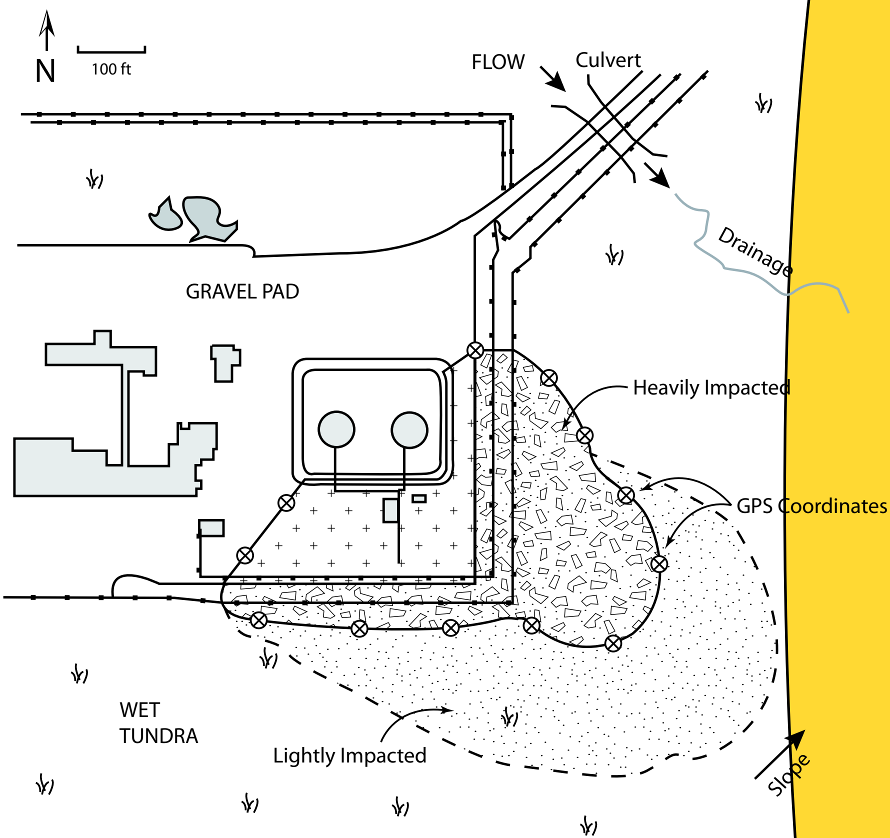
Planning Tactics



Developing Treatment Goals and Strategies

P-1

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 Alaska Department of Environmental Conservation (ADEC). 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. Where natural

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 Alaska Department of Environmental Conservation (ADEC).
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.

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 are adsorbed by the porous root mat, displacing the air and water needed by plant roots. The dry mineral soils in the active layer have the potential to adsorb 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 provides 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 below-ground plant materials may survive and recover. 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 recover spilled material, minimize the potential for migration of contaminants into the surrounding tundra, 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 numbers as guidance. These numbers should be used to help decide when a cleanup should stop because the benefit of additional treatment will be outweighed by the 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.

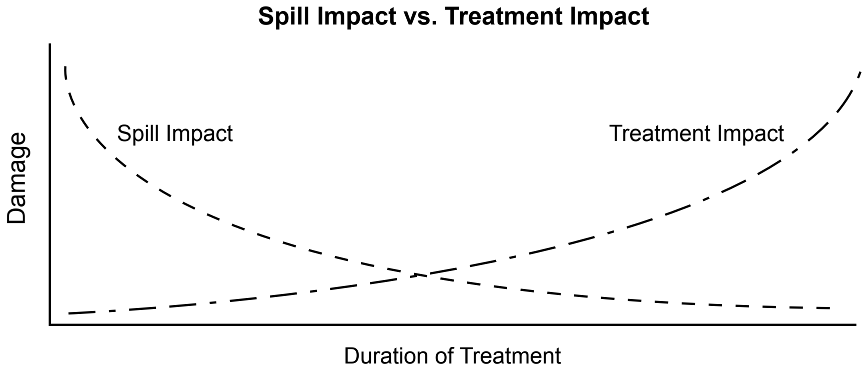


Figure 1. Spill impact vs. treatment impact

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 adsorb 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 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. Use the generalized decision trees in Figure 3 to help develop a strategy for a spill of hydrocarbons (crude oil and diesel), saline substances, or drilling mud.

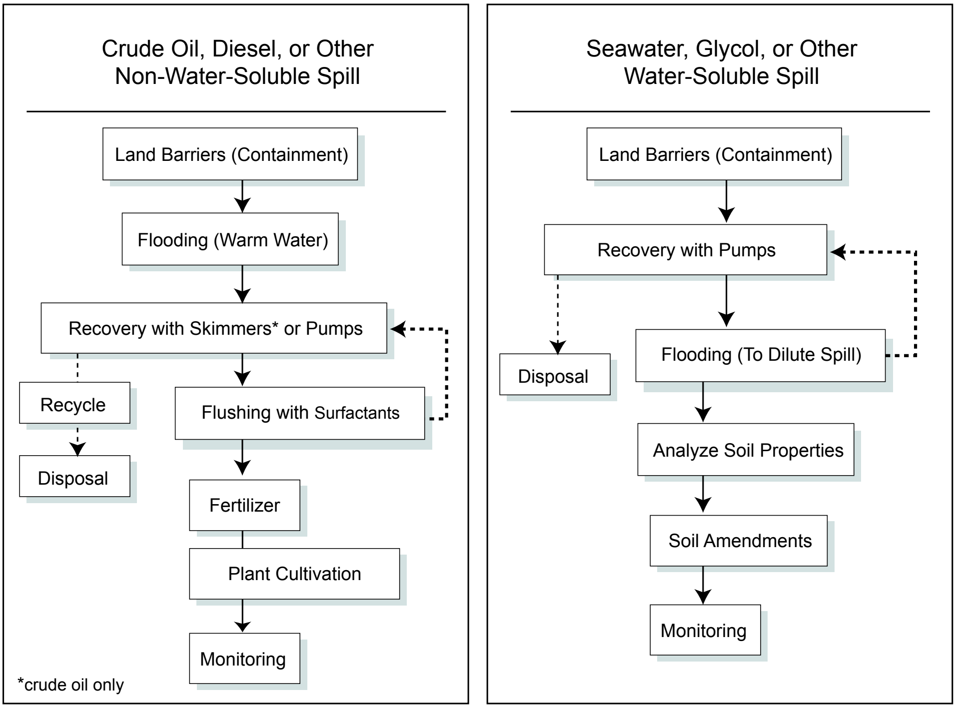


Figure 2. Examples of treatment strategies

Step 6: Monitor Treatment and Recovery

Coordinate with responsible government agencies (including ADEC) 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 (Tactics AM-5 and 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.

Crude Oil or Diesel Spill

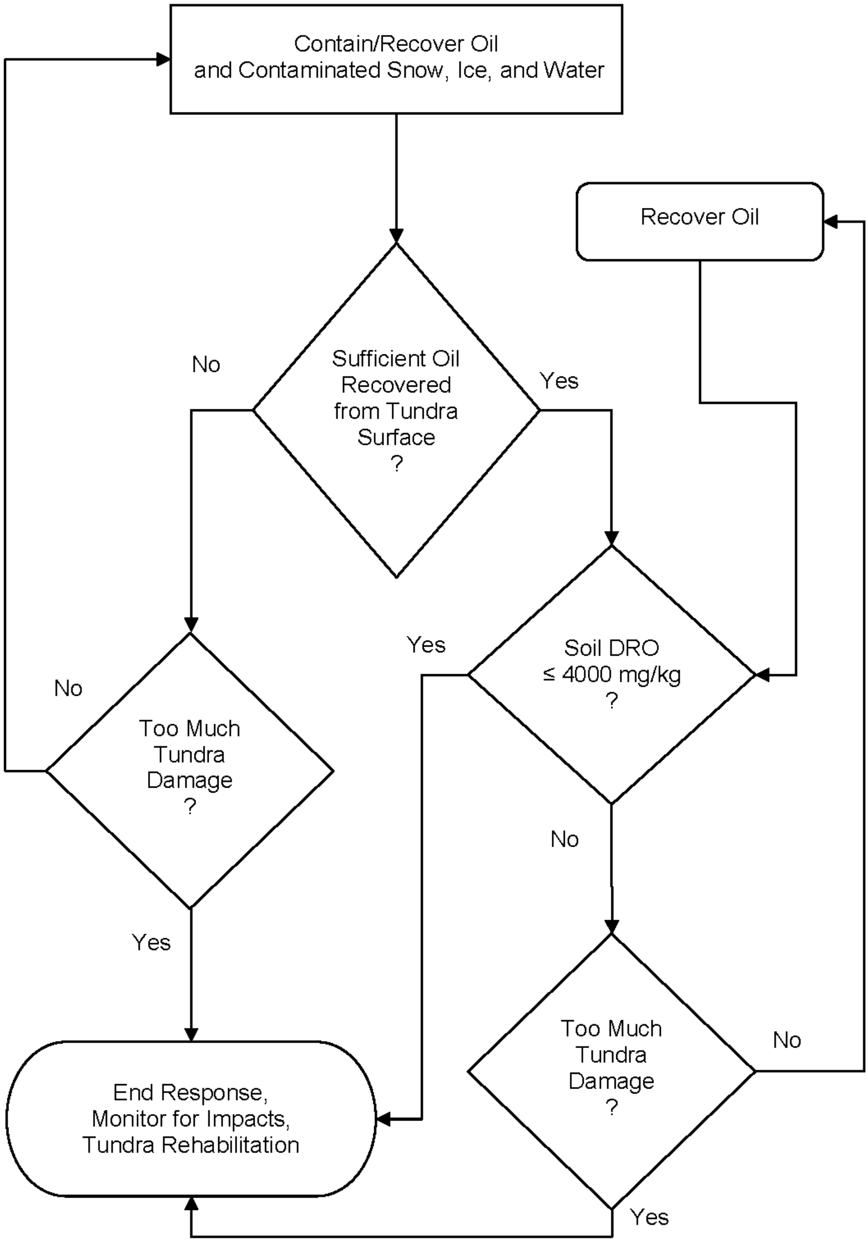


Figure 3a. Generalized example of decision tree to help develop a site-specific treatment strategy for crude oil or diesel spill

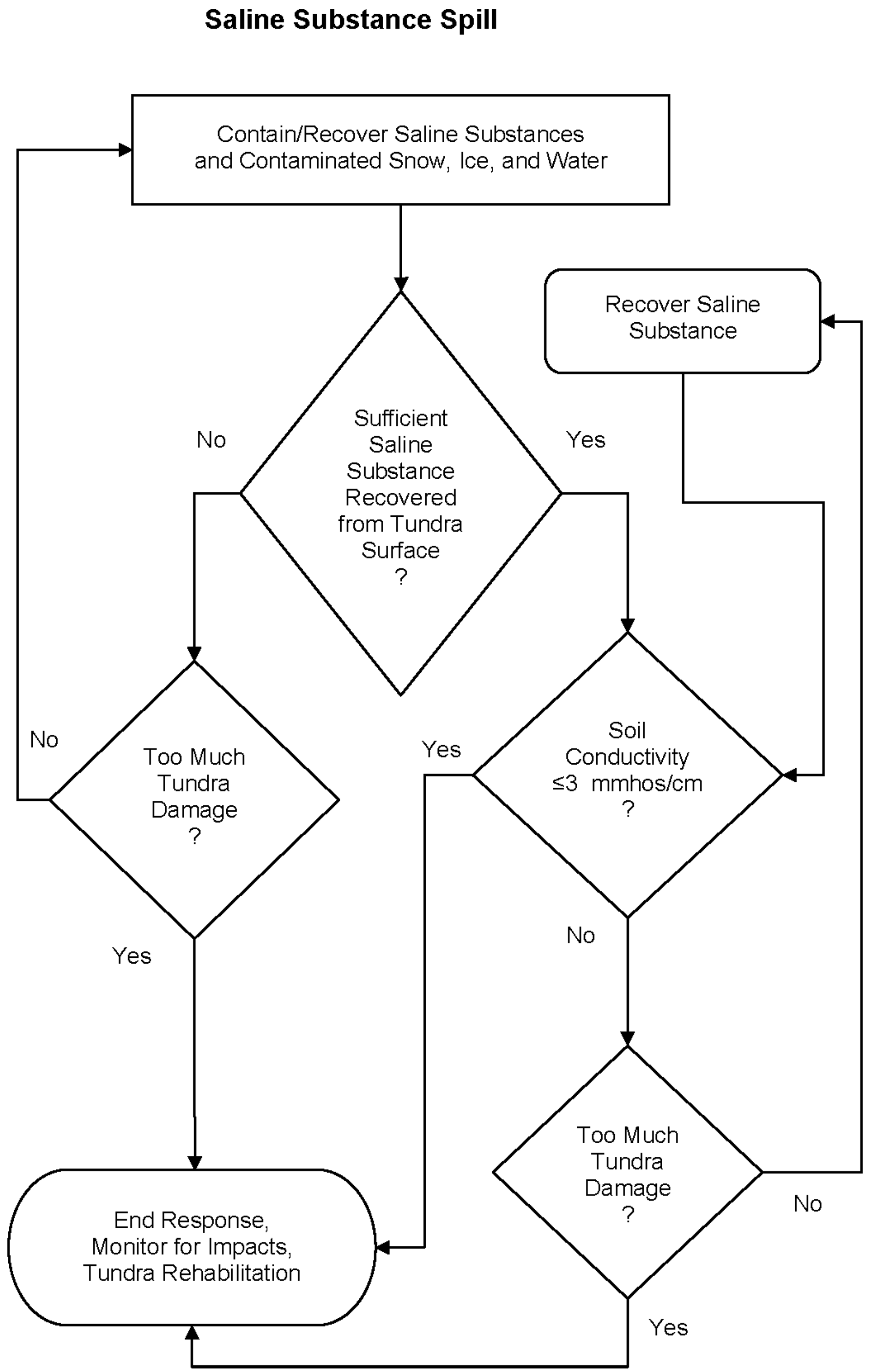


Figure 3b. Generalized example of decision tree to help develop a site-specific treatment strategy for saline substance spill

Drilling Mud Spill

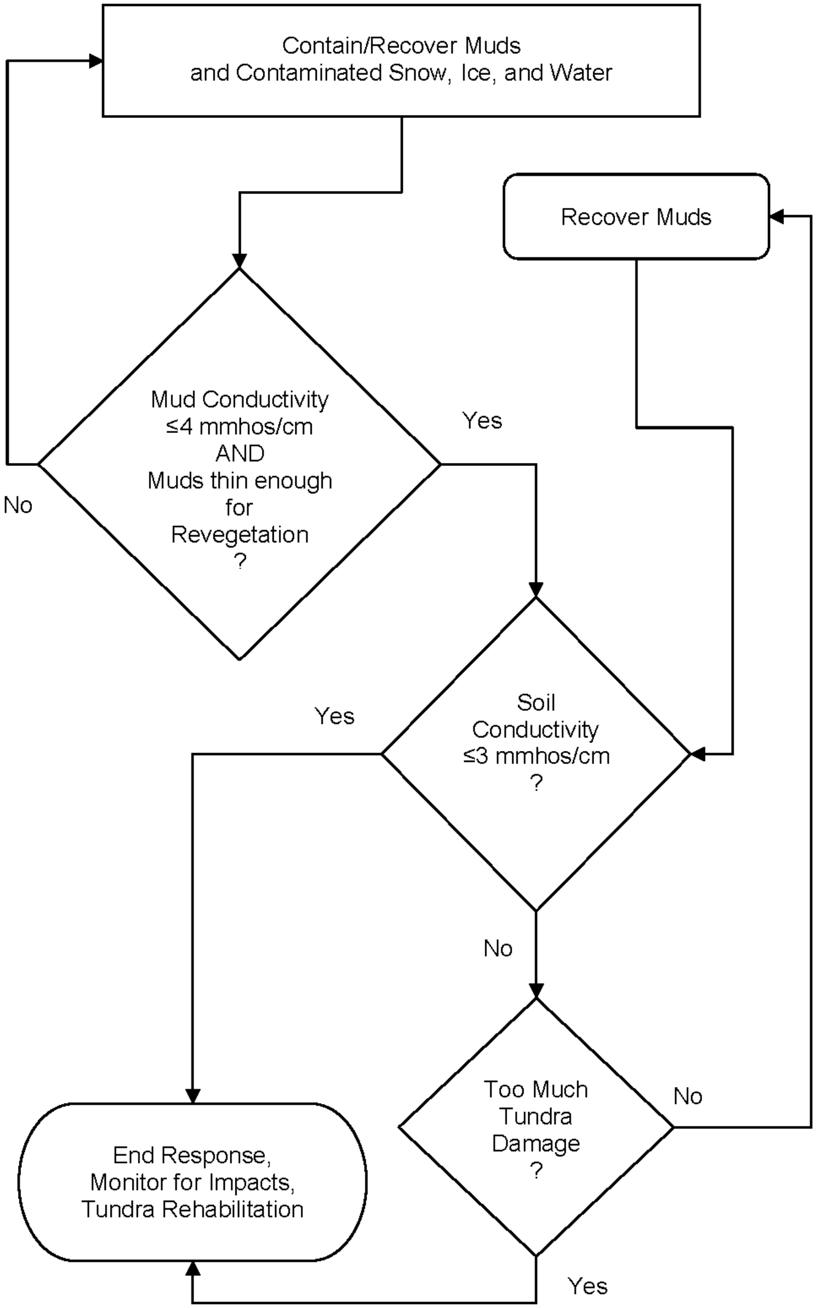


Figure 3c. Generalized example of decision tree to help develop a site-specific treatment strategy for drilling mud spills

Understanding the Tundra Environment

P-2

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 (www.Merriam-Webster.com) or "marshy plain" (Billings 1974). Tundra in this manual is used to describe ecosystems where the indigenous plant cover consists of low herbaceous, dwarf shrub, or lichen vegetation in places which have summers 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

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

is generally cool and 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, 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 poloygons 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 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

Figure 7. Aquatic tundra

Figure 8. Wet tundra

Figure 9. Moist (tussock) tundra

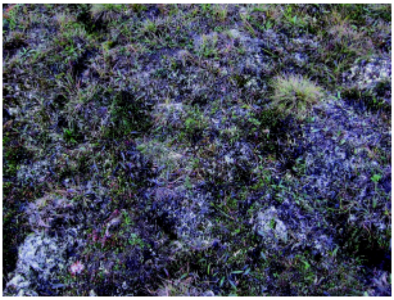


Figure 10. Dry tundra

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.

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 (*Carex 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

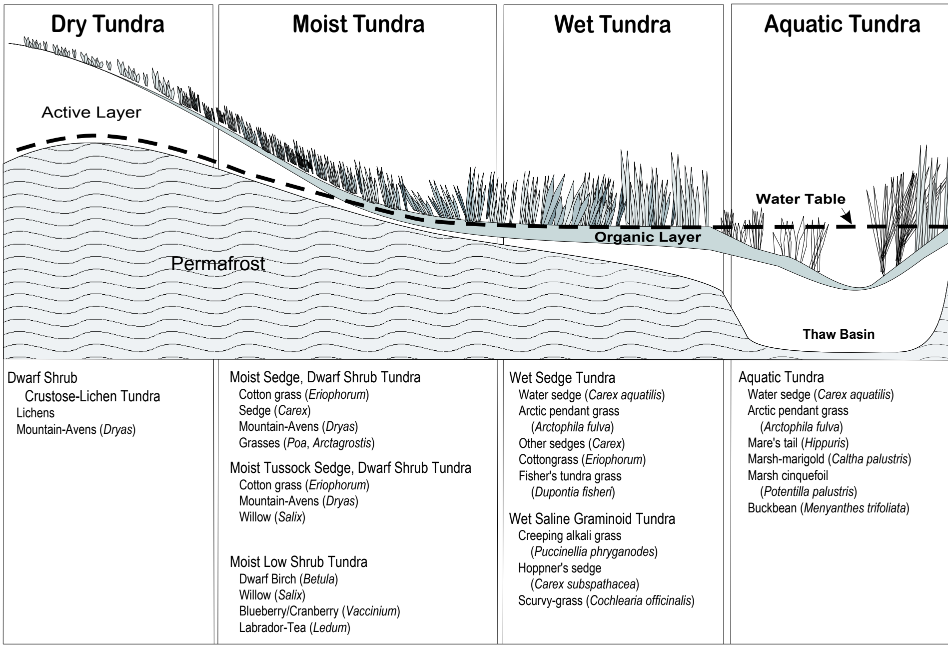


Figure 11. Characteristic plant communities and associated species are listed for the four tundra types (based on Walker et al. 1980)

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*).
- 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 melt 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 may extend to about 3 feet below the tundra surface in wet tundra.

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

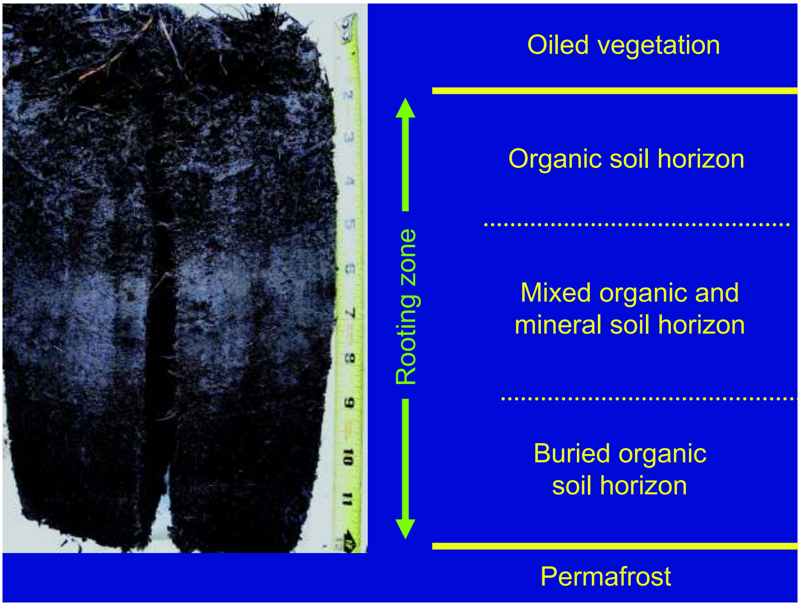


Figure 12. Typical soil profile in wet tundra

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. scheuzeri*), 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, 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 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 cold temperatures

Tundra vegetation 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, but thermokarst in wet tundra also can lead to drier conditions.

Difficulty Treating Spills

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

- Short summer season, when most treatments are easier to implement.
- 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.

Understanding the Effects of Spills on the Tundra

P-3

This tactic provides a brief description of some potential spill substances and their expected effects on tundra vegetation and soils. Information was summarized recently in *Tundra Spill Cleanup and Remediation Tactics: A Study of Historic Spills and Literature* (Behr-Andres 2001).

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. Substances of concern include crude oil, diesel fuel, gasoline, Therminol, glycol (ethylene and propylene), methanol, drilling fluids and muds, produced water, seawater, and acids. Spills within the arctic oilfields 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 areas outside the oilfields, spills of diesel, gasoline, and sewage are the main potential concerns. Spills of other substances would typically be small, and 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 adsorb to fine particles in tundra soil. Once adsorbed, PAHs may persist for a long time because they are unavailable to soil microbes that degrade hydrocarbons. However, the adsorption of PAH molecules by soil can reduce phytotoxicity by reducing the amount of hydrocarbons in contact with plant roots.

Direct exposure to diesel will kill leaves, and can kill the entire plant if roots and buds are also exposed. As explained above (see Crude Oil), spills to

Table 1. Conversions for oiling rates, surface thickness, and soil concentrations of crude

Surface Oiling Rate				Surface Thickness		Percent Oil in Soil by Volume		Percent Oil by Dry Weight (soil bulk density = 0.4 g/cm³)		Parts per Million (ppm; mg/kg); Dry Weight Basis	
Liters/m²	Quarts	Gallons/ acre	bbl/acre	mm	Inches	Soil Oiling Depth (cm) 10	5	Soil Oiling Depth (cm) 10	5	Soil Oiling Depth (cm) 10	5
10	2-1/4	10,691	255	10	3/8	10	20	22	44	220,000	440,000
5	1	5,346	127	5	3/16	5	10	11	22	110,000	220,000
1	1/4	1,069	25	1	1/16	1	2	2.2	4.4	22,000	44,000
0.1	--	107	3	0.1	--	0.1	0.2	0.22	0.44	2,200	4,400

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 highly volatile and 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 explained 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.

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 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. 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 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 wildlife protection, followed by containment and 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 MSDS).

Minimizing Physical Damage to Tundra

P-4

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.

Figure 13. Using plywood to avoid trampling

- Limit use of invasive treatment tactics (e.g. 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.

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).

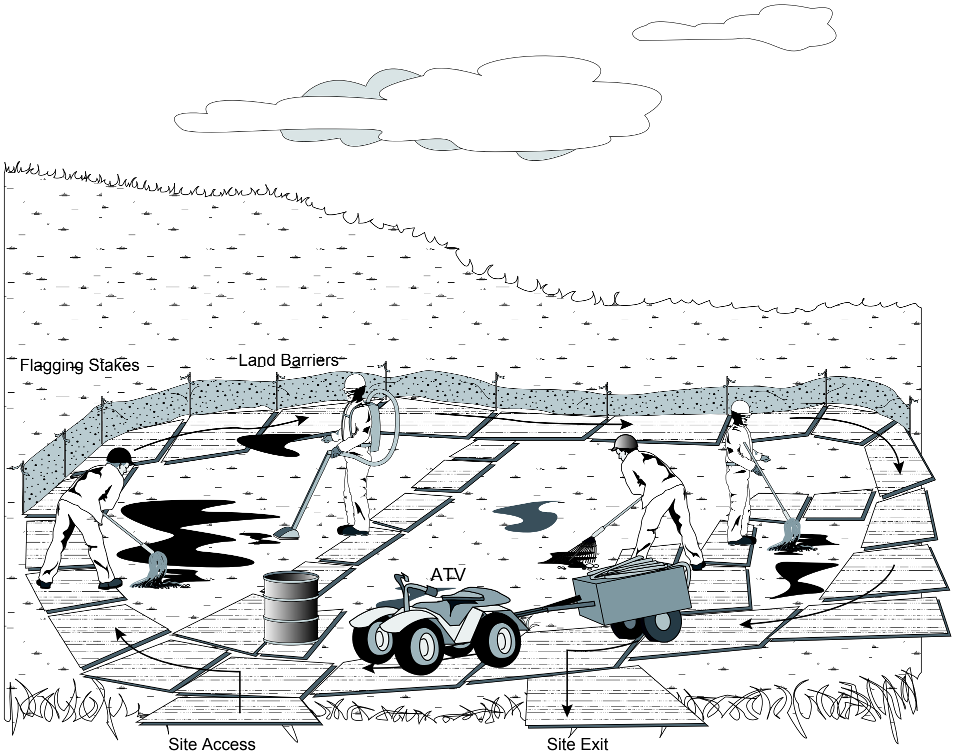


Figure 14. Typical layout of plywood and equipment

Tundra Travel

P-5

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 policy of the Alaska Department of Natural Resources, Division of Land (DNR) requires a permit for any vehicle traveling on tundra during any season. 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 avoid causing too much tundra damage (see Tactics P-4 and 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 (http://dnr.alaska.gov/mlw/tundra/mgmt_strat.htm) that separate tundra into two distinct geographical areas (Coastal and Foothill Areas, see Figure 1 in Tactic P-1). The regulations may be changed to allow travel on tundra when soil temperatures are colder than or equal to –5 degrees C (23.1° 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 vehicle 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 snow has become too soft and/or too limited in extent to allow travel without damaging vegetation. Operators are then given 72 hours notice to move vehicles and other equipment off the tundra.

Summer Tundra Travel

See DNR guidelines for complete listing of travel requirements. The following vehicles have been tested and approved by DNR for summer tundra travel:

- Argo 8 I/C with smooth tracks
- Roller-driven Rolligon
- Haggland Bearcat with smooth track configuration
- Tucker-Terra Sno-Cat model 1600 with smooth track configuration
- 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.

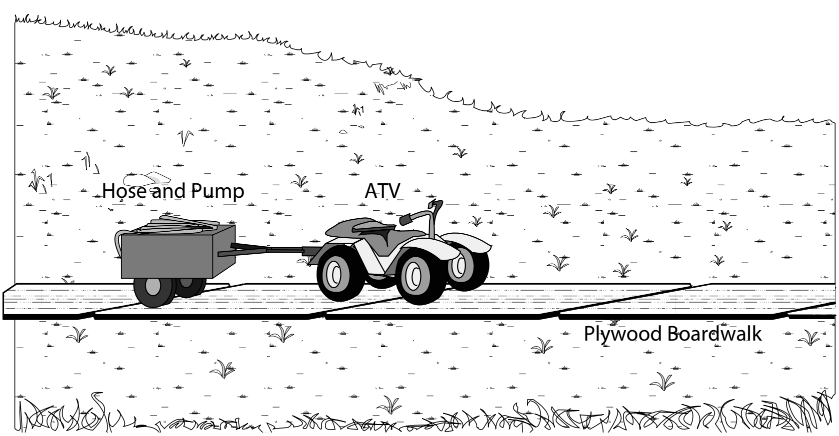


Figure 15. Using 4-wheel all-terrain vehicle on plywood

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 at all possible.
- Crossing ponds or lakes or the wetlands immediately bordering these areas is not authorized.
- 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 Division of Land within 72 hours of occurrence.
- Vehicles cannot carry more payload than was carried during the certification test.

Considerations and Limitations

- Other regulations may apply for travel on lands managed by government organizations (e.g., North Slope Borough) and federal agencies (e.g., Bureau of Land Management).

Figure 16. Vehicle designed for tundra travel in summer