Draining and Dewatering

TR-1

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. Trenches or sumps (Tactic CR-6) 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 (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.

Figure 69. Vacuum truck dewatering site

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).

Figure 70. Natural low spot used for dewatering

Extending the Growing Season

TR-2

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 as long as 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 must be placed perpendicular 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.

Figure 71. Clearing snow from site

Figure 72. Site after snow removal

Figure 73. Deep snow cleared from site in spring

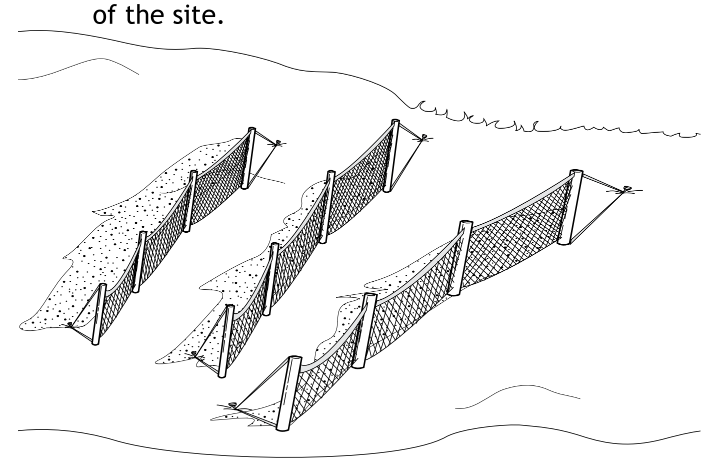

Figure 74. Tiered snow fencing

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

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 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

Figure 76. Heated tent to thaw soil

- 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, and inflate tent.

Fertilization for Hydrocarbon Degradation (Bioremediation)

TR-3

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).

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. 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.

Figure 77. Push spreader

Figure 78. Filling push spreader

Figure 79. Chest 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.

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 (TR-8).

Figure 80. Spreader pulled by 4-wheeler

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.
- 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 air tight 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).

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

Irrigation

TR-4

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. 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.
- Verify that water is free of hydrocarbons and salts before using it to irrigate tundra.
- Rainfall events may require modification of the watering schedule.

Figure 81. Watering with hoses

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.

Figure 82. Sprinkler system

Figure 83. Covering site with snow

Aeration

TR-5

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 organic 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 organic soil horizon. 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

Tilling TR-6

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, re-establish site contours, using surrounding tundra topography as a guide.

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.

Figure 86. Rototilling contaminated soil

Figure 87. Tilling with disk harrow

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.

Enhancing Natural Revegetation

TR-7

Natural revegetation occurs when plants re-establish on a disturbed or spill-affected site without seeding or planting. Enhancing natural revegetation, rather than applying plant cultivation treatments, is appropriate under any of the following conditions:

- 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.
- Seeding or planting would interfere with eventual re-establishment of native tundra plants.

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. Long-term observations have shown that seeding can provide ground cover quickly (1–3 years), however, these grasses are eventually replaced by indigenous species better adapted to the tundra growing conditions. 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 previously (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 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 re-establish.
- Concentration of spilled substance in soils cannot be phytotoxic (lethal to plants).
- Monitor the site (Tactic AM-6) for several growing seasons to evaluate revegetation trends.
- Natural revegetation typically requires 15 to 30 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.


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

Fertilization for Vegetation Recovery

TR-8

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 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. Fertilizer can also be applied to enhance microbial degradation of hydrocarbons (Tactic TR-3).

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. 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 the boundaries of the spill, to enhance seed production in the surrounding tundra and increase seed rain onto the affected area.

When and How Often to Apply

Fertilizer should be applied before 15 July or after 1 September. Elevated nutrient levels are not desirable late in the growing season, as they can delay normal plant senescence and result in winter mortality. One application of fertilizer often is enough to enhance plant growth for several years, but multiple fertilizer applications over one or more growing seasons may be required to meet vegetation performance standards.

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.

* 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.

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. 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 air tight 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).

Figure 92. Push spreader

Figure 93. Filling push spreader

Figure 94. Chest spreader

Figure 95. Spreader pulled by 4-wheeler

Transplanting Vegetation

TR-9

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.

- 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.
- 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 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.

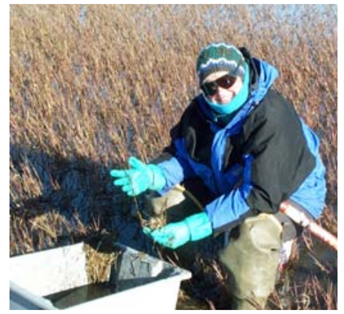

Figure 96. Harvesting pendant grass

Figure 97. Transplanting pendant grass sprigs

Figure 98. Transplanted pendant grass

- 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 in each hole, then place each plug with its soil surface slightly below surrounding surface. Replace 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 in each planting hole.
- To reduce moisture loss, plant cuttings with only 2–4 inches above ground.

Figure 99. Transplanted tundra plugs

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*	
	Tundra grass	*Dupontia fisheri*	Salt tolerant
Moist and Dry	American dunegrass	*Leymus mollis*	Salt tolerant, adapted to sandy soils
	Feltleaf willow	*Salix alaxensis*	
	Richardson's willow	*Salix lanata*	Generally lower survival than *S. alaxensis*

Considerations and Limitations

- A land use permit from Alaska Department of Natural Resources Division of DNR Division of Mining, Land & Water is required for collecting plants on State of Alaska lands.
- Refer to *Streambank Revegetation and Protection* (Muhlberg and Moore 1998) 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).
- 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.

Figure 100. Tundra plugs

Figure 101. Harvesting tundra plugs

Figure 102. Transplanted willow

Figure 103. Transplanting dunegrass

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.
- *21-gram landscaping fertilizer tablets* (1 per sprig, 2 per tundra plug, 1–2 per willow cutting).

Figure 104. Dunegrass sprigs

Tundra Sodding TR-10

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.

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.

Figure 105. Sodded area

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 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 ft 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).

Figure 106. C. Hopson demonstrating sod harvesting

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) should be placed on the soil surface. The pieces of sod should be placed touching each other to maximize soil contact, 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 thick pieces of sod will minimize heat transfer, but the addition of backfill material before the placement of sod may still be necessary if the transplanted sod is to be at the same grade as the surrounding tundra.
- A permit may be needed from the U.S. Army Corps of Engineers if backfill is used.

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. Harvested sod

- 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.
- 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") 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.

Figure 111. Rails used to move sod onto a site

Figure 112. Moving large sod pieces

Seeding

TR-11

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, improve the appearance of the site, provide habitat for wildlife, and promote the eventual development of a plant community similar to the original tundra.

The type of seed to use depends on the tundra type, material spilled, and goals of the seeding effort. Cultivars of native grasses are appropriate for many sites, particularly where relatively rapid establishment of plant cover is required. The most commonly used cultivars on the North Slope are 'Gruening' alpine bluegrass (*Poa alpina*), 'Tundra' glaucous bluegrass (*Poa glauca*), 'Nortran' tufted hairgrass (*Deschampsia caespitosa*), and 'Alyeska' polargrass (*Arctagrostis latifolia*). In addition, spiked trisetum (*Trisetum spicatum*) has been seeded at several sites. It is generally advisable to sow a mixture of at least two species, especially if conditions vary within the site. Seed of native-grass cultivars is available from Alaska commercial growers (e.g., Alaska Garden and Pet Supply in Anchorage). The *Revegetation Manual for Alaska*, prepared by the Plant Materials Center (Palmer), can provide information about other possible seed sources (http://dnr.alaska.gov/ag/RevegManual.pdf).

Although the commercially available grasses 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 sedges and/or forbs may be appropriate. Indigenous seed can be collected from natural stands, often immediately adjacent to the site. Some species, primarily sedges, can be harvested using a line trimmer with a bag attachment (Grin Reaper™, Environmental Survey Consulting, Austin, TX) (Fig. 113). Other seeds, including legumes, can be collected by hand (Fig. 114). If the seed will not be sown immediately after processing, seal it in plastic bags and store frozen for future use. Little information is available about the long-term viability of seed of tundra plants, so long-term storage is not recommended. Most seeds used for revegetation purposes usually ripen in July and August, but seed collecting is still feasible in September.

Fertilizer should be applied before seeding to provide an adequate supply of nutrients for plant establishment and initial growth (Tactic TR-8). Broadcast large amounts of seed using a cyclone spreader (Fig. 115). The small volume of seeds typically 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. A hydroseeder can be used for very large areas. Even distribution of seed will require some practice. One useful method is to measure and mark off an area to be seeded, fill the spreader with the amount of seed appropriate for the given area, and move in a grid pattern at a steady pace over the area multiple times until the spreader is empty.

If the surface is very flat and smooth, it may be helpful to scarify 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).

A list of commercially available grass seed, and seed of indigenous plants that must be collected locally, is provided in Table 5 (next page). This table also recommends species and application rates for different tundra types, including those affected by salts.

Considerations and Limitations

- A land use permit from Alaska Department of Natural Resources Division of DNR Division of Mining, Land & Water is required for collecting plants on State of Alaska lands.
- 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 salt before seeding (Tactic AM-5), to help determine what 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.

Figure 113. Collecting seed with line-trimmer

Figure 114. Collecting sedge seed by hand

Figure 115. Cyclone spreader

Figure 116. Sowing legume seeds by hand

Equipment, Materials, and Personnel

- *Necessary quantity of appropriate seed*, purchased from a commercial supplier or collected from natural stands.
- *Scale* - for weighing out seed for each area of site.
- *Containers* - for weighing seed.
- *Cyclone spreaders* (1 worker per spreader) - to broadcast seed.
- *Vehicle approved for tundra travel* (1 operator) - to pull cyclone spreader for larger sites.
- *Vehicle approved for tundra travel* (1 operator) and chain-link fence - to scarify surface at larger sites.
- *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.
- *Rakes* (1 worker per rake) - to scarify surface after seeding.
- *Paper and cloth bags* - for collecting seed of tundra plants.

—Continued

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* *Dupontia fisheri*	5	*C. saxatilis* and *C. membranacea* are also suitable, as well as other *Carex* species adapted to wet conditions
Moist	*Arctagrostis latifolia* (Alyeska polargrass) *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* (Gruening alpine bluegrass) *Trisetum spicatum* (spiked trisetum)	20–40	Legumes (e.g., *Astragalus alpinus, Oxytropis viscida*) *Artemisia arctica* *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

Backfilling

TR-12

Use backfilling to help stabilize the thermal balance at the tundra surface. The addition of soil can lower the rate of heat transfer into underlying permafrost. If the site remains stable, subsidence of the ground surface caused by thermokarst will be minimized, 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.

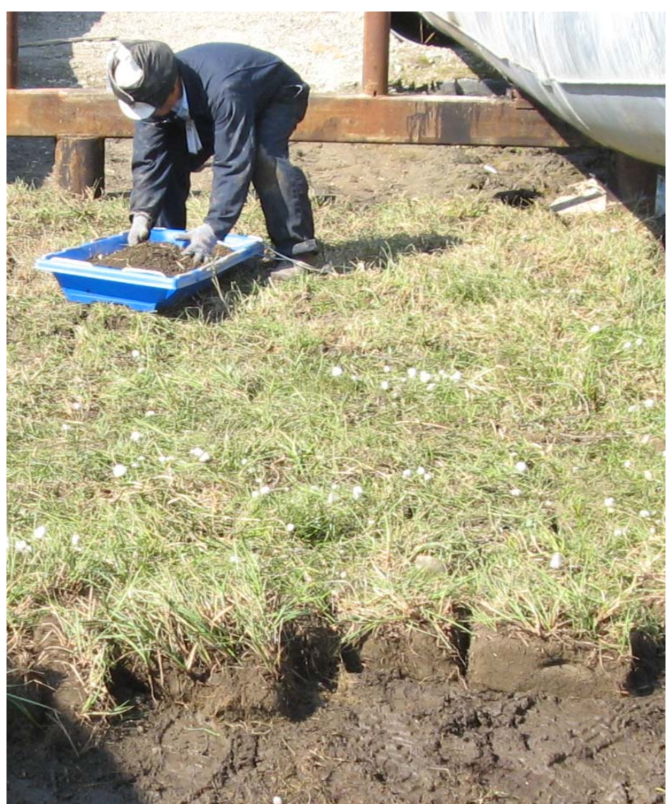

Figure 117. Sodded area

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.

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 particle size, 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 backfill.
- *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

Soil Amendments

TR-13

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. If soil testing (Tactics AM-4 and AM-5) or active-layer water monitoring shows that soils are extremely acidic or saline, applying an amendment may be appropriate. 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. Periodic monitoring (bi-weekly) of active-layer water (Tactic AM-4) can track changes in soil properties faster than soil testing. Apply soil amendments during the growing season when soils are free of snow and water, if possible.

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

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 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).

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.

Lime or gypsum may be applied simultaneously with fertilizer (Tactics TR-3 and 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 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.

Figure 119. Push spreader

Figure 120. Applying lime

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, such as the University of Alaska Fairbanks Agricultural and Forestry Experiment Station in Palmer, AK. Some analytical laboratories, where soils are analyzed for contaminants, may also be equipped to calculate the need for soil amendments.
- Extremely alkaline 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).

Figure 121. Chest spreader

Figure 122. Spreader pulled by 4-wheeler