground. Polar Record 211:385–390.

Bech, C., and P. Sveum. 1991. Spreading of oil in snow—a field experiment. Pages 57–71 *in* Proceedings of 14th annual arctic and marine oil spill program. Environment Canada, Ottawa, CA.

Behr-Andres, C., J. K. Wiegers, S. Forester, and J. S. Conn. 2001. Tundra Spill Cleanup and Remediation Tactics: A Study of Historic Spills and Literature. State of Alaska Department of Environmental Conservation, Juneau, AK.

Bergstein, P. E., and J. R. Vestal. 1978. Crude oil biodegradation in arctic tundra ponds. Arctic 31:158–169.

Billings, W. D. 1973. Arctic and Alpine Vegetation: Similarities, Differences, and Susceptibility to Disturbance. BioScience 23:697–704.

———. 1974. Arctic and alpine vegetation: plant adaptations to cold summer climates. Pages 403–443 *in* J. D. and R. G. Barry Ives, (eds.). Arctic and Alpine Environments. William Clowes and Sons Ltd., Great Britain.

Bishop, S. C., J. G. Kidd, T. C. Cater, L. J. Rossow, and M. T. Jorgenson. 1998. Land rehabilitation studies in the Kuparuk Oilfield, Alaska, 1997. Twelfth annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services. 66 pp.

———. 1999. Land rehabilitation studies in the Kuparuk Oilfield, Alaska, 1998. Thirteenth annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services. 72 pp.

Blackburn, A. J., H. M Clilverd, R. Samuel, K. M. Holland, and D. M. White. 2007. Chemistry of North Slope, Alaska, Lakes and Reservoirs: September 2005 to May 2007. University of Alaska Fairbanks, Water and Environmental Research Center, Fairbanks, AK. Report No. INE/WERC 07.13.

Bliss, L. C., G. M. Courtin, D. L. Pattie, R. R. Riewe, D. W. Whitfield, and P. Widden. 1973. Arctic tundra ecosystems. Annual Review of Ecological Systematics 4:359–399.

Bonham, Charles D. 1989. Measurements for Terrestrial Vegetation. John Wiley & Sons, New York.

BP Exploration (Alaska), Inc. 1994. 1993 X-pad restoration progress report cooperative reclamation plan. September 1, 1993 to August 31, 1996. Environmental Regulatory Affairs, Anchorage, Alaska.

Braddock, J. F., and K. A. McCarthy. 1996. Hydrologic and microbiological factors affecting persistence and migration of petroleum hydrocarbons spilled in a continuous-permafrost region. Environmental Science and Technology 3:2626–2633.

Brady, N. C., and R. R. Weil. 1996. The Nature and Properties of Soils. Prentice-Hall, Upper Saddle River, NJ.

Brendel, J. E. 1985. Revegetation of arctic tundra after an oil spill: a case history. Pages 315–318 *in* Proceedings of 1985 Oil Spill Conference: American Petroleum Institute, Environmental Protection Agency, United States Coast Guard.

Brendel, J. E., and T. G. Eschenbach. 1985. Check valve 23 revegetation study. Pages 230–239 *in* M. L. Lewis, ed. Proc. Eighth Ann. Meet. Int. Soc. Petr. Indust. Biol. Northern hydrocarbon development environmental problem solving. Banff, Alberta.

Brown, A. L., and J. D. McKendrick. 1987. Joint industry/agency/university revegetation feasibility project. Fifth Symposium on Coastal and Ocean Management (Coastal Zone '87). Seattle, WA.

Brown, J., B. E. Brockett, and K. E. Howe. 1984. Interaction of gravel fills, surface drainage, and culverts with permafrost terrain. Alaska Department of Transportation and Public Facilities, Fairbanks, AK. Rep. No. AK-RD-84-11. 35 pp.

Brown, J., R. Haugen, and S. Parrish. 1975. Selected climate and soil thermal characteristics of the Prudhoe Bay Region. J. Brown, editor. Ecological Investigations of the Tundra Biome in the Prudhoe Bay Region, Alaska. University of Alaska, Fairbanks, Alaska. 215 pp.

Brown, J., W. Rickard, and D. Victor. 1969. The effect of disturbance on permafrost terrain. Cold Regions Research and Engineering Lab, Hanover, NH. CRREL Special Report 138.

Brown, R. W., R. S. Johnston, and K. Van Cleve. 1978. Rehabilitation problems in alpine and arctic regions. Pages 23–44 *in* Reclamation of Drastically Disturbed Lands. ASA-CSSA.

Burgess, R. M., T. C. Cater, and M. T. Jorgenson. 1996. In situ bioremediation at the drill site 1 and 2 relief pits, Prudhoe Bay, Alaska, 1991–1995. Final report prepared for CH2M Hill, Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 30 pp.

———. 1996. In-situ Bioremediation at the DS-L2 Spill, Prudhoe Bay, Alaska, 1992–1995. Final Report prepared for ARCO Alaska, Inc. and CH2M Hill, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 24 pp.

Burgess, R. M., T. C. Cater, M. T. Jorgenson, and B. A. Anderson. 1995. Ecological Impact Assessment and Restoration Options for the Pt. McIntyre Oil Spill. Final Report prepared for CH2M Hill, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 63 pp.

Burgess, R. M., M. T. Jorgenson, T. C. Cater, B. A. Anderson, L. L. Jacobs, and B. E. Lawhead. 1995. Ecological impact assessment and restoration options for the DS-5 oil spill. Final Report prepared for CH2MHill and ARCO Alaska, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 63 pp.

Burgess, R. M., E. R. Pullman, T. C. Cater, and M. T. Jorgenson. 1999. Rehabilitation of salt-affected land after close-out of reserve pits. Third Annual Report prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 48 pp.

Campbell, W. B., R. W. Harris, and R. E. Benoit. 1973. Response of Alaskan tundra microflora to a crude oil spill. Pages 53–62 *in* Proceedings of the Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Institute of Arctic Biology, Univ. of Alaska, Fairbanks, AK.

Cargill, S. M., and F. S. Chapin III. 1986. Establishment of native plants on disturbed soils in arctic Alaska. P. J. Webber, ed. Restoration and Vegetation Succession in Circumpolar Lands. Proceedings of the 7th Conference Comite Arctique Int. Reykjavik, Iceland.

———. 1987. Application of successional theory to tundra restoration: A review. Arctic and Alpine Research 19:366–372.

Carter, R. 1994. Revegetation Plant Identification Field Guide. Alaska Plant Materials Center, Anchorage, AK. 84 pp.

Cater, T. C., R. M. Burgess, and M. T. Jorgenson. 1996. In-situ bioremediation of contaminated tundra at the central gas facility, Prudhoe Bay, Alaska, 1995. Final Report prepared for ARCO Alaska, Inc., and CH2M Hill, Anchorage, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 21 pp.

———. 1997. Assessment of phytotoxicity of tundra soil contaminated with diesel fuel, Drill Site-L2, Prudhoe Bay, Alaska, 1996. Final Report prepared for ARCO Alaska, Inc., Anchorage, AK, and CH2M Hill, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 28 pp.

Cater, T. C., and M. T. Jorgenson. 1993. Land Rehabilitation Studies in the Kuparuk Oil Field, Alaska, 1992. Seventh Annual Report prepared for ARCO Alaska Inc. and Kuparuk River Unit, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 38 pp.

———. 1994. Remediation of gravel and tundra at the SWPT Pad, Kuparuk Oil Field, Alaska, 1993. Unpublished Report prepared for ARCO Alaska, Inc., by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 46 pp. + appendices.

———. 1995. Long-term ecological monitoring of tundra affected by a crude oil spill near Drill Site 2U, Kuparuk Oilfield, Alaska. 1994 Annual Report prepared for ARCO Alaska, Inc., Anchorage, AK, and Kuparuk River Unit, Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 42 pp.

———. 1996. Land Rehabilitation Studies in the Kuparuk Oil Field, Alaska, 1995. 10th Annual Report prepared for ARCO Alaska, Inc. and the Kuparuk River Unit, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 72 pp.

———. 1996. Sewage sludge application on a thick gravel pad in the Kuparuk Oilfield, Alaska, 1989–1995. Final Report prepared for ARCO Alaska, Inc., Anchorage AK and Kuparuk River Unit, Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 34 pp.

———. 1999. Assessing damage from hydrocarbons and cleanup operations after crude oil spills in Arctic Alaska. Final Report prepared for ARCO Alaska, Inc., Anchorage, AK and Kuparuk River Unit, Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 80 pp.

Cater, T. C., E. R. Pullman, R. M. Burgess, and M. T. Jorgenson. 1998. Cleanup and bioremediation of crude oil and methanol at Drill Site 16, Prudhoe Bay oilfield, Alaska, 1997. Final Report prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 48 pp.

Cater, T. C., L. J. Rossow, and M. T. Jorgenson. 1999. Long-term ecological monitoring of tundra affected by a crude oil spill near Drill Site 2U, Kuparuk Oilfield, 1996. Annual Report prepared for ARCO Alaska, Anchorage, AK, by ABR Inc.—Environmental Research and Services, Fairbanks, AK. 53 pp.

Cater, T. C., T. C. Hopson, and B. Streever. 2015. The use of the Inupiaq technique of tundra sodding to rehabilitate wetlands in northern Alaska. Arctic 68 (4):435–444.

Chapin, F. S. III. 1986. Controls over growth and nutrient use by Taiga forest trees. Pages 96–111 *in* K. Van Cleve, F. S. Chapin III., P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, eds. Forest Ecosystems in the Alaskan Taiga. Springer-Verlag, New York. Ecological Studies 57.

Chapin, F. S. III, and G. R. Shaver. 1985. Individualistic growth response of tundra plant species to environmental manipulations in the field. Ecology 66:654–576.

Chester, A. L., and G. R. Shaver. 1982. Seedling dynamics of some cottongrass-tussock tundra species during the natural revegetation of small disturbed areas. Holarctic Ecology 5:207–211.

Clark, R. C., and John S. Finley. 1977. Effects of oil spills in arctic and subarctic environments. Pages 411–476 *in* Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Vol. II. Academic Press, New York, N.Y. 500 pp.

Collet, D. 2004. Willows of Interior Alaska. U.S. Fish and Wildlife Service, Anchorage, Alaska. 111 pp.

Collins, C. M., C. H. Racine, and M. E. Walsh. 1993. Fate and effects of crude oil spilled on subarctic permafrost terrain in Interior Alaska: fifteen years later. U.S. Cold Reg. Res. Eng. Lab., Hanover, NH. CRREL Rep. 9313. 20 pp.

CONCAWE. 1981. A field guide to coastal oil spill control and clean-up techniques. September. CONCAWE, Brussels, The Hague, Belgium.

———. 1983. A field guide to inland oil spill clean-up techniques. December. CONCAWE, Brussels, The Hague, Belgium.

Corapcioglu, M. Y., and S. M. Panday. 1993. Simulation of hydrocarbon spills in permafrost. Pages 100–104 *in* Proceedings Sixth International Permafrost Conference. South China Univ. of Tech. Press, Wushan Guangzhou China.

Costerton, J. W., G. J. Brunskill, T. Hutchinson, and P. Widden. 1978. Summary of workshop on ecological effects of the hydrocarbon spills in Alaska. Arctic 31:408–411.

Deneke, F. J., B. H. McCown, P. I. Coyne, W. Rickard, and J. Brown. 1975. Biological aspects of terrestrial oil spills: USA CRREL Oil Research in Alaska, 1970–

1974. Cold Regions Research and Engineering Laboratory, Hanover, NH. Research Report 346. 66 pp.

Densmore, R. V., B. J. Neiland, J. C. Zasada, and M. A. Masters. 1987. Planting willow for moose habitat restoration on the North Slope of Alaska, USA. Arctic and Alpine Research 19:537–543.

Department of Environmental Conservation. 2024. Field Sampling Guidance. Division of Spill Prevention and Response Contaminated Sites Program, Juneau, Alaska. https://dec.alaska.gov/spar/csp/guidance-forms/

Dickman, M., and V. Lunardini. 1973. Some effects of a deliberate small-scale oil spill on the overlying vegetation and the thaw depth near Inuvik, NWT. D. Mackay, and W. Harrison, eds. Oil and the Canadian environment. Univ. of Toronto, Institute of Environmental Sciences and Engineering, Toronto.

Dragun, J. 1988. Recovery techniques and treatment technologies for petroleum and petroleum products in soil and groundwater. Pages 211–217 *in* P. T. Krostecki, and E. J. Calabrese, ed., Petroleum contaminated soils. Lewis Publishers, Inc., Chelsea, MI.

———. 1988. The Soil Chemistry of Hazardous Materials. Haz. Mat. Control Res. Inst., Silver Spring, MD.

Ebersole, J. J. 1987. Short-term vegetation recovery at an Alaskan arctic coastal plain site. Arctic and Alpine Research 19:422–450.

Ebersole, J. J., and P. J. Weber. 1983. Biological decomposition and plant succession following disturbance on the Arctic Coastal Plain, Alaska. Pages 266–271 *in* Permafrost Fourth International Conference Proceedings. Univ. of Alaska. National Academy Press, Washington, D. C.

Emers, M., and J. C. Jorgenson. 1997. Effects of winter seismic exploration on tundra vegetation and the soil thermal regime on the Arctic National Wildlife Refuge, Alaska. Pages 443–456 *in* R. M. M. Crawford, Ed. Disturbance and Recovery in Arctic Lands, An Ecological Perspective. Kluwer Academic Publishers, Dordrecht, Netherlands.

Everett, K. R. 1978. Some effects of oil on the physical and chemical characteristics of wet tundra soils. Arctic 31:260–276.

Everett, K. R., D. L. Kane, and L. D. Hinzman. 1996. Surface water chemistry and hydrology of a small Arctic drainage basin. Pages 185–201 *in* J. F. Reynolds, and J. D. Tenhunen (eds.), Landscape Function and Disturbance in Arctic Tundra. Ecological Studies: Analysis and Synthesis, Springer-Verlag, Berlin, Heidelberger Platz 3/W-1000 Berlin 33/Germany.

Exxon. 1992. Oil spill response manual. Exxon Production Research Company, 193 pp.

Federle, T. W., J. R. Vestal, G. R. Hater, and M. C. Miller. 1979. The effects of Prudhoe Bay crude oil on primary production and zooplankton in arctic tundra thaw ponds. Marine Envir. Res. 2:3–18.

Felix, N. A., and M. K. Raynolds. 1989. The effects of winter seismic trails on tundra vegetation in northeastern Alaska, USA. Arctic and Alpine Research 21:188–202.

Felix, N. A., M. K. Raynolds, J. C. Jorgenson, and K. E. DuBois. 1992. Resistance and resilience of tundra plant communities to disturbance by winter seismic vehicles. Arctic and Alpine Research 24:69–77.

Fetcher, N., and G. R. Shaver. 1983. Life histories of tillers of Eriophorum vaginatum in relation to tundra disturbance. Journal of Applied Ecology 71:131–148.

Filler, D. 2000. Spill response, assessment, and the need for a tundra treatment protocol. Environment Canada's 23rd Arctic and Marine Oilspill (AMOP) Technical Seminar. Activity Updates & Contingency Planning, Coast Plaza Suite Hotel at Stanley Park in Vancouver, British Columbia, Canada.

Filler, D. M., and D. L. Barnes. 2003. Technical procedures for recovery and evaluation of chemical spills on tundra. Cold Regions Science and Technology 37:121–135.

Forbes, B. C. 1996. Plant communities of archeological sites, abandoned dwellings, and trampled tundra in the eastern Canadian Arctic: a multivariate analysis. Arctic 49:141–154.

———. 1998. Cumulative impacts of vehicle traffic on high arctic tundra: soil temperature, plant biomass, species richness and mineral nutrition. Pages 269–274 *in* A. G. Lewkowicz, and M. Allard, eds., Proceedings of Seventh International Permafrost Conference. Universite Laval, Sainte-Foy, Quebec. Collection Nordicana, No. 57.

Foster, M. S., J. A. Tarpley, and S. L. Dearn. 1990. To clean or not to clean: the rationale, methods, and consequences of removing oil from temperate shores. The Northwest Environmental Journal 6:105–120.

Freedman, W., and T. C. Hutchinson. 1976. Physical and biological effects of experimental crude oil spills on low arctic tundra in the vicinity of Tuktoyaktuk, N.W.T., Canada. Can. J. Bot. 54: 2219–2230.

French, H. M. 1985. Surface disposal of waste drilling fluids, Ellef Ringnes Island, N.W.T.: short-term observations. Arctic 38:292–302.

Gartner, B. L., F. S. Chapin III, and G. R. Shaver. 1983. Demographic patterns of seedling establishment and growth of native graminoids in an Alaskan tundra disturbance. Journal of Applied Ecology 20:965–980.

Giblin, A. E., K. J. Nadelhoffer, G. R. Shaver, J. A. Laundre, and A. J. Mckerrow. 1991. Biogeochemical diversity along a riverside toposequence in Arctic Alaska. Ecological Monographs 61:415–435.

Harding Lawson Associates (HLA). 1988. Reserve pit tundra environmental chemistry study, Kuparuk River Unit, Alaska. Final rep. prepared for ARCO Alaska, Inc., Anchorage, AK, by Harding Lawson Associates, Anchorage, AK.

Harper, K. A., and G. P. Kershaw. 1996. Natural revegetation on borrow pits and vehicle tracks in shrub tundra, 48 years following construction of the CANOL No. 1 Pipeline, N.W.T., Canada. Arctic and Alpine Research 28:163–171.

———. 1997. Soil characteristics of 48-year-old borrow pits and vehicle tracks in shrub tundra along the CANOL No. 1 pipeline corridor, Northwest Territories, Canada. Arctic and Alpine Research 29: 105–111.

Hemenway, C. G. 1990. Wildlife cleanup products meet with icy reception. Environment Today. May 1990.

Henry, G. H. R., and A. Gunn. 1991. Recovery of tundra vegetation after overgrazing caribou in Arctic Canada. Arctic 44:38–42.

Herlugson, C. J., J. D. McKendrick, and J. A. Parnell. 1996. Gravel pad restoration on Alaska's North Slope. In International Conference on Health, Safety & Environment. New Orleans, LA.

Hernandez, H. 1973. Natural plant recolonization of surficial disturbances, Tuktoyaktuk Peninsula region, Northwest Territories. Canadian Journal of Botany 51:2177–2196.

Holt, S. 1987. The effects of crude and diesel oil spills on plant communities at Masters Vig, Northeast Greenland. Arctic and Alpine Research 19: 410–497.

Horowitz, A., A. Sextone, and R. M. Atlas. 1978. Hydrocarbons and microbial activities in sediment of an Arctic lake one year after contamination with leaded gasoline. Arctic 31:180–191.

Howard, P. D. 1991. Handbook of environmental degradation rates. Lewis Publishers, Chelsea, Michigan.

Hultén, E. 1968. Flora of Alaska and Neighboring Territories. Stanford University Press, Stanford, CA.

Hutchinson, T. C. 1984. Recovery of arctic and subarctic vegetation nine summers after crude and diesel oil spills. Department of Indian Affairs and Northern Development, Ottawa. Environmental Studies No. 22. 39 pp.

Jacobs, L. J., M. T. Jorgenson, and T. C. Cater. 1993. Wetland creation and revegetation on an overburden stockpile at Mine Site D, Kuparuk Oilfield, 1992. Second Annual Rep. prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Inc., Fairbanks. 23 pp.

———. 1994. Wetland creation and revegetation on an overburden stockpile at Mine Site D, Kuparuk Oilfield, 1993. Third Annual Rep. prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Inc., Fairbanks. 29 pp.

Jenkins, T. F., L. A. Johnson, C. M. Collins, and T. T. McFadden. 1978. The physical, chemical, and biological effects of crude oil spills on black spruce forest, interior Alaska. Arctic 31:305–323.

Johnson, A. W., and B. J. Neiland. 1983. An analysis of plant succession on frost scars, 1961–1980. Pages 537–542 *in* Fourth International Permafrost Conference Proceedings. Univ. of Alaska. National Academy Press, Washington, D.C.

Johnson, L., and L. Viereck. 1983. Recovery and active layer changes following a tundra fire in northwestern Alaska. Pages 543–547 *in* Fourth International Permafrost Conference Proceedings. University of Alaska Fairbanks, Alaska. National Academy Press, Washington, D.C.

Jordan, M. J., J. E. Hobbie, and B. J. Peterson. 1978. Effect of petroleum hydrocarbons on microbial populations in an arctic lake. Arctic 31: 170–179.

Jorgenson, E. E., S. Demarais, and T. Monasmith. 2000. A variation of line intercept sampling: comparing long transects to short transects. Texas Journal of Science 52:48–52.

Jorgenson, M. T. 1988. Revegetation of the Lake State 1 exploratory well site, Prudhoe Bay Oilfield, Alaska, 1987. Final rep. prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 74 pp.

Jorgenson, M. T. 1989. An overview of rehabilitation research in the Kuparuk Oilfield. Rep. prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 64 pp.

———. 1997. Effects of Petroleum spills on tundra ecosystems. NPR-A Symposium Draft Proceedings on Science, Traditional Knowledge, and the Resources of the Northeast Planning Area of the National Petroleum Reserve-Alaska. Anchorage, Alaska.

———. 1997. Patterns and rates of, and factors affecting natural recovery on land disturbed by oil development in arctic Alaska. Pages 421–442 *in* Disturbance and Recovery in Arctic Lands: and Ecological Perspective. Kluwer Academic Publishers, Dordrecht, Netherlands. NATO ASI Series 2 Environment, Vol. 25.

Jorgenson, M. T., and T. C. Cater. 1992. Bioremediation and tundra restoration after a crude-oil spill near Drill Site 2U, Kuparuk Oilfield, Alaska. Final rep. prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 45 pp.

———. 1992. Land rehabilitation studies in the Kuparuk Oilfield, Alaska, 1991. Sixth annual report prepared for ARCO Alaska, Inc., Anchorage, by Alaska Biological Research, Inc., Fairbanks. 51 pp.

———. 1995. Cleanup, bioremediation, and tundra restoration after a crude-oil spill, S.E. Eileen Exploratory Well Site, Prudhoe Bay, Alaska, 1993. Final report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 57 pp.

———. 1996. Minimizing ecological damage during cleanup of terrestrial and wetland oil spills. Pages 257–293 *in* Storage Tanks: Advances in Environmental Control Technology. Gulf Publishing, Houston, TX.

Jorgenson, M. T., T. C. Cater, M. Joyce, and S. Ronzio. 1992. Cleanup and bioremediation of a crude-oil spill at Prudhoe Bay, Alaska. Pages 715–722 *in* Proceedings of the Fifteenth Arctic and Marine Oil Spill Program Technical Seminar. Edmonton, Alberta. Environment Canada, Ottawa, Ontario.

Jorgenson, M. T., T. C. Cater, and K. Kielland. 1991. Bioremediation and tundra restoration after a crude-oil spill near Drill Site 2U, Kuparuk oilfield, Alaska, 1991. Annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 52 pp.

Jorgenson, M. T., T. C. Cater, and L. A. Nix. 1993. Cleanup, bioremediation, and tundra restoration after a crude-oil spill, S.E. Eileen Exploratory Well Site, Prudhoe Bay, Alaska, 1992. Annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 45 pp.

Jorgenson, M. T., T. C. Cater, M. Smith, and B. A. Anderson. 1995. Remote sensing of salinity and gravel impacts to tundra ecosystems using vegetation indicators at four drill sites in the Kuparuk Oilfield, 1994. Final report prepared for ARCO Alaska, Inc., Anchorage, AK, by ABR, Inc.—Environmental Research & Services.

Jorgenson, M. T., T. T. Heffernan, and B. K. Lance. 1990. Land rehabilitation studies in the Kuparuk Oilfield, Alaska, 1989. Fourth annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 132 pp.

Jorgenson, M. T., and M. R. Joyce. 1994. Six strategies for rehabilitating land disturbed by oil development in arctic Alaska. Arctic 47:374–390.

Jorgenson, M. T., and J. G. Kidd. 1993. Remote sensing of vegetation impacts adjacent to eight drill sites in the Prudhoe Bay Oilfield, Alaska. Final report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 40 pp.

———. 1994. Extent of vegetation impacts adjacent to eight drill sites in the Prudhoe Bay Oilfield, 1993 Final Report prepared for ARCO Alaska, Inc. and CH2M Hill by Alaska Biological Research, Inc.

Jorgenson, M. T., K. Kielland, B. S. Schepert, and J. B. Hyzy. 1991. Bioremediation and tundra restoration after a crude-oil spill near Drill Site 2U, Kuparuk oilfield, Alaska, 1990. Annual report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 82 pp.

Jorgenson, M. T., L. W. Krizan, and M. R. Joyce. 1991. Bioremediation and tundra restoration after an oil spill in the Kuparuk Oilfield, Alaska, 1990. Pages 149–154 *in* Proceedings of the 14th Annual Arctic and Marine Oil Spill Technical Program. Vancouver, BC. Environ. Canada, Ottawa, Ontario.

Jorgenson, M. T., L. A. Nix, and T. C. Cater. 1993. Site assessment at SWPT Pad, Kuparuk Oilfield, Alaska, 1992. Final report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 33 pp.

Jorgenson, M. T., M. A. Robus, C. O. Zachel, and B. E. Lawhead. 1987. Effects of a brine spill on tundra vegetation and soils in the Kuparuk Oilfield, Alaska. Final report prepared for ARCO Alaska, Inc., Anchorage, AK, by Alaska Biological Research, Inc., Fairbanks, AK. 142 pp.

Joyce, M. R. 1987. Revegetation in the Arctic. Fifth Symposium on Coastal and Ocean Management (Coastal Zone '87). Seattle, WA.

Kershaw, G. P. 1990. Movement of crude oil in an experimental spill on the SEEDS simulated pipeline right-of-way, Fort Norman, N.W.T. Arctic 43:176–183.

Kershaw, G. P., and L. J. Kershaw. 1986. Ecological characteristics of 35-year-old crude-oil spills in tundra plant communities of the Mackenzie Mountains, N.W.T. Can. J. Botany 64:2935–2947.

———. 1987. Successful plant colonizers on disturbances in tundra areas of Northwestern Canada. Arctic Alp. Res. 19:451–460.

Kidd, J. G., T. C. Cater, L. J. Rossow, and M. T. Jorgenson. 1997. Land rehabilitation studies in the Kuparuk Oilfield, Alaska, 1996. Eleventh annual report prepared for ARCO Alaska, Inc., Anchorage, by ABR, Inc.—Environmental Research & Services, Fairbanks. 66 pp.

Klinger, L. F., D. A. Walker, M. D. Walker, and P. J. Webber. 1983. The effects of a travel road on adjacent tundra vegetation. Prudhoe Bay Waterflood Monitoring Program, Anchorage. 162 pp.

Komarkova, V. 1983. Recovery of plant communities and summer thaw at the 1949 Fish Creek Test Well 1, Arctic Alaska. Pages 645–650 *in* Fourth International Permafrost Conference Proceedings. Univ. of Alaska. National Academy Press, Washington, D.C.

Lambert, J. D. H. 1972. Plant succession on tundra mudflows: preliminary observations. Arctic 25:99–106.

Lawson, D. E., J. Brown, K. R. Everett, A. W. Johnson, V. Komarkova, B. M. Murray, D. F. Murray, and P. J. Webber. 1978. Tundra disturbances and recovery following the1949 exploratory drilling, Fish Creek, Alaska. Cold Regions Research and Engineering Laboratory, Hanover, NH. CRREL Rep. 78-26.

Linkins, A. E., R. M. Atlas, and P. Gustin. 1978. Effect of surface applied crude oil on soil and vascular plant root respiration, soil cellulase, and hydrocarbon hydroxylase at Barrow, Alaska. Arctic 31:355–365.

Linkins, A. E., and N. Fetcher. 1983. Effect of surface applied Prudhoe Bay crude oil on vegetation and soil processes in tussock tundra. Pages 723–728 *in* Fourth International Permafrost Conference Proceedings. Univ. of Alaska. National Academy Press, Washington, D.C.

Linkins, A. E., L. A. Johnson, K. R. Everett, and R. M. Atlas. 1984. Oil spills: damage and recovery in tundra and taiga. Pages 135–155 *in* Restoration of habitats impacted by oil spills. Butterworth Publishers, Boston, MA.

Lockhart, W. L., and R. W. Danell. 1992. Field and experimental tainting of arctic freshwater fish by crude oil and refined petroleum products. Pages 763–772 *in* Proceedings of the fifteenth arctic and marine oil spill program technical seminar. Edmonton, Alberta. Environment Canada, Ottawa, Ontario.

Mackay, D. 1985. The physical and chemical fate of spilled oil. F. R. Englehardt, ed., Petroleum Effects in the Arctic Environment. Elsevier Applied Science Publishers, London.

MacKay, D., M. E. Charles, and C. R. Philips. 1974. The physical aspects of crude oil spills on northern terrain. Information Canada, Ottawa. Report no. 73-42.

MacKay, D., T. W. Ng, W. Y. Shiu, and B. Reuber. 1984. The degradation of crude oil in northern soils. Report prepared for Arctic Land Use Research Program. North Environmental Protection and Renewable Resources Branch, Department of Indian Affairs and Northern Development, Ottawa, Ontario. Environmental Studies No. 32. 40 pp.

Mackay, J. R. 1970. Disturbances to the tundra and forest tundra environment of the western Arctic. Canadian Geotechnical Journal 7 :420–432.

McCown, B. H., F. J. Deneke, W. E. Rickard, and L. L. Tieszen. 1972. The response of Alaskan terrestrial plant communities to the presence of petroleum. Pages 34–43 *in* Proceedings of the Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Institute of Arctic Biology, Univ. of Alaska, Fairbanks, AK.

McCown, D. D., and F. J. Deneke. 1973. Plant germination and seedling growth as affected by the presence of crude petroleum. Pages 44–51 *in* Proceedings of the Symposium on the Impact of Oil Resource Development on Northern Plant Communities. Institute of Arctic Biology, Univ. of Alaska, Fairbanks, AK.

McKendrick, J. D. 1983. Alaska's rangelands Chapter 11. Pages 125–156 *in* H. L McNicholas, ed. Alaska's Agriculture and Forestry. Alaska Rural Development Council Publication #3.

———. 1986. Final cleanup at selected (1975–1981) wellsites, sampling and testing of waters and bottom muds in the reserve pits and the recording of tundra plant responses on the National Petroleum Reserve in Alaska (NPRA), III recording of plant responses. prepared for U.S. Geological Survey, Anchorage, Alaska, by Nuera Reclamation Co. 225 pp.

———. 1987. Plant succession on disturbed sites, North Slope, Alaska, U.S.A. Arctic and Alpine Research 19:554–565.

———. 1991. Arctic tundra rehabilitation—observations of progress and benefits to Alaska. Agroborealis 23:29–40.

———. 1993. *Arctophila fulva*. Transplanting *Arctophila fulva* to create emergent vegetation habitats in arctic Alaska. North Slope Habitat Series. Prepared for BP Exploration (Alaska) Inc.

———. 1996. Rehabilitating arctic tundra in Alaska. C. Bathala, ed. North American Water and Environment Congress, American Society of Civil Engineers. Anaheim, California. New York.

———. 1996. Vegetation recolonization on salt-damaged soil in Arctic Alaska. Proceedings of High Altitude Revegetation Workshop No. 12. Colorado State University, Fort Collins, CO.

———. 1997. Long-term tundra recovery in northern Alaska. Pages 503–518 *in* R. M. M. Crawford, Ed. Disturbance and Recovery in Arctic Lands, An Ecological Perspective. Kluwer Academic Publishers, Dordrecht, Netherlands.

———. 1997. Recovery and rehabilitation of disturbed wetland sites. NPR-A symposium of Science, Traditional Knowledge, and the Resources of the Northeast Planning Area of the National Petroleum Reserve Alaska. Anchorage, AK.

———. 1999. Arctic tundra recovery from crude oil after 24 years, Prudhoe Bay. AgroBorealis 31:28–35.

McKendrick, J. D., G. O. Batzli, K. R. Everett, and J. C. Swanson. 1980. Some effects of mammalian herbivores and fertilization on tundra soils and vegetation. Arctic and Alpine Research 12:565–578.

McKendrick, J. D., J. D. LaPerriere, and T. E. Loynachan. 1981. Cold Climate Oil Spills: A terrestrial and freshwater research review. prepared for Municipal Environmental Research Laboratory, Cincinnati, Ohio, by Environmental Protection Agency, Office of Research and Development. 84 pp.

McKendrick, J. D., and W. W. Mitchell. 1978. Effects of burning crude oil spilled onto six habitat types in Alaska. Arctic 31:277–295.

———. 1978. Fertilizing and seeding oil-damaged Arctic tundra to effect vegetation recovery Prudhoe Bay, Alaska. Arctic 31:296–304.

Miller, M. C., V. Alexander, and R. J. Barsdate. 1978. The effects of oil spills on phytoplankton in an arctic lake and ponds. Arctic 31:192–218.

Miller, O. K., A. E. Linkins, and M. A. Chmielewski. 1978. Fungal biomass responses in oil perturbed tundra at Barrow, Alaska. Arctic 31:394–407.

Mitchell, W. W. 1970. Revegetation problems and progress. Agroborealis 2:18–19, 22.

———. 1978. Development of plant materials for revegetation on Alaska. Pages 113–125 *in* S. T. Kenny, ed. High-Altitude Revegetation Workshop No. 3. Fort Collins, CO.

Mitchell, W. W., T. E. Loynachan, and J. D. McKendrick. 1979. Effects of tillage and fertilization on persistence of crude oil contamination in an Alaskan soil. J. Environ. Qual. 8:525–532.

Mitchell, W. W., and J. D. McKendrick. 1975. Report of research progress on reclamation of land damaged by oil spills. Univ. of Alaska, Palmer Research Center, Prepared for Alyeska Pipeline Service Company. 41 pp.

Mitchell, W. W., J. D. McKendrick, F. J. Wooding, and M. A. Barzee. 1974. Agronomists on the banks of the Sagavanirktok. Agroborealis 6:33–35.

Mozley, S. C., and M. G. Butler. 1978. Effects of crude oil on aquatic insects of tundra ponds. Arctic 31:229–241.

Muhlberg, G. A., and N. J. Moore. 1998. Streambank Revegetation and Protection. A guide for Alaska. Technical Report No. 98-3. Alaska Department of Fish and Game.

Murray, D. F. 1978. Vegetation, floristics, and phytogeography of northern Alaska. Pages 19–36 *in* L. L. Tieszen, Vegetation and Production Ecology of an Alaskan Arctic Tundra. Springer-Verlag, New York.

Myers, K. C., and M. H. Barker. 1984. Examination of drilling reserve pit fluids and effects of tundra disposal at Prudhoe Bay, Alaska, 1982–1983. Report prepared for ARCO Alaska, Inc., Anchorage, AK.

National Applied Resource Sciences Center (NARSC). 1999. Sampling vegetation attributes. Bureau of Land Management National Business Center, Denver, CO. 164 pp.

Natural Resources Conservation Service (NRCS). 2004. Soil survey laboratory methods. Soil Conservation Service, Washington, DC. Soil Surv. Invest. Rept. No. 42. 400 pp.

Newell, R. L. 1987. Revegetation in the Arctic. Page 1759 in O. Magoon, H. Converse, D. Miner, L. T. Tobin, D. Clark, and G. Domurat, eds. Proceedings of the Fifth Symposium on Coastal and Ocean Management (Coastal Zone ‘87). Seattle, WA. ASCE, New York.

Nicholson, F. H. 1978. Permafrost modification by changing the natural energy budget. 3rd Permafrost conference. Edmonton, Alberta, Canada. McGill Subarctic research laboratory, Schefferville, P.Q., Canada. Department of Geography, McGill University, Montreal, P.Q., Canada.

NOAA. 1994. Options for minimizing environmental impacts of freshwater spill response. Hazardous Materials Response & Assessment Division.

———. 1994. Shoreline countermeasures manual. Hazardous Materials Response and Assessment Division.

O'Brien, W. J. 1978. Toxicity of Prudhoe Bay crude oil to Alaskan arctic zooplankton. Arctic 31:219–228.

Ott, A. G. 1993. An evaluation of the effectiveness of rehabilitation at selected streams in North Slope oilfields. Alaska Dept. Fish and Game, Juneau, AK. Tech. Rep. 93-5. 61 pp.

Owens Coastal Consultants. 1994. North slope shoreline oil spill countermeasures manual. Prepared for Alaska Clean Seas, by Owens Coastal Consultants.

Owensby, C. E. 1973. Modified step-point system for botanical composition and basal cover estimates. Journal of Range Management 26:302–303.

Plice, M. J. 1991. Some effects of crude petroleum on soil fertility. Soil Science 13:413–416.

Pollen, M. R. 1986. Final cleanup at selected (1975–1981) wellsites, sampling and testing of waters and bottom muds in the reserve pits, and the recording of tundra plant responses on the National Petroleum Reserve in Alaska (NPRA) Vol. II, sampling and testing of waters and bottom muds in the reserve pits. Unpublished report prepared for U.S. Geological Survey, Anchorage, AK, by Neura Reclamation Co., Anchorage, AK. 164 pp.

Pope, P. R., S. O. Hillman, and L. Safford. 1982. Arctic coastal plains tundra restoration: a new application. Pages 93–108 *in* Proceedings of the Fifth Arctic Marine Oil Spill Program Technical Seminar. Edmonton, Alberta. Environment Canada, Ottawa, Canada.

Post, R. A. 1991. Restoring Alaska's Wetlands. National Wetlands Newsletter 9:8–11.

Pratt, V. E. 1989. Field Guide to Alaskan Wildflowers. Alaskakrafts Publishing, Anchorage, AK. 136 pp.

Preslo, L., M. Miller, W. Suyama, M. Mclearn, P. Kostecki, and E. Fleischer. 1988. Available remedial technologies for petroleum contaminated soils. Pages 115–125 *in* P. T. Kostecki and E. J. Calabrese, eds., Petroleum Contaminated Soils. Lewis Publishers, Inc., Chelsea, MI. Vol. 1. 357 pp.

Racine, C. H. 1981. Tundra fire effects on soils and three plant communities along a hill-slope gradient in the Seward Peninsula, Alaska. Arctic 34:71–84.

Racine, C. H., L. A. Johnson, and L. A. Viereck. 1987. Patterns of vegetation recovery after tundra fires in northwestern Alaska, U.S.A. Arctic and Alpine Research 19:461–469.

Reiley, B. A., J. D. McKendrick, and S.C. Lombard. 1995. Evaluation of liquid calcium (LCA II) in reducing salinity for arctic tundra rehabilitation. Mary C. Landin, ed. National Interagency Workshop on Wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi.

Reynolds, C. M., W. A. Bradley, M. D. Travis, L. B. Perry, and I. K. Iskandar. 1998. Bioremediation of hydrocarbon-contaminated soils and groundwater in northern climates. Hanover, NH. CRREL Special Report 98-5. 26 pp.

Rickard, W. 1972. Preliminary ecological evaluations of the effects of air cushion vehicle tests on the arctic tundra of northern Alaska. CRREL, Hanover, NH. 182. 23 pp.

Rickard, W. E., Jr., and J. Brown. 1974. Effects of vehicles on arctic tundra. Environmental Conservation 1:55–62.

Robus, M. A., S. M. Murphy, R. M. Burgess, and B. A. Anderson. 1986. Natural revegetation and bird use of three disturbed sites in the Kuparuk Oilfield, Alaska, 1985. Final report prepared for ARCO Alaska, Inc., by Alaska Biological Research. 75 pp.

Rogers, H. B., C. A. Beyrouty, T. D. Nichols, D. C. Wolf, and C. M. Reynolds. 1996. Selection of cold-tolerant plants for growth in soils contaminated with organics. Journal of Soil Contamination 5:171–186.

Rovansek, R. J., L. D. Hinzman, and D. L. Kane. 1996. Hydrology of a tundra wetland complex on the Alaskan Arctic Coastal Plain, USA. Arctic and Alpine Research 28:311–317.

Sagers, M. 1994. Oil spill in Russian Arctic. Polar Geog. Geol. 18:95–102.

Salanitro, J. P., P. B. Dorn, M. A. Huesemann, K. O. Moore, I. A. Rhodes, L. M. Rice-Jackson, T. M. Vipond, M. M. Western, and H. L. Wisniewski. 1997. Crude oil hydrocarbon bioremediation and soil ecotoxicity assessment. Environmental Science Technology 31:1769–1776.

Sankvist, J. 1989. Oil spills in arctic regions environmental hazards and recovery techniques. Page 1281 *in* Port and Ocean Engineering Under Arctic Conditions. Lulea, Sweden.

Schepart, B. S., J. B. Hyzy, and M. T. Jorgenson. 1992. Laboratory evaluation of biodegradation of crude oil contaminated tundra soil. Pages 689–714 *in* Proceedings of the 15th Arctic and Marine Oilspill Program Tech. Seminar. Edmonton, Alberta, Canada. Technology Dev. Branch, Environment Canada, Ottawa, Ontario, Canada.

Schoeneberger, P. J., D. A. Wysocki, E. C. Benham, and W. D. Broderson. 2002. Fieldbook for describing and sampling soils Version 2.0. Natural

Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Selkregg, L. L. 1975. Alaska regional profiles, Arctic region. University of Alaska, Arctic Environmental Information and Data Center. 218 pp.

Seppelt, R. D., G.A. Laurson, and R.W. Lichvar. 2006. Wetland Indicator Bryophytes of Interior and South Central Alaska. University of Alaska, Fairbanks, AK.

Sexstone, A., P. Gustin, and R. M. Atlas. 1978. Long-term interactions of microorganisms and Prudhoe Bay crude oil in tundra soils at Barrow, Alaska. Arctic 31:348–354.

Sexstone, A., K. R. Everett, T. Jenkins, and R.M. Atlas. 1978. Fate of crude and refined North Slope soils. Arctic 31:339–347.

Shaver, G. R., and F. S. Chapin III. 1986. Effect of fertilizer on production and biomass of tussock tundra, Alaska, U.S.A. Arctic Alpine and Research 31:348–354.

Shaver, G. R., B. L. Gartner, F. S. Chapin III, and Linkins A.E. 1983. Revegetation of arctic disturbed sites by native tundra plants. Pages 1133–1138 *in* Fourth International Permafrost Conference Proceedings. Univ. of Alaska. National Academy Press, Washington, D.C.

Shirazi, M. A., P. K. Haggerty, C. W. Hendricks, and M. Reporter. 1998. The role of thermal regime in tundra plant community restoration. Restoration Ecology 6:111–117.

Simmons, C. L., K. R. Everett, D. A. Walker, A. E. Linkins, and P. J. Webber. 1983. Sensitivity of plant communities and soil flora to sea-water spills, Prudhoe Bay, Alaska. Cold Regions Research Engineering Laboratory, Hanover, NH. CRREL 83-24. 35 pp.

Skinner, Q. D., S. J. Wright, R. J. Henszey, J. L. Henszey, and S. K. Wyman. 2012. A field guide to Alaska grasses. Education Resources Publishing, Cumming, GA.

Smith, P. D. J. 1988. Cost Analysis report of revegetation various sites with *Arctophila fulva*. *Arctophila* Revegetation Study. Under subcontract to the University of Alaska Fairbanks, pp. 16–29

Smith, P. D. J., J. D. McKendrick, G-L. Turner, R. Hoffman, B. Elder, B. Gerken, and B. F. Collver. 1992. Revegetation Project Report—ARCO 1992 General Environmental Services CH2MHILL Project No. ANC24446.GG. prepared for ARCO Alaska, Inc., by Phillip D.J. Smith & Associates, Inc./PSA, Inc. and ARCO Alaska, Inc. 27 pp.

Sveum, P., and C. Bech. 1991. Burning of oil in snow: experiments and implementation in a Norsk Hydro drilling contingency plan. 14th annual Arctic and Marine Oil Spill Program. Vancouver, BC. Environ. Canada.

Tande, G., and R. Lipkin. 2003. Wetland Sedges of Alaska. Report prepared for the U.S. Environmental Protection Agency. Alaska Natural Heritage Program (UAA), Kenai River Center, AOO/Kenai, AK. 138 pp.

Thomson, J. W. 1984. American arctic lichens, 1. The Macrolichens. Columbia University Press, New York, NY. 504 pp.

———. 1997. American Arctic Lichens: 2. The Microlichens. Columbia University Press, New York, NY.

Threlkeld, N. 1991. Flowering Plants of the High-Arctic. Flora Publishing, Las Cruces, NM.

Trapp, S., A. Köhler, L. C. Larsen, K. C. Zambrano, and U. Karlson. 2001. Phytotoxicity of fresh and weathered diesel and gasoline to willow and poplar trees. J Soils & Sediments 1(2):71–76. DOI: http://dx.doi.org/10.1065/jss2001.07.018

Trelawny, J. G. 2003. Wildflowers of the Yukon, Alaska, and Northwest Canada. Sono Nis Press, Victoria, B.C., Canada.

U.S. Environmental Protection Agency. 2002. Guidance for Quality Assurance Project Plans. EPA/240/R-02/009. Office of Environmental Information, Washington, D.C.

Van Cleve, K. 1977. Recovery of disturbed tundra and taiga surfaces in Alaska. Pages 422–455 *in* J. Cairns, K. L. Dickson, and E. E. Herricks, eds. Proceedings of the International Symposium on the Recovery of Damaged Ecosystems. Blacksburg, VA. Virginia Polytechnic Institute.

Van Cleve, K., and J. Manthei. 1972. Summary report of the tundra-taiga surface stabilization study. Inst. of Arctic Biology, Fairbanks, AK.

Vandermeulen, J. H. 1984. Restoration of habitats impacted by oil spills. Page 182 *in* J. Cairns, Jr., and A. L. Buikema, Jr., eds., Butterworth Publ., Boston., MA.

Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska Vegetation Classification. Pacific Northwest Research Station, U.S. Forest Service, Portland, OR. Gen. Tech. Rep. PNW-GTR-286. 278 pp.

Viereck, L. A., and E. L. Little. 2007. Alaska Trees and Shrubs. University of Alaska Press, Fairbanks, AK.

Vitt, D. H., J. E. Marsh, and R. B. Bovey. 1988. Mosses, lichens, and ferns of Northwest North America. Lone Pine Publishing, Edmonton, Alberta, Canada.

Wahrhaftig, C. 1965. Physiographic Divisions of Alaska. U.S. Geological Survey, Washington, D.C. Professional Paper 482. 52 pp., 6 plates.

Walker, D. A. 1983. A hierarchical tundra vegetation classification especially designed for mapping in northern Alaska. Pages 1332–1337 *in* Fourth International Permafrost Conference Proceedings. Univ. of Alaska, Fairbanks, AK. National Academy Press, Washington, D.C.

———. 1985. The vegetation and environmental gradients of the Prudhoe Bay Region, Alaska. Cold Regions Research and Engineering Lab, Hanover, NH. CRREL Report 85-14. 239 pp.

———. 1997. Arctic Alaskan vegetation disturbance and recovery. Pages 457–480 *in* R. M. M. Crawford, ed. Disturbance and Recovery in Arctic Lands, An Ecological Perspective. Kluwer Academic Publishers, Dordrecht, Netherlands.

Walker, D. A., D. Cate, J. Brown, and C. Racine. 1987. Disturbance and recovery of arctic Alaskan tundra terrain: a review of recent investigations. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH. CRREL Rep. 87-11. 63 pp.

Walker, D. A., and K. R. Everett. 1991. Loess ecosystems of northern Alaska—regional gradient and toposequence at Prudhoe Bay. Ecol. Monogr. 61:437–464.

Walker, D. A., K. R. Everett, P. J. Webber, and J. Brown. 1980. Geobotanical atlas of the Prudhoe Bay region, Alaska. U.S. Army Corps of Engineers Cold Regions Research and Engineering, Hanover, NH. Laboratory Report 80-14. 69 pp.

Walker, D. A., and M. D. Walker. 1991. History and pattern of disturbance in Alaskan arctic terrestrial ecosystems: a hierarchical approach to analyzing landscape change. J. Appl. Ecol. 28:244–276.

Walker, D. A., P. J. Webber, K. R. Everett, and J. Brown. 1978. Effects of crude and diesel oil spills on plant communities at Prudhoe Bay, Alaska, and the derivation of oil spill sensitivity maps. Arctic 31:242–259.

Walker, M. D., D. A. Walker, and K. A. Everett. 1989. Wetland soils and vegetation, Arctic foothills, Alaska. National Ecology Research Center, U.S. Fish and Wildlife Service, Biol. Rep. 89 (7) June. 89 pp.

Walter, J., D. Hughes, and N. J. Moore. 2005. Streambank revegetation and protection. A guide for Alaska. Original Technical Report 98-3 March 1998. Alaska Department of Fish and Game.

Webber, P. J., and J. D. Ives. 1978. Damage and recovery of tundra vegetation. Environmental Conservation 5:171–182.

Webber, P. J., and D. A. Walker. 1975. Vegetation and landscape analysis at Prudhoe Bay, Alaska, a vegetation map of the Tundra Biome study area. J. Brown, ed. Ecological investigations of the Tundra Biome in the Prudhoe Bay region, Alaska. University of Alaska, Fairbanks, AK. Special Report 2. pp. 80–91.

Wein, R. W. 1971. Revegetation-A preliminary report on revegetation trials related to the proposed gas arctic pipeline. Towards an environmental impact assessment of a gas pipeline from Prudhoe Bay, Alaska to Alberta.

Environmental Protection Board, Winnipeg, Man. 49 pp.

West, R. L., and E. Snyder-Conn. 1987. Effects of Prudhoe Bay reserve pit fluids on water quality and macroinvertebrates of Arctic tundra ponds in Alaska. U.S. Fish and Wildlife Service, Washington, DC. 87. 48 pp.

Williams, P. J., and M.W. Smith. 1989. The Frozen Earth: Fundamentals of Geocryology. Cambridge University Press, Cambridge.

Woodward-Clyde . 1995. Wainwright Alaska Spill. ADEC #94310114401. prepared for Alaska Department of Environmental Conservation, by Woodward-Clyde Consultants.

Wright, J. M. 1981. Response of nesting Lapland Longspurs (*Calcarius lapponicus*) to burned tundra on the Seward Peninsula. Arctic 34:366–369.

Wright, S. 1994. Beach wildrye planting guide for Alaska. Plant Materials Center, Alaska Dept. of Natural Resources, Palmer, AK.

Wright, S. J. 1989. Final Report of data and observations obtained from the 2C Access Spur and Mine Site D herbaceous evaluation plots located in the Kuparuk Unit. Alaska Department of Natural Resources - Division of Agriculture, Plant Materials Center, Palmer, AK. 85 pp.

———. 2008. A Revegetation Manual for Alaska. U.S. Department of Agriculture, http://dnr.alaska.gov/ag/RevegManual.pdf

Younkin, W. E., M. T. Strosher, and D. L. Johnson. 1980. Environmental assessment of the terrestrial disposal of waste drilling muds in Alberta; chemistry of sump fluids and effects of vegetation and soils. Canadian Petroleum Assoc., Calgary, Alberta, Canada.

Back cover:

Views after 2 (top) and 7 (bottom) growing seasons of vegetation sprouting from rootstock that survived a spill of hydrocarbons and produced water, as well as the subsequent flushing to recover contaminants. Fertilizer was applied to stimulate the degradation of residual hydrocarbons by indigenous soil bacteria. Note bottom photo shows leaf tips of the wetland sedge *C. aquatilis* (water sedge) that have been clipped by grazing wildlife and a dense cover of mosses that developed in response to fertilizer treatment.

Photographs by Timothy C. Cater, Senior Scientist, ABR.

Tundra Treatment Guidelines is a living document that provides the best available information based on the latest technological and engineering advancements, combined with practical knowledge gained from use of the manual in the field.

This document may be copied, in any format, for all uses excluding those for profit. Readers also may visit the DEC website to use the on-line version of this manual or to download a printed version of the manual for free. The Department of Environmental Conservation welcomes suggestions for improvements that will be considered for future editions. A form is provided for submitting corrections, updates, or refinements.