CHAPTER 12

Oil Spills on Land

While the vast majority of oil spills in Canada occur on land (see statistics in Chapter 1), land spills are less dramatic than spills on water and receive less attention from the media and the public. This chapter deals with the behaviour of oil spilled on land and describes common methods of containment and cleanup for such spills.

Two types of land spills are discussed — those that occur primarily on the surface of the land and those that occur partially or totally in the subsurface. The sources and the cleanup methods differ for these types of spills. Most surface spills in Canada are the result of oil production, such as spills from pipelines and battery sites, whereas most subsurface spills are from leaking underground fuel storage tanks or pipelines. Whether on the surface or subsurface, however, each spill is unique in terms of the type of material spilled, the habitat in which the oil is spilled, its location, and the weather conditions during and after the spill.

Protecting human health and safety is still the top priority when cleaning up oil spills on land and in the subsurface, although this is only an issue with some spills, such as gasoline. Minimizing long-term damage to the environment and protecting agricultural land are more often the main concerns with spills on land. This is followed by protecting nonessential uses, such as recreation.

BEHAVIOUR OF OIL ON LAND

The spreading of oil across the surface and its movement downwards through soil and rock are far more complicated and unpredictable on land than the spreading of oil on water. The movement of the oil varies for different types of oil and in different habitats and is influenced by conditions at the spill site, including the specific soil types and their arrangement, moisture conditions in the soil, the slope of the land, and the level and flow rate of the groundwater. Other factors, which vary in different habitats, are the presence of vegetation and its type and growth phase, the temperature, the presence of snow and ice, and the presence of micro-features, such as rock outcrops. Some properties of different oils and their effects on the environment are shown in Table 15.
The basic types of soil to consider in relation to oil spills are sand/gravel, loam, clay, and silt. "Soil" is defined as the loose unconsolidated material located near the surface, while "rock" is the hard consolidated material, i.e., bedrock, usually found beneath the soil. Most soils consist of small fragments or grains that form openings or pores when compacted together. If these pores are sufficiently large and interconnected, the soil is said to be "permeable" and oil or water can pass through it. Sand is the most permeable type of soil. Materials such as clay, silt, or shale are termed "impervious" as they have extremely small, poorly interconnected pores and allow only limited passage of fluids. Soils also vary in terms of long-term retentivity. Loam tends to retain the most water or oil due to its high organic content.

<table>
<thead>
<tr>
<th>Petroleum</th>
<th>Plant</th>
<th>Water</th>
<th>Viscosity</th>
<th>Adhesion</th>
<th>Penetration</th>
<th>Degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Diesel fuel</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Light crude</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Heavy crude</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bunker fuel</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

Lower numbers indicate more favourable conditions to the environment and faster recovery after a spill.

As most soils are an inhomogeneous mixture of these different types of soil, the degree of spreading and penetration of oil can vary considerably in a given location. The types of soil are often arranged in layers, with loam on top and less permeable materials such as clay or even bedrock underneath. If rock is fractured and contains fissures, oil can readily pass through it.

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The oil’s ability to permeate soils and its adhesion properties also vary significantly. Viscous oils, such as bunker fuel oil, often form a tarry mass when spilled and move slowly, particularly when the ambient temperature is below their pour point. Non-viscous products, such as gasoline, move in a manner similar to water in both summer and winter. For such light products, most spreading occurs immediately after a spill.

Crude oils have intermediate adhesion properties. In an area with typical agricultural loam, spilled crude oil usually saturates the upper 10 to 20 cm of soil and rarely penetrates more than 60 cm. Generally, the oil only penetrates to this depth if it has formed pools in dry depressions. If the depressions contain water, the oil may not penetrate at all.

**Movement of Oil on Land Surface**

Both the properties of the oil and the nature of the soil materials affect how rapidly the oil penetrates the soil and how much the oil adheres to the soil. For example, a low viscosity oil penetrates rapidly into a dry porous soil such as coarse sand and therefore its rate of spreading over the surface is reduced.

When oil is spilled on land, it runs off the surface in the same direction and manner as water. The oil continues to move horizontally down-gradient until either blocked by an impermeable barrier or all the oil is absorbed by the soil. The oil will also sink into any depressions and penetrate into permeable soils.

The process whereby oil penetrates through permeable soils is shown in Figure 30. The bulk of the oil moves downward through permeable material under the influence of gravity until it is stopped by either the groundwater or an impermeable layer. It then moves down-gradient along the top of the impermeable layer or groundwater until it encounters another impermeable barrier or all the product is absorbed in the soil. Once in contact with the water-soluble material, the oil dissolves into and is transported away with the groundwater. Oils and fluids can flow along the top of the groundwater and reappear much later in springs or rivers.

The descending oil is often referred to as a “slug” of oil. As the slug moves through the soil, it leaves material behind that adheres to the soil. This depends on the adhesion properties of the spilled product and the nature of the soil. More of the adhered oil is moved downwards by rainfall percolating through the soil. The rain water carries dissolved components with it to the water table. The movement of the oil will be greatest where the water drainage is good.

**Movement of Oil in the Subsurface**

Regardless of its source, oil released into the subsurface soil moves along the path of least resistance and downwards, under the influence of gravity, as shown in Figure 31. Oil often migrates towards excavated areas such as pipeline trenches, filled-in areas around building foundations, utility corridors, and roadbeds. Such areas are often filled with material that is more permeable or less compacted than the material removed during the excavation.
The oil may continue to move downwards until it reaches the groundwater or another impermeable layer. If the soil is absorptive and capillary action occurs, however, the oil can also move upwards and even reappear at the surface, sometimes as far as a kilometre away from the spill. This is what happens when pipeline spills appear at the surface of the trench in which the pipeline is laid.

**Habitats/Ecosystems**

As the effects of oil and its behaviour vary in different habitats, cleanup techniques and priorities are tailored to the habitat in which the spill takes place. Returning the habitat as much and as quickly as possible to its original condition is always a high priority when cleaning up oil spills.

It is important to note that each site may be very inhomogeneous in terms of its vegetation, soil types, and soil profile, and how the oil behaves in or affects each component of the soil. Furthermore, the amount of time it takes for the vegetation to grow back naturally differs widely from one habitat to another. The estimated amount of time for surface vegetation to recover in various oiled habitats is shown in Table 16. Residual amounts of oil remain in some habitats for many years or even decades.

When spills occur in the **urban habitat**, protecting human health and safety and quickly restoring the land use are top priorities. Environmental considerations are generally not important as endangered species or ecosystems are not often found in the urban habitat. The urban environment usually includes a range of ecosystems, from natural forest to paved parking lots. Thus a spill in an urban area often affects several ecosystems, each of which is treated individually.
The roadside habitat is similar to the urban one in that restoring the use and surficial appearance of the land is given top priority. Roadside habitats are varied and include all the other ecosystems. The roadside habitat is different from the urban one, however, in that it is exposed to many emissions and is not generally viewed as a threatened or sensitive environment.

On agricultural land, the priority in cleaning up oil spills is to restore land use, e.g., crop production. In this habitat, oil is more likely to penetrate deeply into the subsurface as plowing the fields creates macropores that petroleum products and crude oils can rapidly penetrate. As oil penetrates deeper into dry agricultural land, the danger of groundwater contamination is greater than in other habitats.
On mineral soils, however, oil can make the soil non-wettable, so that water runs off rather than soaking into the soil. This causes a water shortage, which can result in poor rehabilitation in the area. The opposite occurs in low-lying sites or poorly drained soils where water fills the macropores of the soil, but is not absorbed into the soil itself because of the presence of the oil. This excludes air from the soil and the site becomes difficult to treat or cultivate and anaerobic conditions quickly develop.

Anaerobic conditions and restricted plant growth can also develop when oil on the surface weathers and forms an impermeable crust that again reduces the air exchange. Recovery is affected by the amount of oil spilled on a given area. Lightly oiled soil recovers much faster than a heavier oiled area as the soil is not completely saturated and both air and water can still penetrate. Residual oil in the soil can also slow recovery by inhibiting seed germination.

**Dry grassland** is similar to agricultural land in that the priority for cleanup is restoring the soil so that the crop, in this case grass, can continue to grow. The surface of the grassland is often less permeable than agricultural land. Once the surface is penetrated, however, the substrate may be permeable and groundwater can be affected. Dry grassland recovers quickly from spills if the oil runs off or if the excess oil is removed without too much surface damage. The presence of dead vegetation is viewed as a symptom, not a problem. When excess oil is removed, replanting and fertilization can speed recovery of an oiled grassland. As with agri-
cultural land, oil on the surface of grassland can sometimes weather and form an impermeable crust that reduces air exchange and causes anaerobic conditions.

Unlike most habitats, the forest has two distinct levels of vegetation: low-lying vegetation such as shrubs and grasses, and trees. The low-lying vegetation is much more sensitive to oiling than trees, but is much easier to replant and recovers much faster. Most species of trees are not seriously affected by light oil spills. If enough oil is spilled to affect the tree’s roots, most trees will be killed and the forest will not recover fully for decades. It is therefore very important to rapidly remove excess oil that has not yet been absorbed by the soil.

If a forest has mineral soil, the oil can make it non-wettable so that water runs off the soil rather than soaking in. In low-lying sites or forests with poorly drained soil, the opposite occurs. Water fills the macropores of the soil, but not the soil itself because of the presence of the oil. This excludes air from the soil and the site does not revegetate quickly. Oil on the surface of forest soils can weather and form an impermeable crust that also reduces air exchange or restricts the growth of plants. Due to the presence of large trees, the forest is far more difficult to access and treat than most other habitats.

Wetlands are the habitat most affected by oil spills because they are at the bottom of the gravity drainage scheme. Usually, oil cannot flow out of a wetland system and oil from other areas flows into the system. Although there is a variety of wetlands, oil tends to collect in all of them, creating anaerobic conditions that slow oil degradation. Wetlands are also extremely sensitive to physical disturbance as many plants in this habitat propagate through root systems. If these root systems are damaged by the oil or the cleanup process, it takes years or even decades for
the plants to grow back. Wetlands are the habitat of many species of birds and fish, as well as other aquatic resources. Wetlands are difficult to access and to clean up.

**Taiga**, which is characterized by coniferous trees and swampy land, generally forms the transition between northern forests and the tundra farther to the north. It is either underlain by permafrost or has a high water table. Many of the plants propagate through root systems and are highly sensitive to physical disturbance. Over a period of time, heavy loadings of oil will kill the coniferous trees. Oil on the surface of the taiga can weather and form an impermeable crust that reduces the air exchange and restricts plant growth. Degradation of remaining oil is slow in this habitat, which takes a long time to recover. The presence of trees and the high moisture level make the taiga more difficult to access and clean up than most other habitats.

**Tundra** is the far northern habitat, characterized by low plant growth and no trees. Tundra is underlain by permafrost that is generally impermeable to oil. Vegetation on the tundra grows in tufts that are generally grouped into polygons. Oil spilled on the surface drains into the spaces between the tufts and polygons and eventually kills the vegetation. Without the layer of vegetation, the permafrost melts and serious land damage results. Degradation of remaining oil on the tundra is very slow and could take hundreds of years.
In all the more sensitive habitats, which include the forest, the taiga, and the tundra, the priority for cleanup operations is to remove the excess oil as rapidly as possible and without causing physical damage.

**Cleanup of Surface Spills**

When dealing with oil spills on land, cleanup operations should begin as soon as possible. It is important to prevent the oil from spreading by containing it and to prevent further contamination by removing the source of the spill. It is also important to prevent the oil from penetrating the surface and possibly contaminating the groundwater.

**Berms or dikes** can be built to contain oil spills and prevent oil from spreading horizontally. It must be ensured, however, that the oil does not back up behind the berm and permeate the soil. Berms can be built with soil from the area, sand bags, or construction materials. Berms are removed after cleanup to restore the area’s natural drainage patterns. **Sorbents** can also be used to recover some of the oil and to prevent further spreading. The contaminated area can sometimes be flooded with water to slow penetration and possibly float oil to the surface, although care must be taken not to increase spreading and to ensure that water-soluble components of the oil are not carried down into the soil with the water. **Shallow trenches** can be dug as a method of containment, which is particularly effective if the water table is high and oil will not permeate the soil. Oil can either be recovered directly from the trenches or burned in the trenches. After the cleanup, trenches are filled in to restore natural water levels and drainage patterns.

A variety of methods exist for cleaning up surface oil spills on land, with the method used depending on the habitat in which the spill occurs. The various methods and which should be used in the different habitats are shown in Table 17.

**Natural Recovery**

This is the process of leaving the spill site to recover on its own. This method is sometimes chosen for extremely sensitive habitats such as wetlands, taiga, and tundra and is always done after the excess oil has been removed from the site. In these cases, the excess oil that can be recovered is removed using techniques that do not disturb the surface or physically damage the environment. This is important as it can take years for wetlands or tundra to recover from vehicular traffic. In habitats such as wetlands and taiga where the vegetation propagates through root systems, more damage can be done by the cleanup operation than by the oil.

**Removal of Excess Oil**

Any excess oil that can be recovered without causing physical damage to the environment is always removed from a spill site, using techniques that do not disturb the surface. If excess oil on the surface is not removed quickly, the oil can penetrate into the soil, contaminating the groundwater and destroying vegetation.
Suction hoses, pumps, vacuum trucks, and certain skimmers and sorbents, both natural and synthetic, are generally effective in removing excess oil from the surface, especially from ditches or low areas. The use of sorbents can complicate cleanup operations, however, as contaminated sorbents must be disposed of appropriately. Sorbents are best used to remove the final traces of oil from a water surface. Any removal of surface or vegetation also entails replanting and fertilization.

Manual removal of oil involves removing oil and often highly oiled soil and vegetation with shovels and other agricultural tools. This is always followed by fertilization, selective reseeding, or transplanting plugs of vegetation from nearby

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**Table 17** Cleanup Methods for Surface Land Spills

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Removal of Excess Oil</th>
<th>Natural Recovery</th>
<th>Manual Oil Removal</th>
<th>Mechanical Oil/Surface Removal</th>
<th>Enhanced Bio-degradation</th>
<th>In-Situ Burning</th>
<th>Hydraulic Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>√</td>
<td>+</td>
<td>√</td>
<td>+</td>
<td></td>
<td></td>
<td>√</td>
</tr>
<tr>
<td>Roadside</td>
<td>√</td>
<td>+</td>
<td>√</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Agricultural Land</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>√</td>
</tr>
<tr>
<td>Grassland</td>
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<td>+</td>
</tr>
<tr>
<td>Forest</td>
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<td>√</td>
<td>+</td>
<td></td>
<td>√</td>
<td>√</td>
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<td>Wetland</td>
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<td>×</td>
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<tr>
<td>Taiga</td>
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<td>√</td>
<td>×</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Tundra</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>×</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

√ — acceptable or recommended
+
— can be used under certain circumstances
× — should not be used
◊ — only marginally acceptable

**Photo 135** This spill is being recovered with pumps and a vacuum truck. (Environment Canada)
unaffected areas. This form of removal is labour-intensive and can severely damage the surface, especially in sensitive environments.

**Mechanical recovery equipment**, such as bulldozers, scrapers, and front-end loaders, can cause severe and long-lasting damage to sensitive environments. It can be used in a limited capacity to clean oil from urban areas, roadsides, and possibly on agricultural land. The unselective removal of a large amount of soil leads to the problem of disposing of the contaminated material. Contaminated soil must be treated, washed, or contained before it can safely be disposed of in a landfill site. This can cost thousands of dollars per ton.

**Other Cleanup Methods**

**Enhanced biodegradation** is another possible method for cleaning up spills on land. Certain portions of oil are biodegradable and the rate of biodegradation can sometimes be accelerated as much as tenfold by the proper application of fertilizers. For example, in one study, an oil spill on tundra showed good degradation when a phosphorus fertilizer was applied. The amount of nutrients added is often calculated on the ratio of 100:10:1 C:N:P, where C is the carbon represented by the oil, N is the nitrogen, and P is the phosphorus.

The amount of degradation varies with the type of oil. Diesel fuel will largely degrade on the land surface, whereas Bunker C will only slightly degrade. Under ideal conditions and using fertilizers to enhance degradation, however, it can still take from 3 to 100 years for more than half of an oil to degrade, even if this oil is biodegradable. During this time, some of the oil will be removed by other processes such as evaporation or simply by movement.

Scientists are now exploring the use of plants and their associated microorganisms for remediation, which is called **phytoremediation**. This is a low cost process that is proving effective for a wide variety of contaminants, including petroleum hydrocarbons. It can be used in combination with other remediation technologies and may prove useful in the future for treating oiled soils or wetlands. It takes several years to remediate a site and cleanup is limited to the depth of the soil within reach of the plant’s roots.

**In-situ burning** has been used for several years to deal with oil spills on land. This technique removes oil quickly and without disturbing the area extensively, although it does damage or kill shrubs and trees. The heat from burning can also destroy propagating root systems and change the soil’s properties. In addition, it can leave a hard crust of residual material that inhibits plant growth and changes natural water levels and drainage patterns.

These disadvantages can be overcome in some habitats. Some areas can be flooded before burning to minimize the effect of the heat and to remove oil by floating it out of the ground. Crust formation can be avoided by physically removing residue after a burn. On wetlands and in areas with high water levels, sorbents can be used to remove residues left after burning to ensure that they do not coat plants or soil after water levels fall. In marshes, burning is best done in spring when the water table is high.
Hydraulic measures, such as flooding and cold or warm water sprays, can be used to deal with land spills, although they are only effective in limited circumstances. Flooding an area where the oil is not strongly retained can cause the oil to rise to the water’s surface where it can subsequently be removed using skimmers or suction devices, or by burning. This is effective in areas where the water table is high or the top layer of ground is underlain by impermeable material. Flooding may not work on soils that are high in organic material, however, as they strongly retain oil. Cold or warm water sprays can be used to clean oil from hard surfaces. Catchment basins and interceptor trenches are built to capture the released oil, which is then skimmed or pumped from the trenches.

A number of other techniques have been tried for cleaning up oil spills on land, with varying degrees of success. Tilling or aeration of soil is done to break up the crust surface and re-aerate the soil. In areas where vegetation propagates by root systems, however, tilling kills all plants and destroys the potential for re-growth. Tilling oil into the soil can actually slow natural degradation because the soil becomes anaerobic when it re-compresses. Vegetation cutting is useful only if there is a risk that oil on vegetation could re-contaminate other areas. Many plants cannot survive cutting, however, and growth is not re-established in the area. To date, there are no effective chemical agents for cleaning up oil spills. Surfactant agents can actually increase oil penetration into the soil and could result in the more serious problem of groundwater contamination.

All cleanup methods include site restoration, which involves returning the site as closely as possible to the pre-spill conditions. The drainage pattern of the site is restored by removing dykes, dams, and berms, and filling in ditches or drains. It may be necessary to replace any soil that was removed and to re-vegetate the site by fertilizing, re-seeding, or transplanting vegetation from nearby.

Cleanup of Subsurface Spills

Oil spills in the subsurface are much more complicated and expensive to clean up than those on the surface and the risk of groundwater contamination is greater. Spills in the subsurface can be difficult to locate and without a knowledge of the geology of the area, it can be difficult to predict the horizontal and downward movement of the oil.

Initially, the oil must be contained and its horizontal and downward movement stopped or slowed. Containment methods are difficult to implement and may cause physical damage to the site. Digging an interceptor trench can be effective in reducing horizontal spread. Such trenches are filled in after the cleanup operation to restore the natural drainage patterns of the land. Another method is to place “walls” around the spill source to stop its spreading. These can be “slurry walls” consisting of clay or cement mixtures that solidify and retain the oil, or solid sheets of steel or concrete can be positioned to retain the oil.

Once the subsurface spill is contained, there are a number of cleanup methods that can be used. The most appropriate method for a particular spill depends on the type of oil spilled and the type of soil at the site, as shown in Table 18.
Hydraulic measures for cleaning up subsurface spills include flooding, flushing, sumps, and French drains. These methods are most effective in permeable soil and with nonadhesive oils. They all leave residual material in the soil, which may be acceptable, depending on the land use. Flooding is the application of water either directly to the surface or to an interceptor trench in order to float out the oil. Flooding is effective only if the spilled oil has not already been absorbed into the soil, if sufficient water can be applied to perform the function, and if the oil is not accidentally moved into another area. Flushing involves the use of water to flush oil into a sump, recovery well, or interceptor trench. Placement of a sump or a deep hole is only effective for a light fuel in permeable soil above an impermeable layer of soil. A French drain is a horizontal drain placed under the contamination, from which the fuel and often water are pumped out. Although effective in permeable soils, they are expensive and difficult to install.

Interceptor trenches are ditches or trenches dug down-gradient from the spill, or in the direction in which the spill is flowing, to catch the flow of oil. They are placed just below the depth of the groundwater so that oil flowing on top of the groundwater will flow into the trench. Both water and oil are removed from the trench to ensure that flow will continue. Interceptor trenches are effective if the groundwater is very close to the surface and the soil above the groundwater is permeable.
Soil venting is done to remove vapours from permeable soil above a subsurface spill. This is effective for gasoline in warm climates and for portions of very light crude oils. Other oils do not have a high enough rate of evaporation to achieve a high recovery rate. Venting can be passive, in which vapours are released as a result of their own natural vapour pressure, or active, in which air is blown through the soil and/or drawn out with a vacuum pump. The fuel vapours are subsequently removed from the air to prevent air pollution. Soil venting is also done to enhance biodegradation.

Excavation is a commonly used technique for cleaning up subsurface spills, especially in urban areas where human safety is an issue. Vapours from gasoline can travel through the soil and explode if ignited. These vapours can also penetrate houses and buildings, forcing evacuation of the area. To prevent these situations, contaminated soils are often quickly excavated and treated or packaged for disposal in a landfill. Excavation may not always be possible, however, depending on the size of the spill and prevailing conditions at the site.

Recovery wells are frequently used in cleaning up subsurface spills. The well is drilled or dug to the depth of the water table so that oil flowing along the top of the water table will also enter the well. The water table is sometimes lowered, by pumping, to speed the recovery of the oil and to increase the area of the collection.
zone. The oil is recovered from the surface of the water by a pump or a specially
designed skimmer.

Other methods are constantly being proposed or tried for cleaning up subsurface
spills. One such method is biodegradation in-situ, although its effectiveness is very
much restricted by the availability of oxygen in the soil and the degradability of the
oil itself. An adaptation of the venting method has been used to try to solve the
oxygen problem. So far, however, biodegradation methods have not been rapid
enough to be an acceptable solution. Chemical agents have also been proposed for
cleaning up subsurface spills, although most of them actually make the problem
worse. For example, surfactants can release the oil from soil, but then render it
dispersible in the groundwater. Government approval must be obtained before using
chemical agents.

If the groundwater does become contaminated, it is pumped to the surface and
treated to remove the dissolved components. Common treatment methods include
reverse osmosis and carbon filtration. Groundwater treatment is expensive and gen-
erally involves a lengthy process before contamination levels are below acceptable
standards.