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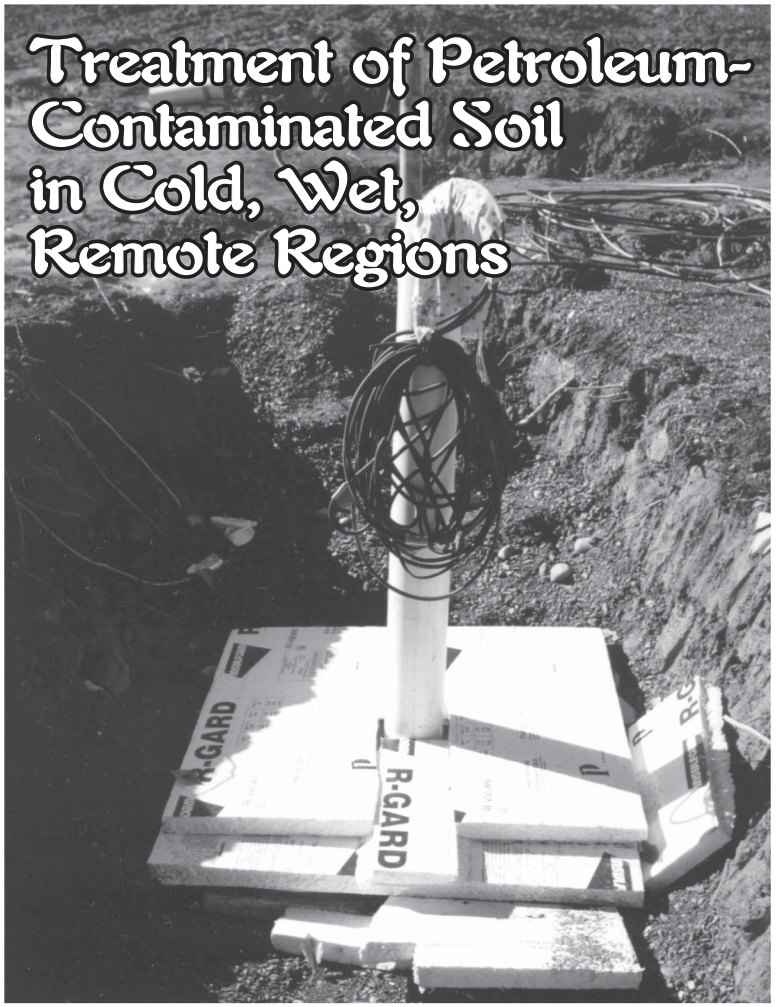
# Treatment of Petroleum-Contaminated Soil in Cold, Wet, Remote Regions

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# Introduction

The number of sites contaminated with hazardous compounds in recent years has prompted environmental engineers to develop new technologies and to adapt existing technologies to treat contaminated groundwater and soil. Environmental engineers already knew how to treat domestic wastewater and industrial wastewater. Because they had some control over these processes, engineers had a fairly good understanding of the characteristics of the wastes and the technologies that would work best to treat them. Environmental engineers are now faced with treating soil and groundwater contaminated with petroleum products. Engineers usually have less knowledge of the characteristics of this waste. Adding to the new challenges, contaminants in soil and groundwater are dispersed throughout the media; in other words, the contaminants are not contained as an industrial or domestic waste would be.

Environmental engineers have adapted proven technologies and have developed new technologies to reduce contaminants in soil and groundwater ex situ (removed from the original location) and in situ (in place). Ex situ treatment methods incorporate both chemical and biological processes. Over the years, experience has shown that ex situ treatment processes can be costly in capital, operations, and maintenance. In situ methods attempt to stabilize or reduce the mass of contaminants in soil and groundwater using physical, chemical, and biological processes. In most cases, these treatment methods are more difficult to control than ex situ methods. The complexity of these treatment methods can be attributed to heterogeneities in soil properties.

Soil and groundwater contamination is not limited to industrial or urban locations. Contamination can be found in rural and even in remote locations. The U. S. Department of Agriculture, Forest Service is now addressing small-volume (less than 400 cubic meters) soil contamination by petroleum products in remote national forest locations where climate, utility access, and accessibility present challenges to economical restoration. This report addresses the Tongass and Chugach National Forests in Alaska (figures 1 and 2). These forests are in cold regions with temperatures dropping as low as about –2 °C during winter (Valdez weather station, data from Alaska Climate Research Center, University of Alaska Fairbanks). They are also wet, receiving more than 500 centimeters of rainfall annually (Whittier weather station, data from Alaska Climate Research Center, University of Alaska Fairbanks). Access and utility accessibility are key issues for engineers in these remote national forests.

This report will provide Forest Service engineers some guidance to help them choose a treatment technology that will reduce the level of petroleum contamination in contaminated soils. Selecting the appropriate treatment technology (or technologies) is a challenge that requires knowledge of the science involved and some professional judgment. This report is not meant to provide a "cookbook" method of selecting a technology for treating contaminated soils.

Because of uncertainties in soil properties, the total mass of contaminant released, the lateral and vertical extent of contamination, seasonal fluctuations in the water table, and weather conditions, it is very difficult to predict the outcome of a soil treatment technology (Massmann, J.; Schock, S.; Johannesen, L. 2000; Barnes and McWhorter 2000). The goal of the design engineer is to choose and design the most economical treatment system (a treatment system can be made up of

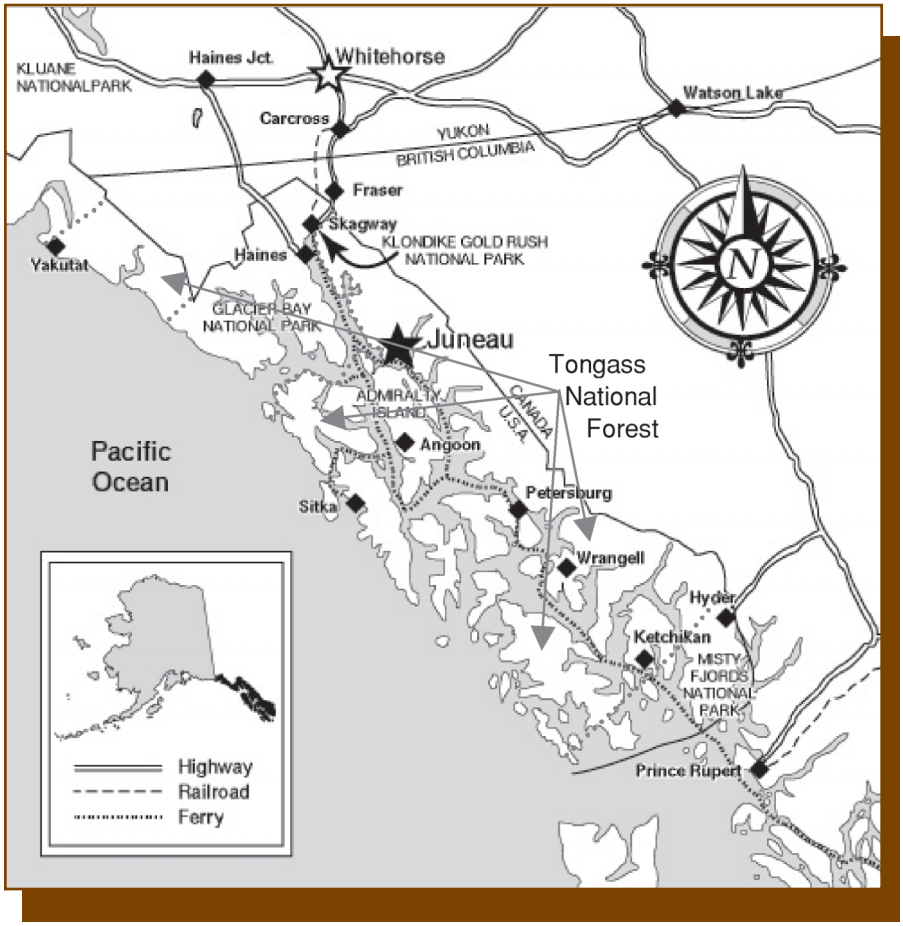


Figure 1—Approximate boundaries of the Tongass National Forest. Boundaries are shown as dotted lines.

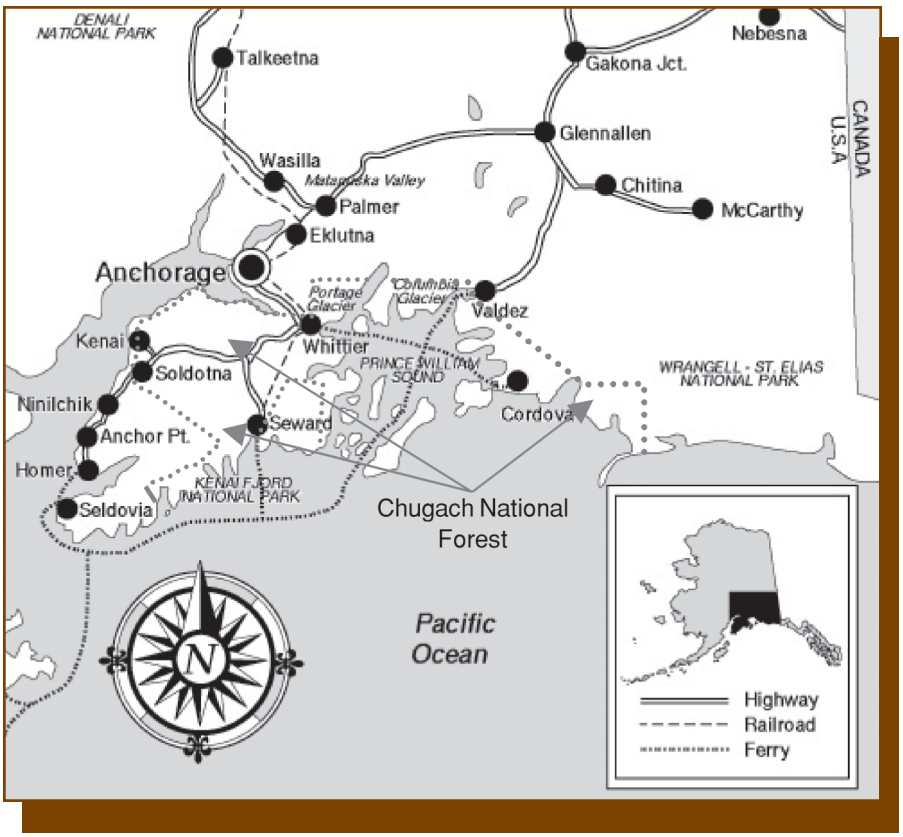


Figure 2—Approximate boundaries of the Chugach National Forest. Boundaries are shown as dotted lines.

more than one technology) that has a high probability of attaining the intended goal. Because of the uncertainties listed above, the design engineer may have difficulty achieving the stated goal. For example, if the engineer specifies the use of landfarming to treat contaminated soil, an unseasonably cold summer could inhibit the effectiveness of this technique, delaying the project's completion. Designing systems under conditions of uncertain variables is not a new problem. Terzaghi (1961) addressed this issue as it applied to geotechnical engineering. Others have also investigated this topic (Peck 1969; Peck 1980; Dean and Barvenik 1992). The conclusion from decades of working on this issue is that "cookbook" design protocols do not work. A method that has been successfully applied in geotechnical engineering is one that relies on good engineering judgment and a 'learn as you go' approach to the design. While this manuscript is not a primer on this design approach, the manuscript was written with this approach in mind.

This report discusses several technologies that are known to be successful for treating petroleum-contaminated soils in cold, wet, and remote regions. The documented performance of each technology is a compilation of the experience of different commercial companies and Alaskan engineers specializing in restoration of contaminated soil. Appendix C lists the commercial and engineering companies that provided information for this report.

Actual costs for the different technologies have not been included in this document. Instead, items that need to be included in a cost estimate are listed. Including actual costs for different items would date the report, making the information less useful with time. The costs for services, such as incineration of contaminated soil, will vary depending on the vendor. Finally, the authors assume that Forest Service engineers have the best information on costs for such items as labor and equipment rental.

Before engineers address any waste treatment issue, they must have an understanding of the waste to be treated and, in the case of contaminated soil, the medium in which the waste exists. This report will provide a brief description of petroleum products and a simple conceptual model of the movement of petroleum through unsaturated soil. It includes brief descriptions of the climatic conditions in the Tongass and Chugach National Forests. The report also describes each viable treatment technology and discusses its applicability for treating contaminated soil in the Tongass and Chugach National Forests. Treatment technologies addressed in this report are shown in table 1.

Table 1—Viable treatment technologies for petroleum-contaminated soils.

| Ex situ treatment technologies |
|---|
| Excavation and proper disposal |
| Incineration |
| Thermal desorption |
| Soil washing |
| Vapor extraction |
| Composting |
| Landfarming |
| **In situ treatment technologies** |
| Soil vapor extraction |
| Barometric pumping |
| Bioventing |

Before contaminated soil can be treated, the lateral and vertical extent of the contamination needs to be determined. While site investigation is an important topic, a detailed discussion of site investigation is beyond the scope of this report.

# Understanding the Problem

Engineers require an adequate understanding of petroleum and its movement through unsaturated soils to make decisions on the type of treatment technology for petroleum-contaminated soils. The way that petroleum was released to the soil may dictate the lateral distance that petroleum will migrate as it moves through unsaturated soil. Knowledge of the lateral extent of contamination may be a factor in choosing a treatment technology. The following brief discussion provides a description of petroleum products, a conceptual model of how they move through soil, and the climatic conditions of the Tongass and Chugach National Forests.

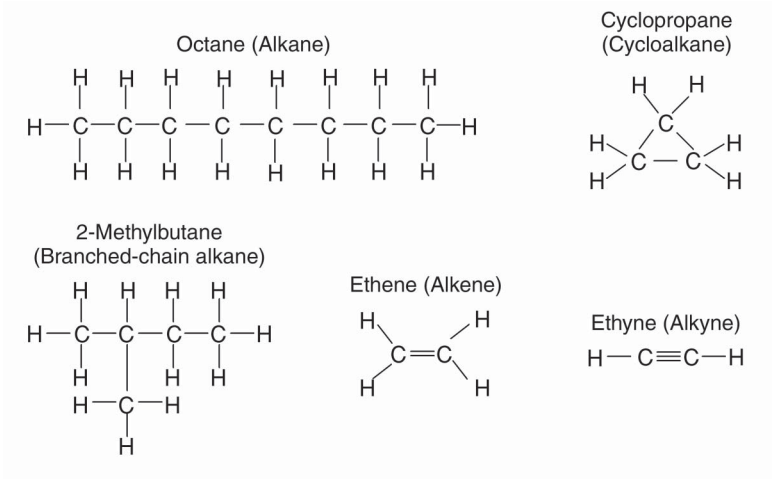


Figure 3—Typical alkanes, cycloalkane, alkenes, and alkyne.

## Petroleum

Soil can be contaminated with petroleum hydrocarbons from releases of crude oil or refined petroleum products such as diesel. Crude oil contains three classes of hydrocarbon compounds:

- Straight- and branched-chain alkanes
- Cycloalkanes
- Aromatics

Refined petroleum also contains alkenes and alkynes, which are formed during the refining process. Examples of the structures of each of these hydrocarbon compounds are shown in figures 3 and 4.

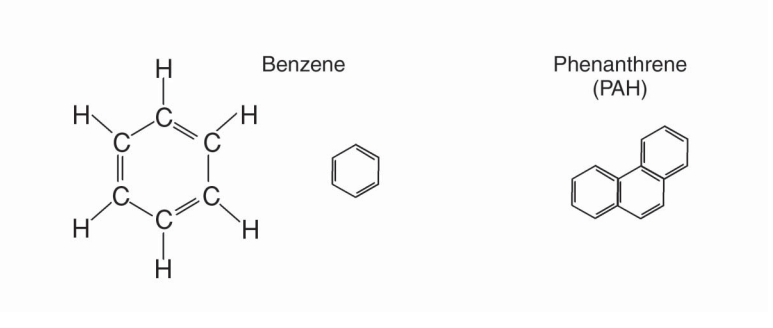


Figure 4—Typical aromatic (shown by two different schemes) and polycyclic aromatic hydrocarbons (PAH).

Straight- and branched-chain alkanes include compounds such as propane, n-octane, and iso-octane. In these compounds, single bonds join the atoms. If a hydrocarbon only contains single bonds, the compound is considered a saturated hydrocarbon (containing the maximum number of bonded hydrogen atoms). Cycloalkanes are saturated hydrocarbons formed into a ring-type structure. This class of hydrocarbons includes such compounds as cyclopentane, cyclobutane, and methylcyclopentane.

Compounds that contain double or triple bonds (they do not contain the maximum number of bonded hydrogen atoms) are considered unsaturated. Alkenes and alkynes are unsaturated compounds. Ethene is an alkene and ethyne is an alkyne. Other alkene and alkyne compounds found in petroleum products include: 1-hexene, 2-methyl-1-butene, and so forth.

Aromatic compounds are probably more familiar to the reader. This special class of highly unsaturated hydrocarbons consists of ring-structured compounds such as benzene, toluene, ethylbenzene, and xylene (collectively known as BTEX). When carbon atoms are shared between rings, compounds are called polycyclic aromatic hydrocarbons, or PAHs.

Designing systems to reduce the mass of hydrocarbons in contaminated soils requires understanding the properties of the different classes of hydrocarbons. The key properties of hydrocarbons are:

- Vapor pressure
- Solubility
- Partitioning of the compound between water and the atmosphere (Henry's law)
- Partitioning of the compound between water and solid (sorption)

The vapor pressure of a compound is the temperature-dependent pressure of the gas phase of the compound in equilibrium with its pure liquid phase. Vapor pressure is directly proportional to the volatility of the compound. In any particular class of hydrocarbon the vapor pressure of different compounds is going to vary by 10 to 100 times or more. Generally, the vapor pressure of most PAHs will be less than the vapor pressure of aromatics, alkanes, alkenes, and alkynes. Table 2 shows vapor pressures for some petroleum hydrocarbons of concern (Alaska Department of Environmental Conservation 2000a).

For all compounds, the vapor pressure will decrease as temperature decreases. A simple empirical equation can be used to estimate the vapor pressure of different compounds at temperatures other than the standard temperature (Schwarzenbach, Gschend, and Imboden 1993).

$$\ln P^\circ = -\frac{B}{T + C} + A$$

In the above equation, $P^\circ$ is vapor pressure (in atmospheres), T is temperature (in degrees Kelvin), and A, B, and C are constants. Values for the constants in the above equation have been tabulated for a variety of different compounds (CRC Handbook of Chemistry and Physics 1985).

Solubility measures the abundance of a compound per unit volume in the aqueous phase when the solution is in equilibrium with the pure compound at a specified pressure and temperature. Figure 5 shows the solubility of different classes of hydrocarbons as a function of the number of carbons in the compound (Curl and O'Donnell 1977). From this figure, some rules of thumb for solubility can be stated:

- Lower molecular weight hydrocarbons are more soluble than higher molecular weight hydrocarbons.
- Unsaturated hydrocarbon rings are more soluble than hydrocarbons comprised of the same number of carbon atoms formed in saturated rings.

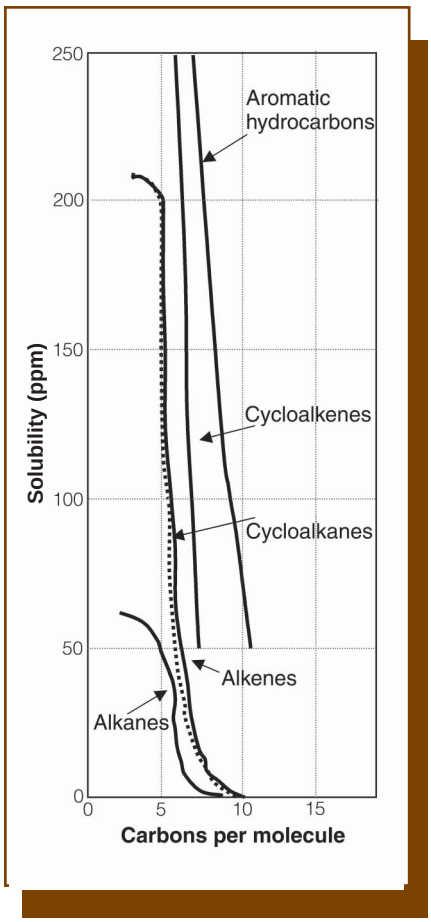


Figure 5—Solubility of the different petroleum hydrocarbon classes adapted from Curl and O'Donnell (1977).

Table 2—Vapor pressure in millimeters of mercury of common petroleum hydrocarbons at different temperatures (Verschueren 1983).

| Petroleum hydrocarbon | Vapor pressure (temperature) |
|---|---|
| 1-Butanol | 4.4 (20 °C) |
| Naphthalene | 0.11 (20 °C) |
| Benzo(a)pyrene | $5.0 \times 10^{-11}$ (25 °C)[a] |
| Benzo(a)anthracene | $5.0 \times 10^{-12}$ (20 °C)[a] |
| 2-Methylphenol | 0.24 (25 °C) |
| Benzene | 76 mm (20 °C), 60 mm (15 °C) |
| Toluene | 22 mm (20 °C), 10 mm (6.4 °C) |
| Ethylbenzene | 7 mm (20 °C) |
| o-Xylene | 5 mm (20 °C) |
| m-Xylene | 6 mm (20 °C) |
| p-Xylene | 6.5 mm (20 °C) |

[a] Data from Montgomery (2000).

- Hydrocarbons in the alkenes class are more soluble than hydrocarbons in the alkane class.
- Aromatic hydrocarbons are more soluble than all other classes of hydrocarbons.

Table 3 lists the solubility of some common hydrocarbons at 20 °C. The solubility of hydrocarbons will vary only by about a factor of two or less between 0 and 35 °C.

The volatility of hydrocarbons that are dissolved in water is quantified by a factor called the Henry's Law constant. Henry's Law is simply the ratio of the equilibrium concentration of a compound in air to the

Table 3—Solubility in milligrams per liter at 20 °C of common petroleum hydrocarbons (Verschueren 1983).

| Petroleum hydrocarbon | Solubility (mg/L) |
|---|---|
| 1-Butanol | 77,000 |
| Naphthalene | 30 |
| Benzo(a)pyrene | 0.003 |
| Benzo(a)anthracene | 0.01 |
| 2-Methylphenol | 26,000[a] |
| Benzene | 1780 |
| Toluene | 470 |
| Ethylbenzene | 152 |
| o-Xylene | 175 |
| m-Xylene | 130 |
| p-Xylene | 198 |

[a] Data from Montgomery (2000).

concentration of the compound dissolved in water. For treatment of petroleum-contaminated soil, this factor helps determine how effectively a hydrocarbon compound can be removed from soil and water by volatilization.

The Henry's Law constants for most hydrocarbons are temperature dependent. Calculating Henry's Law constants at different temperatures given the constant at standard temperature requires a better understanding of physical chemistry than can be presented in this manuscript. For more detailed information, refer to Schwarzenbach and others (1993) and Sawyer and others (1994). Some general rules for Henry's Law constants are:

- Alkanes, alkenes, and alkynes will generally have higher Henry's Law constants than aromatic compounds. The PAHs have the lowest Henry's Law constants.
- As the molecular weight of PAHs increases, the Henry's Law constant decreases.

Table 4 lists the Henry's Law constants for several common hydrocarbons. Reported values of Henry's Law constants vary over a fairly wide range for any particular compound. The values listed here are representative.

The last property that needs to be addressed is sorption, or the partitioning of a hydrocarbon between the aqueous phase and the solid phase. Sorption of hydrocarbons onto soil particle surfaces is highly dependent on the amount of natural organic material in the soil. Different soil types will contain different amounts of natural organic material. For instance, clay contains a higher amount of natural organic material than sand. The dependence of sorption on the amount of natural organic material in soil is due to the highly hydrophobic (water-hating) nature of hydrocarbon compounds. These compounds prefer to reside on the natural organic material when they are dissolved in water.

Sorption of organic compounds is quantified as a ratio between the equilibrium concentration of the compound contained on the solid to the concentration of the compound dissolved in water. The relationship between the organic content in the soil and the sorption coefficient for organic compounds is quantified using the following equation:

$$K_d = K_{oc} \; f_{oc}$$

where $K_{oc}$ is the organic carbon partitioning coefficient and $f_{oc}$ is the fraction of organic carbon contained in the soil. Table 5 lists the $K_{oc}$ value for several common hydrocarbons (Montgomery 2000). Generally speaking, PAHs will have high values of $K_{oc}$ in comparison to other petroleum hydrocarbon classes. Unlike Henry's Law constant and vapor pressure, sorption is not highly temperature dependent (Schwarzenbach, Gschend, and Imboden 1993). As with Henry's Law constants,

Table 4—Henry's Law constant ($K_H$) in atmosphere cubic meters per mole of common petroleum hydrocarbons (Montgomery 2000).

| Petroleum hydrocarbon | $K_H$ (temperature) |
|---|---|
| 1-Butanol | $7.96 \times 10^{-6}$ (25 °C) |
| Naphthalene | $4.76 \times 10^{-4}$ (25 °C) |
| Benzo(a)pyrene | $3.36 \times 10^{-7}$ (25 °C) |
| Benzo(a)anthracene | $8.00 \times 10^{-6}$ (25 °C) |
| 2-Methylphenol | $1.20 \times 10^{-6}$ (25 °C) |
| Benzene | $4.76 \times 10^{-3}$ (25 °C), $3.30 \times 10^{-3}$ (10 °C) |
| Toluene | $6.70 \times 10^{-3}$ (25 °C), $3.80 \times 10^{-3}$ (10 °C) |
| Ethylbenzene | $6.60 \times 10^{-3}$ (25 °C), $3.26 \times 10^{-3}$ (10 °C) |
| o-Xylene | $5.0 \times 10^{-3}$ (25 °C), $2.85 \times 10^{-3}$ (10 °C) |
| m-Xylene | $7.00 \times 10^{-3}$ (25 °C), $4.11 \times 10^{-3}$ (10 °C) |
| p-Xylene | $7.10 \times 10^{-3}$ (25 °C), $4.20 \times 10^{-3}$ (10 °C) |

reported values of $K_{oc}$ vary over a fairly wide range. The values listed in table 5 are representative values.

Table 5—Organic carbon partitioning coefficients ($K_{oc}$) in liters per kilogram for common petroleum hydrocarbons (Montgomery 2000).

| Petroleum hydrocarbon | $K_{oc}$ (liters per kilogram) |
|---|---|
| 1-Butanol | 3.16 |
| Naphthalene | 1,300 |
| Benzo(a)pyrene | $1.15 \times 10^6$ |
| Benzo(a)anthracene | $3.10 \times 10^5$ |
| 2-Methylphenol | 50 |
| Benzene | 80 |
| Toluene | 100 |
| Ethylbenzene | 150 |
| o-Xylene | 250 |
| m-Xylene | 170 |
| p-Xylene | 250 |

The most toxic hydrocarbons in crude oil and refined petroleum products are the aromatics. Other hydrocarbons, ordered from most toxic to least toxic, include: alkenes, cyclic alkanes, and alkanes. The most soluble, least sorptive class of compounds, aromatics, is also the most toxic. As petroleum products age (weather), the overall toxicity of the contaminant decreases because the aromatics are more volatile than the other classes of compounds.

Within each group, the toxicity of the hydrocarbons tends to decrease with increasing molecular weight. Other general rules for toxicity include:

- Octane (8-carbon alkane) and decane (10-carbon alkane) are relatively toxic.
- Dodecane (12-carbon alkane) and alkanes with more than 12 carbons are relatively nontoxic.
- Alkenes and aromatics in the 12-carbon range are considered quite toxic (aromatics are more toxic than alkenes in this category).

More detailed discussion of each reaction can be found in Schwarzenbach and others (1993) and Sawyer and others (1994).

For convenience, compounds that make up petroleum are often divided into groups by the number of carbon atoms in the compounds. The more carbon atoms, the higher the boiling point. Table 6 lists the different categories.

Table 6—Petroleum fractions.

| Name | Carbon atoms | Approximate boiling point |
|---|---|---|
| Gasoline range organics | $C_6$ to $C_{10}$ | 60 °C to 170 °C |
| Diesel range organics | $C_{10}$ to $C_{25}$ | 170 °C to 400 °C |
| Residual range organics | $C_{25}$ to $C_{36}$ | 400 °C to 500 °C |

Knowing the boiling point of a petroleum compound helps when determining the appropriate method for removing the compound from contaminated soil. For example, technologies that depend on volatilizing the contaminant are most effective on compounds with boiling points lower than 300 °C.

Soil cleanup levels established by regulatory agencies usually specify a maximum allowable concentration of gasoline range organics, diesel range organics, and residual range organics that can remain in soil. These maximum levels are established with consideration of such factors as depth to groundwater, mean annual precipitation, soil type, potential receptors, and so forth. For example, under State of Alaska environmental regulations (18 AAC 75.340) an algorithm has been developed to determine the cleanup levels for gasoline range organics and diesel range organics given the depth to groundwater, the mean annual precipitation, the soil type, the location of the nearest public water system, and the volume of contaminated soil (Alaska Department of Environmental Conservation 2000a). Cleanup levels for specific compounds (18 ACC 75.340) have also been established by the State of Alaska (Alaska Department of Environmental Conservation 2000a).

## Movement of Petroleum in Unsaturated Soil

Petroleum products are only slightly soluble in water. Petroleum is considered immiscible in water, or a nonaqueous phase liquid (NAPL). Because petroleum is less dense than water, it is often called a light nonaqueous phase liquid, or LNAPL. The immiscibility of petroleum largely controls the movement of petroleum underground. The following discussion briefly describes the transport and fate of LNAPL in unsaturated soils.

The subsurface is usually divided into three distinct zones: the unsaturated zone (sometimes referred to as vadose zone), the capillary fringe (or nearly saturated zone), and the saturated zone. Once a

LNAPL is released to unsaturated soil, two forces act on the fluid: gravity and capillary pressure. Gravity will be the predominant force as free-phase LNAPL moves down toward the water table. As free phase LNAPL moves toward the capillary fringe, capillary pressure will cause the LNAPL to spread laterally. Lateral spreading depends on the method through which the petroleum was released (a catastrophic sudden release or a slow continuous release). A sudden release will result in more lateral spreading than a slow continuous release, such as a release from a leaking underground storage tank. Even though methods of investigating contaminated sites are not covered in this manuscript, understanding how the contaminant was released to the soil is important when determining the extent of the contamination in the soil.

Water saturation is high in the capillary fringe zone, which has relatively low permeability to LNAPL. Once free-phase LNAPL reaches this zone, the pattern of spreading is complex. In this zone, the tendency is for free-phase LNAPL to spread laterally near the top of the capillary fringe. Free-phase LNAPL will flow near the top of this zone until a critical depth of free-phase LNAPL is achieved. The direction of flow coincides with the gradient of the water table. Once the depth of free-phase LNAPL is sufficient near the top of the capillary fringe, the LNAPL will move to the water table.

As mentioned previously, the free-phase LNAPL flow characteristics depend on the method by which the liquid is released to the soil. If a sufficiently large volume of LNAPL is suddenly released, the critical pressure required for LNAPL to penetrate the capillary fringe is reached with minimal lateral spreading. Free-phase LNAPL flows toward the water table with relatively little resistance. Once free-phase LNAPL reaches the water table, it will spread laterally in the direction of groundwater flow. The extent of free-phase LNAPL flow depends on such factors as the volume released, the gradient, the characteristics of the porous medium, the rise and fall of the groundwater table, and other factors.

When the supply of free-phase LNAPL from the release is exhausted, LNAPL in the unsaturated zone will drain until, for all practical purposes, a minimum volume of LNAPL remains in the unsaturated soil. This minimum volume is often referred to as residual saturation and depends on the soil type and the heterogeneous nature of the porous medium. At residual saturation, LNAPL exists in the pores of the medium as discrete volumes disconnected from LNAPL contained in neighboring pores. Under these conditions, the LNAPL is in a discontinuous phase that is not conducive to flow. Within the unsaturated porous media, a fraction of the LNAPL will partition into existing soil water, adsorb onto the surface of soil particles, and volatilize into pore space. These reactions were discussed previously.

In any waste treatment operation, characterizing the waste is important to designing the treatment system. The description of immiscible fluids in porous media is just an introduction to a very complex topic. For a more thorough description, the reader is referred to: Mercer and Cohen (1990), Bedient, Rifai, and Newell (1999), and Charbeneau (2000).

## Climatic Conditions

Because of the topography of the Tongass and Chugach National Forests, the climate can change drastically in a short distance. Unfortunately, weather station data is only available for a few locations in the areas of the national forests. The available data are provided as a reference for possible conditions that could be encountered in the national forests. Table 7 shows the location for each data set and the corresponding national forest closest to the weather station. Figures 6 to 8 show the monthly maximum, average, and minimum temperatures. Figures 9 to 11 provide the monthly average total precipitation for representative sites in each national forest.

Table 7—Representative weather station locations for the Chugach and Tongass National Forest climate data.

| Chugach National Forest |
| --- |
| Valdez, Whittier, Seward |
| **Tongass National Forest** |
| Ketchikan, Wrangell, Petersburg, Sitka, Juneau |

These data show minimum monthly average temperatures ranging from about –2 °C (Sitka) to –12 °C (Valdez). In the colder regions, average low temperatures that fall below 0 °C are sustained for 6 to 7 months (Valdez and Seward). While these low temperatures are not extreme lows, as would be seen in interior and Arctic regions of Alaska, they will influence the operation of some treatment systems, such as landfarming. These weather stations are at low elevations where temperatures would be warmer than at higher elevations. Figures 9 to 11 show that the maximum monthly rainfall ranges from 20 to 60 centimeters.

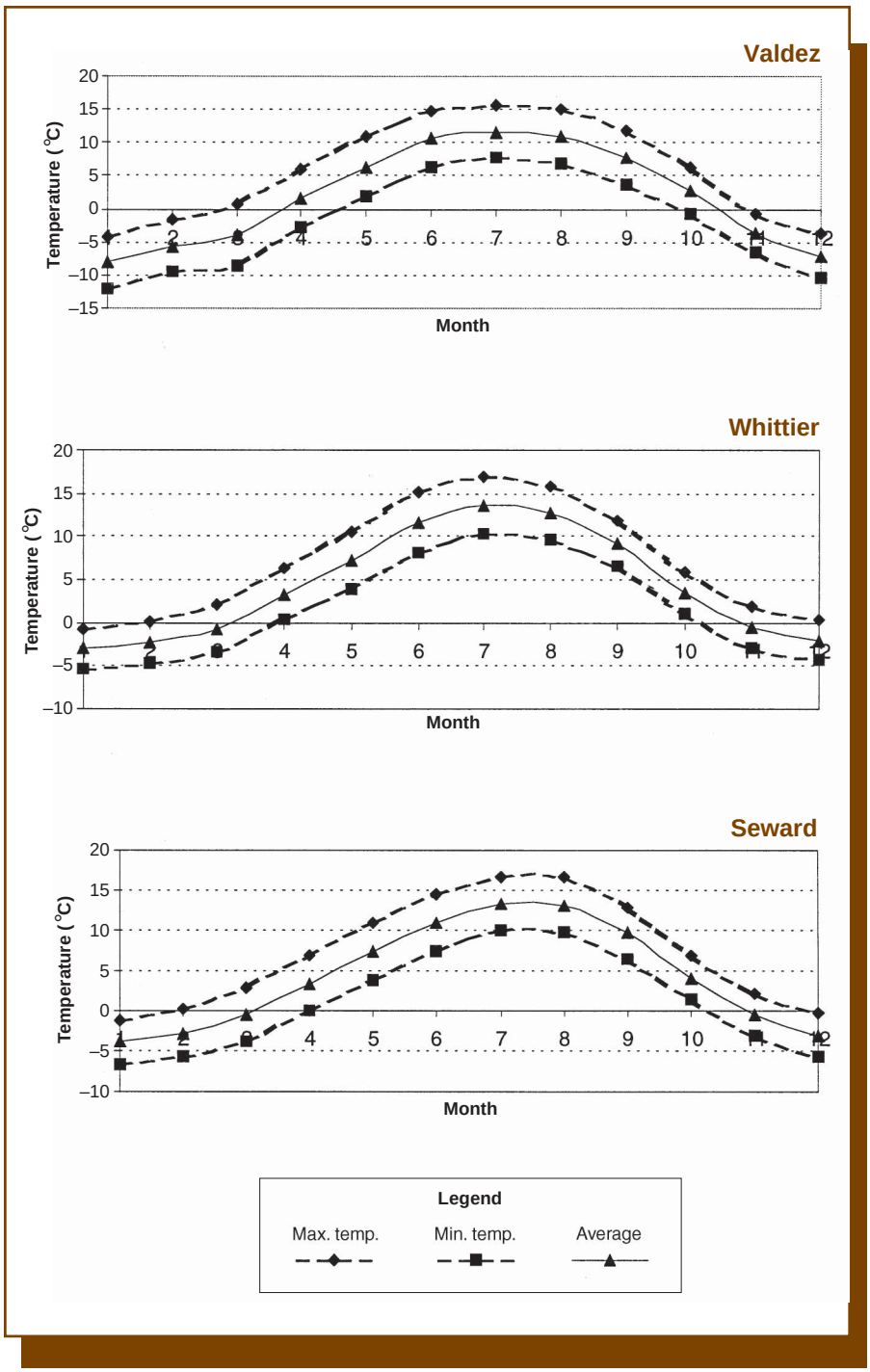


Figure 6—Representative monthly temperature data for the Chugach National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

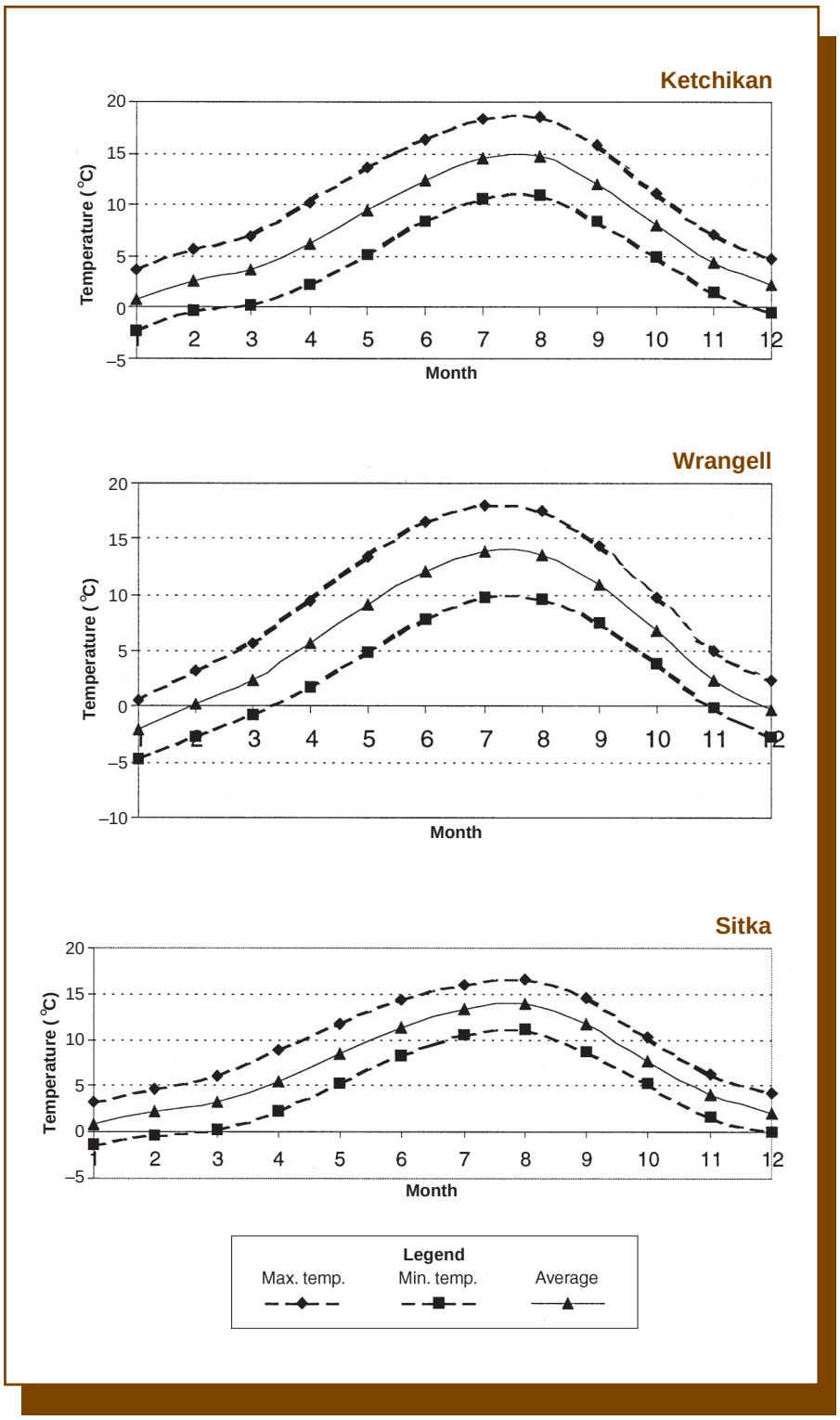


Figure 7—Representative monthly temperature data for the Tongass National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

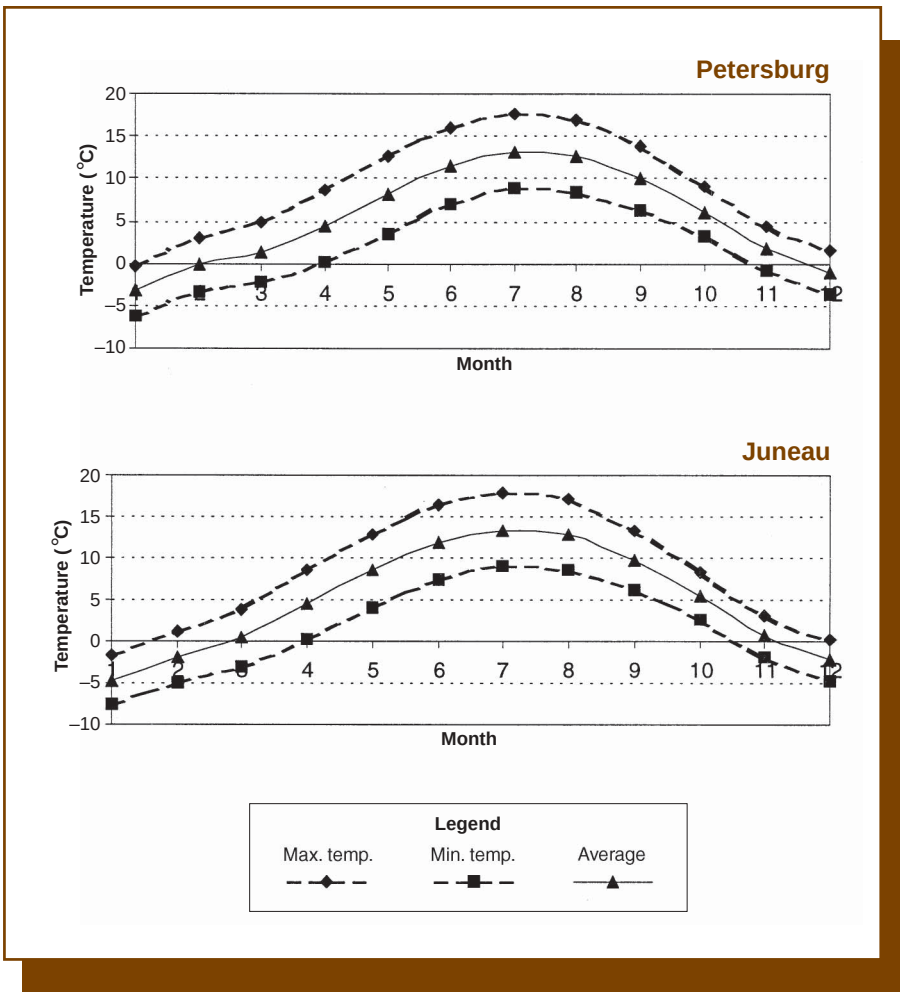


Figure 8—Representative monthly temperature data for the Tongass National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

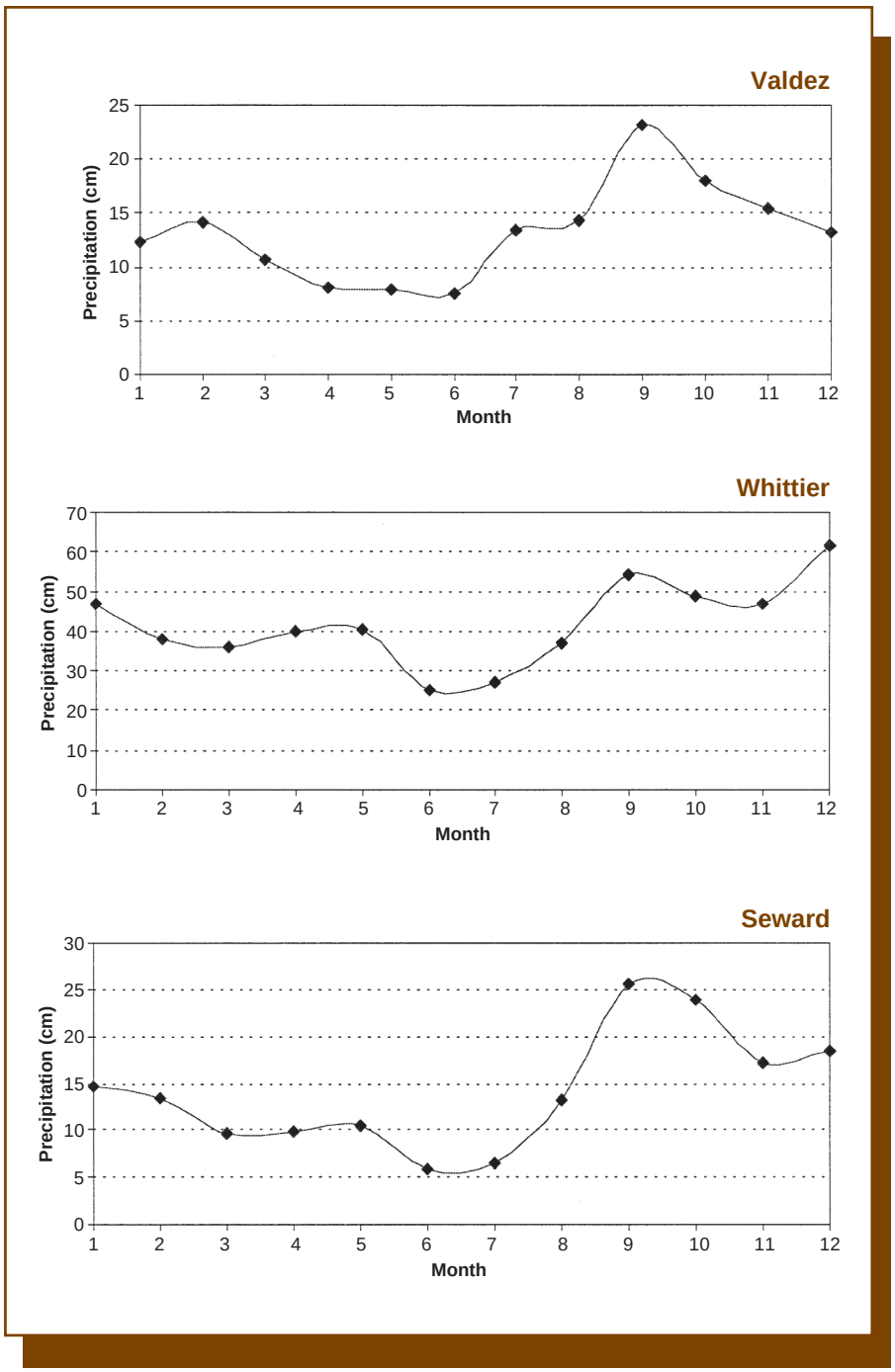


Figure 9—Representative monthly precipitation data for the Chugach National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

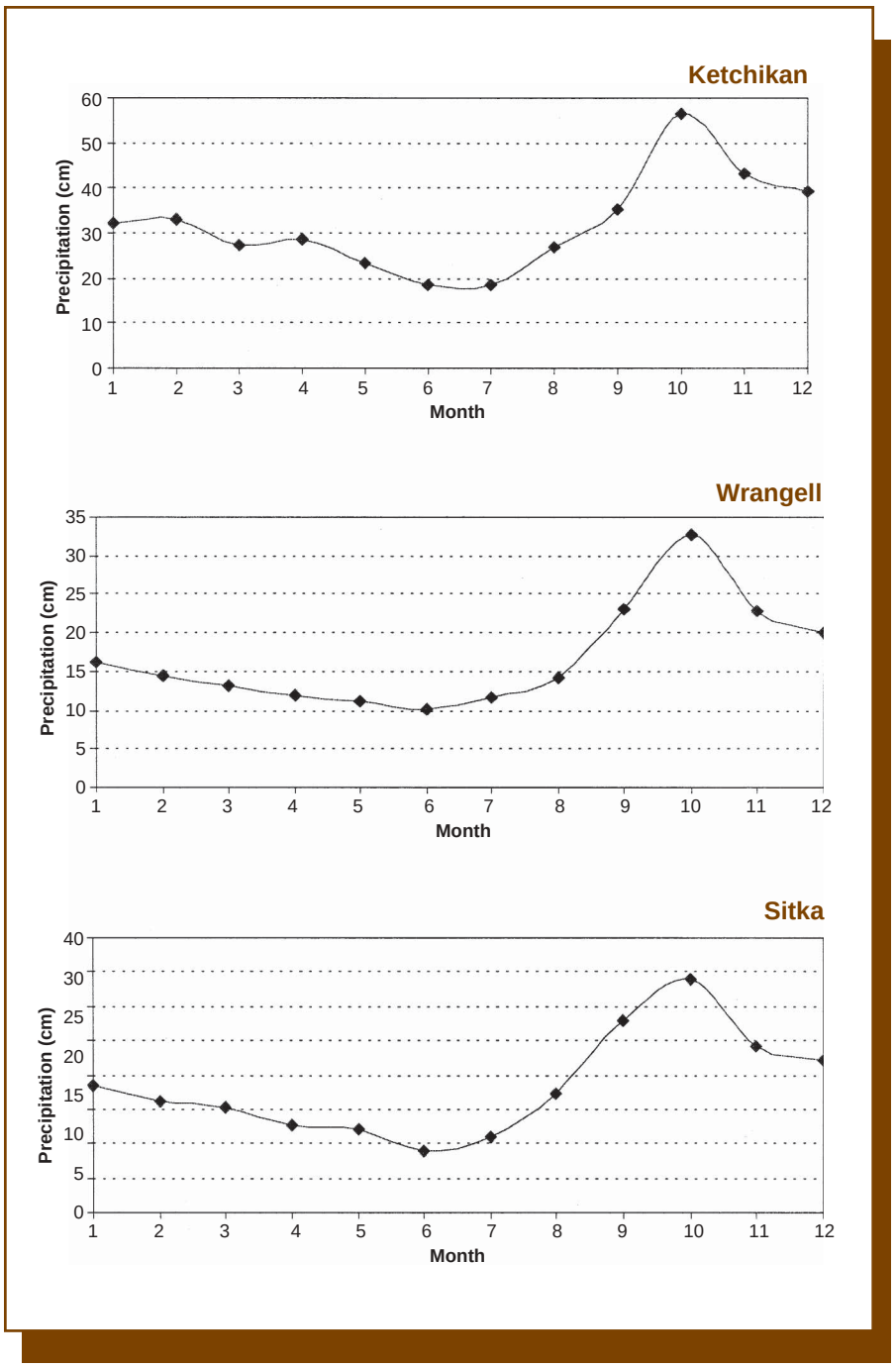


Figure 10—Representative monthly precipitation data for the Tongass National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

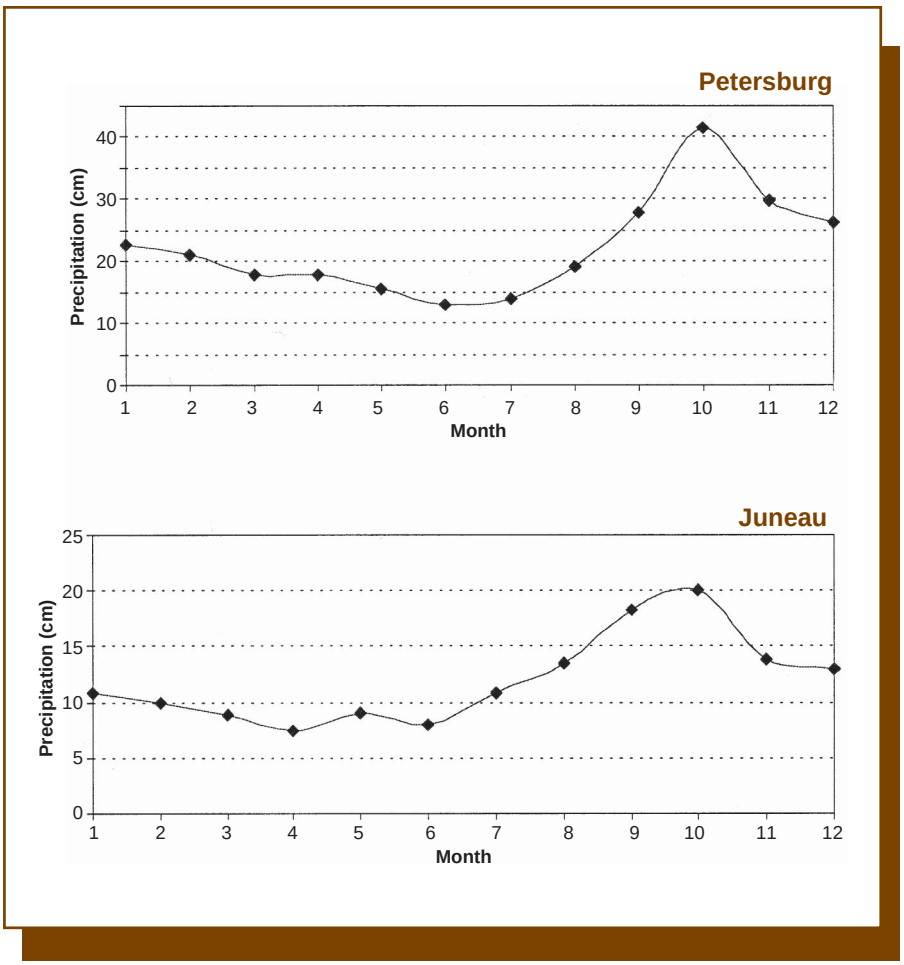


Figure 11—Representative monthly precipitation data for the Tongass National Forest. *—Alaska Climate Research Center, University of Alaska Fairbanks.*

# Treatment Options

## Excavation and Proper Disposal

The quickest and possibly simplest method of reducing the amount of petroleum-contaminated soil is by excavating the contaminated soil and shipping it to an appropriate landfill for disposal or to a facility where the contaminated soil can be incorporated into paving material. This option is also the surest method of reducing human and ecological health risks at the location of the release. Another advantage of removing contaminated soil is that there are no operation and maintenance costs. The major disadvantages are cost, the requirement for clean material to fill the excavation, and the long-term liability associated with disposal of the material.

In Alaska, soil particles with diameters wider than 2 inches do not require treatment or proper disposal (Alaska Department of Environmental Conservation 2000b). Larger particles can be screened, removed from excavated contaminated soils, and set aside for fill material. Sorption of petroleum hydrocarbon compounds is greater on fine-grained soils (clays) because of their larger surface areas. Fine-grained soils have higher concentrations of organic carbon than large soil particles.

A possible use of the excavation and disposal option that has not been fully explored by the environmental engineering community is to combine excavation and disposal with other in situ soil treatments. In some—if not most—cases, in situ treatment technologies such as soil vapor extraction (SVE) are efficient for removing much of the volatile soil contamination. However, the removal of contaminants by in situ methods becomes less efficient with time because of the limitations of diffusion and mass transfer. At that point, it may be cost effective to excavate the remaining contaminated soil and dispose of it. Because the in situ process reduces the bulk of the contamination, the volume of soil requiring excavation and disposal will probably be much less than before treatment. The main advantage to combining excavation and disposal with an in situ technique is that the job will probably be completed more quickly. Also, the cost of restoring the contaminated soil site will probably be less than if the entire volume of soil had been excavated and removed to a proper disposal facility.

**Use in Cold, Wet, Remote Regions—** The challenges of excavation in cold regions apply to all ex situ treatment options. The shear strengths of soils that experience seasonal freeze/thaw cycles are generally much higher when the soils are frozen than when they are thawed. Practical excavation of contaminated soil in cold regions is limited to the months when the soil is thawed. Soils with low moisture content are an exception to this rule.

For proper disposal, excavated soils need to be placed in a container or containers. Dry soils are easier to store than wet soils. Soils are commonly wet in areas with high annual precipitation. In Alaska, engineers have had success with various types of containers (information provided by Nortech Environmental & Engineering Consultants, appendix C). The more common types of containers used have been overpacks (55-gallon open-top drums), large shipping containers (20- to 40-foot containers), and reinforced flexible bags. Each container has advantages and disadvantages. The choice of container is a function of the engineer's preference, site conditions, and the mode of shipping.

Efficient excavation requires powered equipment. Getting this equipment, and the fuel to run it, is a problem at remote sites. Shipping excavated soil to disposal areas is also a problem at remote sites. Once the contaminated soil has been removed, material may be required to fill the excavated site. An extended stay at the site should be figured into the cost estimate. The length of the stay depends on such factors as the volume of contaminated soil, the ease of excavation, weather conditions, and other factors.

**Cost Estimate—**Table 8 lists the items that need to be accounted for in a cost estimate for excavating and disposing of petroleum-contaminated soil in cold, wet, remote regions. Assumptions include:

- Soil contamination does not extend past the digging depth of a typical backhoe (about 15 feet).
- Typical rated power of the backhoe is equal to 98 horsepower.
- On average, the backhoe is operating at 67 percent of rated power.
- The Forest Service owns the backhoe.
- The density of bank-measure material is 1,895 kilograms per cubic meter.
- The density of loose-measure soil is 1,528 kilograms per cubic meter.
- Fill material can be wheel rolled by the backhoe for compaction.

Table 8—Items to be included in a cost estimate for excavation of contaminated soil and proper disposal.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Backhoe. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Containers—About 1.24 cubic yards of container space is required for each cubic yard of soil removed. |
| • Shipping and disposal. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Fill material. |
| • Accommodations for extended stay. |

## Incineration

Incineration has been successfully used to treat soils contaminated with chlorinated hydrocarbons, dioxins, polychlorinated biphenyls (PCBs), and petroleum products. The main goal of incineration is to heat the contaminated media to temperatures between 870 and 1,200 °C, volatilizing and burning halogenated organic compounds and other compounds that are difficult to remove. The operating temperature of a typical incinerator is well within the boiling point of compounds found in petroleum (table 6). Because of these high temperatures, no materials requiring special disposal considerations are produced when petroleum-contaminated soils are incinerated. The four main types of incinerators are: circulating bed combustors, fluidized bed incinerators, infrared combustion incinerators, and rotary kilns.

Contaminated soils can be incinerated onsite or the excavated soil can be transported to an incinerator offsite. Companies that offer onsite incineration usually provide a service that includes rental of the incinerator and a crew (two people per shift) to operate the incinerator. The incinerator is shipped to the site in several different trailer loads. The estimated shipping weight is at least 40,000 pounds. Some type of foundation will probably be required. Typical foundations are gravel pads, concrete, skids, and sheet piles. The foundation is usually 50 feet wide by 100 feet long. An 8- by 20-foot trailer will be required for the controls. The incinerator requires fuel (usually diesel) for combustion and three-phase electrical power. Fuel consumption is estimated at 10 gallons of fuel per ton of soil when the soil has a water content of 10 percent. Several gallons of water per minute are required for cooling and dust suppression. Logs and other large items are removed before the soil is loaded into the incinerator. Incineration takes about 1 hour for every 5 to 10 tons of petroleum-contaminated soil. The incinerator's exhaust gas is clean. The treated soil can be used as fill material.

**Use in Cold, Wet, Remote Regions—** Other than the problem of excavating frozen soils, experience with incineration has been mostly favorable in cold regions. According to vendors contacted for this study, the only operational problem encountered has been freezing of the cooling tower.

Incineration of contaminated soil works best for soils with low water content. This requirement may present challenges when treating contaminated soils in regions with high precipitation. The ideal ratio of soil-water to soil mass for soils to be incinerated is 1:10 (information provided by General Atomics, appendix C). Excavated soil can be covered to help keep it dry.

Incineration requires barge or road access to the work site. You should plan for an extended stay at the site when using this treatment.

Incineration has been used in Alaska on the Kenai Peninsula for soils contaminated with PCBs. The majority of this work was performed in the late 1980s and early 1990s. Diesel-contaminated soil was also successfully treated by incineration at Kotzebue and Kenai, AK (information provided by General Atomics, appendix C). While these sites are not considered remote, the successful treatment of contaminated soil does indicate that incineration is a viable treatment system for cold, wet regions.

**Cost Estimates—**The majority of the cost for incineration will probably be in shipping and renting the incinerator. Costs associated with excavation of the soil have been discussed previously. Table 9 provides additional items to be included in a cost estimate for incineration. Assumptions include:

- The incinerator service is rented.
- After incineration, the treated soil can be used as fill material.
- The Forest Service owns the backhoe.
- The backhoe used for soil excavation can be used for loading soil into the incinerator and for removing treated material for fill.
- The diesel required to operate the incinerator is included in the service cost; however, the cost of shipping the diesel is the responsibility of the Forest Service.
- A 20-horsepower generator is required for three-phase electrical power.
- The generator is owned by the Forest Service.
- No hazardous waste is produced.

Table 9—Items to be included in a cost estimate for incineration of contaminated soil.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Incinerator. |
| • Incinerator shipping. |
| • Service cost. |
| • Diesel for the incinerator—Estimated fuel consumption is 10 gallons per ton of soil. |
| • Fuel for the generator—Estimated fuel consumption is one-half gallon per hour. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Foundation—Estimated material volume required for foundation is 30 cubic yards (2-inch-thick foundation). |
| • Confirmation sampling—The number of samples depends on size of the contaminated site and on the regulatory agency. |
| • Accommodations for extended stay. |

# Thermal Desorption

While the goal of incineration is to oxidize contaminants in the soil, the goal of thermal desorption is to volatilize the contaminants from the soil. Figures 12a and 12b show a typical portable thermal desorption unit. After volatilization, contaminants in the gas phase are removed by a gas treatment system such as granular-activated carbon adsorption. Thermal desorption systems are classified by temperature. Low-temperature thermal desorption (LTTD) units operate between 90 and 320 °C. High-temperature thermal desorption (HTTD) units operate between 320 and 560 °C. Petroleum-contaminated soils are best treated with LTTD.

Thermal desorption units can be purchased or rented. Units are shipped on several trailers (typically four trailers) and assembled on the site. The equipment weighs about 95,000 pounds. Thermal desorption vendors contacted for this study indicated that the units would require some type of foundation. Compacted soil or a gravel pad may be sufficient. The units require natural gas, diesel, or propane for combustion and three-phase electrical power for operation. Some units include three-phase generators, eliminating the need for an external power source. Typical fuel requirements are 18 to 35 gallons of diesel per hour. Water is also required during operation to rehydrate cuttings, reducing dust. Typically, 120 gallons of water per hour is needed to increase the moisture content of the cuttings to 15 percent. Collectively, vendors contacted for this study indicate that this process is very effective on diesel-contaminated soil and that thermal desorption units generate very little or no hazardous wastes (information provided by Enviro-Klean and On-Site Technology, appendix C).

**Use in Cold, Wet, Remote Regions—** The problems of operating thermal desorption units in cold regions seem to be minimal and correctable. Condensed water and water used for rehydration may freeze during operation. A professional engineer contacted during this study experienced soil heating problems while operating one of these units in Alaska. "Tar balls" formed at the bottom of the thermal desorption unit (information provided by Nortech Environmental & Engineering Consultants, appendix C). This problem could have been the result of heat lost out the bottom of the unit into the underlying geologic formation, resulting in a lower operating temperature. Insulation between the unit and the underlying formation may have reduced the heat transfer and the formation of "tar balls."

Figure 12a—Two views of a typical portable thermal desorption unit.

Figure 12b.

Thermal desorption is less efficient on soils with high water content. Extra effort is needed to keep the soil dry in regions with high precipitation. Thermal desorption units have been used near Ketchikan (an area of high rainfall) with relative success.

Because of the complexity of shipping these units, this type of treatment is only practical for accessible sites with large volumes of soil.

**Cost Estimate—** Items to be included in a cost estimate for thermal desorption are similar to those included for incineration. Table 10 lists the items for the cost estimate. The majority of the cost will probably be in the shipping and the provided service. Table 10 was produced using the same assumptions as for table 9.

Table 10—Items to be included in a cost estimate for treating contaminated soil by thermal desorption.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Thermal desorption unit. |
| • Shipping the thermal desorption unit. |
| • Service cost. |
| • Diesel for the incinerator—Fuel consumption is 10 gallons of diesel per ton of soil. |
| • Fuel for the generator—Estimated fuel consumption is one-half gallon per hour. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Exhaust gas treatment system. |
| • Sampling of off gas to monitor treatment progress. |
| • Foundation—Estimated material volume required for foundation is 30 cubic yards. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations for extended stay. |

## Soil Washing

Soil washing is a water-based process for scrubbing soils ex situ to remove contaminants. Two mechanisms remove contaminants: particle size separation and dissolution into the wash water. As discussed previously, some metals and some organics have a tendency to bind to the clay and silt fraction in soils (table 5). A large proportion of the contaminants will be removed by simple particle separation and subsequent treatment or disposal. Contaminants can also be removed from the soil by adding different compounds, such as complexing agents, leaching agents, or surfactants to the wash water, or by adjusting the pH of the wash water. Treatment of the wash water will be required to remove the dissolved contaminants desorbed from the soil. A likely treatment technique for the wash water is granular activated carbon adsorption. Soil washing has been effective on petroleum-contaminated soils.

Figure 13—Typical soil washing unit.

While commercial use of soil washing is uncommon, several companies have successfully used this technology to clean contaminated soils. The process is carried out in a reactor that provides proper mixing and settling. Figure 13 shows a typical soil washing reactor. Soil washing units may be configured in several ways. Specifications given in this report apply to a particular soil washing unit marketed by Biogenesis Enterprises (appendix C). The equipment weighs about 18,000 pounds. The unit is skid mounted and requires a grizzly (coarse screen) to remove the larger soil particles. The process requires three-phase electrical power. About 1,000 gallons of water per day (assuming an 8-hour workday) is used in the treatment process. Unlike the previous treatment technologies, no foundation is required for the soil washing unit. However, the unit must be placed on level ground.

**Use in Cold, Wet, Remote Regions—** Because the washing process generates heat, soil can be washed at temperatures below 0 °C. If the unit is not operating, it could be damaged by water freezing inside it. Low temperatures should have only a minimal effect on the solubility of petroleum hydrocarbons. Cold water temperatures should not greatly reduce the performance of these systems.

In comparison to incinerators and thermal desorption units, soil washing devices are small and transportable. A backhoe will be required for loading the soil into the unit. Other than the difficulties of excavating wet soils, high precipitation should not hinder washing of contaminated soils.

Seawater is readily available in some remote regions of Alaska. It may be possible to use seawater for treating petroleum-contaminated soils by particle separation. Solids settle by gravity in liquids according to Stoke's Law (Fox and McDonald 1978). Stoke's Law was used to compare the settling characteristics of soil particles in seawater (ion concentration of 35 parts per million) to those in freshwater at 20 °C. Results from this simple calculation show that the settling velocity of soil particles in seawater is 96 percent of the settling velocity of the same diameter particle in freshwater. A longer detention time is required in the reactor when seawater is used. Soil washing reduces the mass of soil contamination by both particle separation and dissolution into the wash water. A limited review of the soil washing literature indicates that little is known about soil washing using seawater as the washing fluid. The use of seawater for dissolution treatment will require theoretical analysis and laboratory tests before conclusions can be drawn about its use for treating petroleum-contaminated soil.

Soil washing has been successfully used in Kotzebue, Kenai, and Anchorage, AK, with minimal problems (information provided by Biogenesis Enterprises, appendix C).

**Cost Estimate—**Soil washing units can be purchased or rented. Items to be included in a cost estimate for soil washing are similar to those for incineration and thermal desorption (table 11). Assumptions include:

- After soil washing, the treated soil can be used as fill material.

- The Forest Service owns the backhoe.
- The backhoe used for soil excavation can be used for loading soil into the soil washing unit and to remove treated material for fill.

Table 11—Items to be included in a cost estimate for washing contaminated soil.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Soil washing unit. |
| • Shipping. |
| • Fuel for the generator—Estimated fuel consumption is one-half gallon per hour. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Wash water treatment system. |
| • Wash water additives. |
| • Accommodations for extended stay. |

## Ex Situ Vapor Extraction

The volatile fraction of petroleum products can be removed by passing air through the contaminated soil. Vapor extraction works well on the highly volatile fraction of petroleum hydrocarbons (those with a boiling point below 300 °C). Contaminated soil is spread out on a network of aboveground piping. A vacuum is applied to pull air through the contaminated soil. A vacuum can be created by a power vacuum blower or by a wind-actuated exhaust fan (no external power source is required). Other variations of this process include piling the contaminated soil into a mound aboveground or in the excavated pit, placing slotted piping into and below the mound, and covering the mound with an impermeable liner. Once again, a vacuum is applied to the piping and air is drawn through the contaminated soil. Constructed reactors can also be used for vapor extraction. The contaminated soil is loaded into a reactor and air is drawn through the soil by forcing air into the reactor or by creating a vacuum that draws air through the soil. Whichever process is used, once the flow of air is established in the porous medium, volatile components contained in the soil preferentially partition into the flowing air from:

- The liquid phase volatile petroleum compounds contained in the pore space
- The portion of the compound that is dissolved in the soil water
- The portion of the compound that is adsorbed onto soil particles

Compounds with high vapor pressures, high Henry's Law constants, and low sorption characteristics are best suited for this type of treatment. Aromatics (the most toxic of the petroleum hydrocarbons) are for the most part amenable to venting. However, higher molecular weight PAH compounds such as benzo(a)anthracene and benzo(a)pyrene will not be effectively removed by venting.

Under the right conditions, biological treatment in the soil aided by the movement of air through the soil during vapor extraction may also reduce the level of petroleum hydrocarbons. The common thought is that while biological treatment may be occurring during the extraction process, the dominant removal process is vapor extraction. The extracted vapors may be treated to remove the hydrocarbons by vapor-phase granular-activated carbon or by vapor-phase incineration.

Ex situ vapor extraction is similar to the in situ process of soil vapor extraction that will be described later in this report. There are some advantages to performing vapor extraction ex situ. The main advantage is that there is more control over the process. Having more control means that the diffusion limitation caused by heterogeneous soil may be less of a problem. Also, the temperature of the extraction air can be more efficiently controlled. Increasing the extraction air temperature is advantageous because volatility increases with increasing temperature.

Vapor extraction is a simple process requiring only a blower (or blowers), piping, and possibly an impermeable liner or a constructed reactor. The time required to treat contaminated soil depends on soil type, temperature, and moisture content.

**Use in Cold, Wet, Remote Regions—** Because ex situ vapor extraction offers more control over the extraction process, it seems that ex situ vapor extraction would be more effective in cold regions than in situ vapor extraction. Simple engineering solutions to the process for operating in cold regions include heating the air before passing it through the soil and containing the soil to decrease heat loss. Also, soil that is excavated and treated ex situ may achieve higher temperatures during the summer months than soil below grade. This is particularly true for excavated soil that is spread in a relatively thin layer above grade, as would be the case for one of the vapor extraction scenarios described.

The effect temperature has on vapor extraction in the cold with no engineered controls (heating) can be illustrated with an example. The Henry's Law constant for benzene at 25 °C (table 4) is 0.00476 atmosphere cubic meter per mole and the reported value for $K_H$ is 0.0033 atmosphere cubic meter per mole at 10 °C. Calculating the mass of benzene that will partition to the air phase at the two temperatures shows that 37 percent more time will be required to remove the same amount of benzene dissolved in the soil water at 10 °C as at 25 °C. Obviously, heating the soil in these conditions will increase the efficiency of the removal

process. However, heating may not be cost effective.

High soil moisture in contaminated soil will limit the effectiveness of vapor extraction. Water contained in the soil will decrease the permeability of the media. In heterogeneous soil, water may severely slow the removal process in discrete volumes of soil within the volume of soil to be treated. Covering the soil and using reactors will help decrease the effects of precipitation in wet regions. If vapor extraction is to be performed on soil piles or on soil that has been spread on the surface, liners and berms may be required to contain runoff water during storms.

This treatment process seems to be applicable to remote regions. In addition to the issues associated with soil excavation in remote regions, the only other issue is the provision of three-phase electrical power (unless wind-actuated fans are used) and the need for visits to the site to check on the operation and conduct maintenance. The required number of visits to the site for operation and maintenance depends on factors such as the volume of soil to be treated, the complexity of the venting system, and requirements that might be imposed by regulatory agencies. Accommodations during the installation of the treatment system will also need to be accounted for in a cost estimate.

Ex situ vapor extraction has been successfully used in Alaska. Engineers contacted for this study have used vapor extraction to treat petroleum-contaminated soil in the Arctic during summer months (information provided by Shannon and Wilson, Inc., appendix C). Soil piles (placed above grade or in the excavation pit) and constructed reactors seem to work best in this region. Extraction air is heated to extend the season of operation. Alaskan engineers have also had success using wind-actuated exhaust fans. Ex situ vapor extraction using wind-actuated exhaust fans might noticeably reduce the rate of contaminant mass removal compared to a powered blower system capable of moving larger volumes of air.

**Cost Estimate—**Table 12 shows the items to be considered in developing a cost estimate for vapor extraction. Assumptions include:

- After treatment, the soil can be used as fill material.
- The Forest Service owns the backhoe.
- The backhoe used for soil excavation can be used for placing the soil into the area or in the reactor to be used for vapor extraction and can be used to remove treated soil after treatment is complete.
- No hazardous waste is produced.

Table 12—Items to be included in a cost estimate for treating contaminated soil by vapor extraction.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Reactor (if required). |
| • Vacuum blower. |
| • Pipe and slotted pipe. |
| • Shipping. |
| • Fuel for the generator—Estimated fuel consumption is one-half gallon per hour. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Exhaust gas treatment system. |
| • Sampling of off gas to monitor treatment progress. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

## Composting

Petroleum products are readily biodegradable under the proper conditions. Composting takes advantage of this potential. The most common form of composting consists of spreading the contaminated soil out in rows, commonly called windrows. If required, nutrients are mixed in with the soil. Oxygen required for the aerobic biodegradation is supplied by frequently mixing and turning the windrows. Even when the windrows are not being turned, some oxygen is provided to the organisms through diffusion from the air into the soil matrix. Bulking agents are often mixed with the soil to enhance the oxygen transfer. Soil type and condition control the rate of diffusion.

Sorption of contaminants onto soil surfaces decreases biodegradability. The biodegradation of some PAHs will be hindered because of their high propensity to partition to soil surfaces (table 5). High molecular weight compounds, such as some of the PAH compounds, may be slow to degrade because of their structural complexity. Readily biodegradable compounds include low molecular weight aromatics (BTEX), a key factor when considering the toxicity of these compounds. These compounds are relatively soluble compared to other petroleum hydrocarbons, making them available to microorganisms (table 3). For petroleum hydrocarbons, the ranking of biodegradability from most biodegradable to least is generally: straight chain alkanes, branched chain alkanes, low molecular weight aromatics, cycloalkanes (Leahy and Colwell 1990).

The rate of biodegradation of petroleum hydrocarbons is a function of temperature and soil moisture. Conventional wisdom is that the temperature must be higher than 10 °C for microorganisms to reduce the mass of petroleum hydrocarbons in the soil. Biodegradation may occur at temperatures below the optimum. However, the rate of biodegradation may be low. Further discussion of the effect that temperature has on the rate of biodegradation follows. Optimum soil moisture

content for composting is about 15 percent by weight. For petroleum-contaminated soils, moisture content should not be less than about 50 percent field capacity.

Historically, composting has been performed on organic wastes that have an abundant carbon source. Sewage sludge is an example of waste that can be composted easily. In some situations, petroleum-contaminated soil may not have enough carbon to support an acceptable rate of biodegradation. In these cases, a carbon source, such as sewage sludge, animal or vegetable wastes, and wood chips, can be mixed with the soil to enhance biodegradation.

Microorganisms have three basic requirements to biodegrade petroleum hydrocarbons: an adequate carbon source, oxygen (an electron acceptor), and an adequate supply of nutrients. Carbon and oxygen requirements have been addressed. Some soils do not have an adequate supply of nutrients (specifically nitrogen and phosphorous) to support biological growth. The solution to this problem is to add the proper amount of nutrients to the soil on a routine basis. Nitrogen has been added as urea or as ammonia salts (Cookson 1995). Typical sources of phosphorous include orthophosphoric and polyphosphate salts (Cookson 1995). The simplest method of adding nutrients is by mixing garden or lawn fertilizer into the soil (Cookson 1995). The amount of nutrients required can be estimated by knowing the amount of carbon in the material to be degraded. Estimation methods are well documented in Alexander (1999) and Cookson (1995).

Some believe that adding cultured microorganisms known to biodegrade petroleum hydrocarbons will enhance the biodegradation. This technique is often called "seeding." Several studies have examined the possibility of increasing the rate or extent (or both) of biodegradation in soils by seeding. Leahy and Colwell (1990) reviewed literature pertaining to seeding. The results of that review indicate that seeding is not required for soil contaminated by petroleum products. The main reasons Leahy and Colwell (1990) cite for this conclusion is the large number of hydrocarbon-degrading microorganisms that are found naturally in unsaturated soil. Hydrocarbon degraders naturally present in the soil have adapted to their environment. The additional seeding of organisms that have not adapted to such an environment will have a minimal effect on the rate of biodegradation. Braddock and others (2000) performed a comprehensive study examining the biodegradation of diesel-contaminated Arctic soil in biopiles. Results from this study showed that seeding of petroleum-contaminated soil had little influence on the rate of biodegradation.

Variations on the classic windrow design include aerated static piles and mechanically agitated vessels. Composting soil in aerated static piles is advantageous because the soil does not require mechanical mixing. Slotted pipes attached to blowers or wind-actuated exhaust fans are used to pull (or push) air through the excavated soil that has been formed in a pile (Fahnestock and others 1998). Mechanically mixing soil requires a constructed vessel to contain the soil during treatment. Soil is loaded into the vessel where it is mixed periodically to reaerate it.

In its simplest form, composting requires minimal infrastructure. Berms may be required to control runoff. The main requirement for windrow composting is frequent turning of the windrows to introduce oxygen (unless wind-actuated exhaust fans are used). The more advanced forms of composting require additional equipment.

**Use in Cold, Wet, Remote Regions—** Temperature is the driver for biological treatment of petroleum-contaminated soils. Microorganisms can degrade hydrocarbons in contaminated soil over a temperature range of 10 to 60 °C (Cookson 1995). For composting, maximum microbial activity has been measured at temperatures between 50 and 55 °C (Cookson 1995). Because biological reactions are exothermic (generate heat), these temperatures can be achieved even in cold regions with properly engineered controls. At some point air temperatures may drop to a level where composting will be ineffective, even with engineered controls. This limitation makes composting a seasonal activity.

A moderate level of moisture is required for biodegradation of petroleum in contaminated soils. However, moisture content exceeding 70 percent of field capacity will hinder gas transfer (Cookson 1995). Protection against water runoff during storms should be provided when contaminated soils are composted in wet regions. Composting alternatives that include covering the soil may be more applicable in wet regions.

The need for frequent mixing of the windrows makes traditional composting difficult in remote regions. Alternatives to traditional composting—static piles and mechanical agitation—may be more applicable.

Experience with composting in cold regions includes the use of static piles and a variation of a static pile, a biocell (information provided by Shannon and Wilson, Inc., appendix C). A biocell is essentially a contained static pile. The soil is loaded in a constructed reactor that includes a form of air introduction. To extend the available treatment time in cold regions, static piles have been covered and the inflowing air has been heated. Engineers have successfully treated petroleum-contaminated soil in the Arctic with this configuration. Thermally enhanced biocells have also successfully treated petroleum-contaminated soil in the Arctic.

**Cost Estimate—**The items to be considered in developing a cost estimate for composting are shown in table 13. Assumptions include:

- After composting, the treated soil can be used as fill material.
- The Forest Service owns the backhoe.
- The backhoe used for soil excavation can be used to place the soil into the

area or the reactor used for composting and for removing treated soil.

- No hazardous waste is produced.

Table 13—Items to be included in a cost estimate for treating contaminated soil by composting.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Reactor (if required). |
| • Vacuum blower (if required). |
| • Liner material. |
| • Shipping. |
| • Fuel for the generator—Estimated fuel consumption is 2.6 gallons per hour. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

## Landfarming

In landfarming, as in composting, petroleum products are biodegraded by spreading the contaminated soil on the land surface in a relatively thin layer. However, in landfarming, air is not mechanically introduced into the soil with the same frequency as in composting. Diffusion into the soil matrix is the main mechanism for oxygen transfer. Soils with an air-filled porosity higher than 15 percent are best suited for this treatment. The contaminated soil can be placed directly on the ground surface or on an impermeable liner (depending on the native soil type). Temperature and soil moisture requirements are the same as in composting. Both biological activity and volatilization reduce the contamination.

**Use in Cold, Wet, Remote Regions—** While adaptations of the traditional form of composting allow for an extension of the time available for practical soil treatment, landfarming is restricted to the warmer summer months. For unlined landfarming operations, water infiltration during storms may cause petroleum contamination to penetrate underlying native soil. Biodegradation in the underlying soils may reduce this impact. Runoff is also a problem in areas with high precipitation. Berms will reduce petroleum-laden surface water runoff. Increases in soil moisture content and associated decreases in air-filled porosity are expected during precipitation events. Because landfarming relies on oxygen diffusion to maintain aerobic conditions, decreases in air-filled porosity will decrease the rate of oxygen transfer and temporarily slow the rate of biodegradation. The aerobic conditions should rebound as the water evaporates and drains from the soil.

If sufficient space is available and the soil to be treated meets the requirements for air-filled porosity, landfarming is perfectly suited for treating petroleum-contaminated soil in remote regions. Past experience has shown that turning the soil periodically will aid in oxygen transfer. Generally, after the contaminated soil has been spread, landfarming operations require little maintenance.

Landfarming of petroleum-contaminated soil has been successfully practiced in Alaska (information provided by Geosphere, Inc., appendix C). Several field demonstrations were completed in Bettles, Huslia, Chandalar Lake, and King Salmon. At each site, contaminated soil was spread in 1-foot layers across the unlined ground surface. Soil-moisture content, precipitation, infiltration, soil temperature, the concentration of gasoline and diesel range organics in the landspread soils and in the native underlying soils were measured at each site. Significant reductions were noted in concentrations of both ranges of organics in the landfarmed soil. Testing of the underlying native soils showed little increase in concentrations of diesel range organics. Biodegradation was credited for the low concentrations.

Engineers in Alaska have also noted a marked increase in the mass reduction rate during warm and dry periods. This increase can be attributed to greater volatilization during these periods.

**Cost Estimate—**Table 14 shows the items to be considered in developing a cost estimate for landfarming. Assumptions include:

- After landfarming, the treated soil can be used as fill material.
- The Forest Service owns the backhoe.
- The backhoe used for soil excavation can be used for spreading the contaminated soil and for removing treated material.
- The contaminated soil is spread in a 1-foot-thick layer.
- No hazardous waste is produced.

Table 14—Items to be included in a cost estimate for treating contaminated soil by landfarming.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Liner material (if required)—About 34 square feet of liner is required for every estimated cubic yard of contaminated soil requiring excavation and treatment. |
| • Fuel for the backhoe—Estimated fuel consumption is 2.6 gallons per hour. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

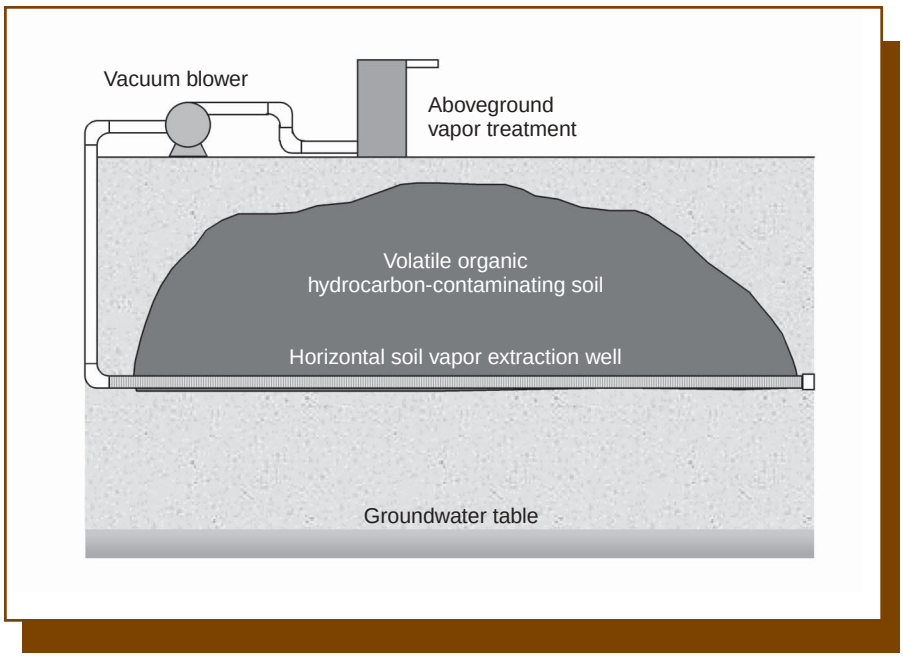


Figure 14—Schematic of a typical soil vapor extraction system.

## Soil Vapor Extraction

Soil vapor extraction (SVE) is an in situ technology that uses flowing air (soil gas) to volatilize volatile organic compounds (VOCs) in the contaminated soil, removing the contaminant from the soil (figure 14). The air flow is created by vacuum blowers attached to extraction wells installed in the unsaturated zone. The soil gas containing the VOCs is treated aboveground to remove the VOC. The treated air is discharged into the atmosphere. This step of the process will produce a waste that requires proper disposal.

Once the flow of soil gas is established in the porous medium, volatile components contained in the soil preferentially partition into the flowing soil gas from the liquid phase VOC contained in the pore space, from the portion of compound that is dissolved in the soil water, and from the portion of the compound that is adsorbed onto soil particles. Compounds that are readily removed by venting were discussed previously.

Soil vapor extraction wells can be installed vertically, horizontally, or at an angle. Conventional water well drilling techniques can be used to install SVE wells. Alternatively, SVE wells can be installed with excavation equipment if the depth of contamination is shallow. For instance, horizontal wells can be installed with directional drilling techniques or by using a backhoe for trenching.

**Use in Cold, Wet, Remote Regions—** Soil vapor extraction has been used extensively in Alaska to treat petroleum-contaminated soils (information provided by Hartcrowser, appendix C). The most notable cold-related problem has been freezing of condensed water in aboveground piping. Heating elements and insulation have been used to reduce this problem. Figure 15 shows insulation around a typical SVE extraction wellhead. Low temperatures reduce the volatility of the volatile fraction of the organics, slowing their removal. As in the ex situ venting process described above, heating the soil may increase the rate of removal.

In any soil, high soil moisture decreases the soil's permeability to air. In areas that experience high precipitation, the mass removal rate of volatile compounds will be reduced during periods of water infiltration. Covering the surface of the contaminated soil region will reduce infiltration. Covering the contaminated region helps remove contaminants by extending the lateral influence of the flowing air.

Soil vapor extraction requires single- or three-phase electrical power for the blowers, which will be a problem in remote regions. The problem is compounded by heterogeneities in soil properties that may limit flow, slowing the removal of contaminants by SVE. One option is to use SVE technology to remove a large fraction of the volatile contaminant from the soil and then use an alternate method to further reduce the contaminant, such as an ex situ technique or excavation and disposal of the remaining contaminated

Figure 15—Insulation installed around a typical SVE extraction well.

soil. This methodology makes good practical sense. Experience has shown that large fractions of volatile organics in contaminated soils are reduced in a short period of time by SVE. The volatile compounds that remain in the soil are probably in areas of low permeability. Removal of contaminants from these areas is dominated by diffusion transport processes, which are slow compared to advective transport processes (motion along a gradient) that are dominant in the zones of soil with relatively high permeabilities.

Application of this soil treatment procedure in cold, remote regions would be a two-step process. Step one would be to use SVE to remove the bulk of the volatile contaminants during the warmer summer months. Depending on the soil type and the extent of contamination, this step may be completed quickly. Step two would be to remove the remaining contaminant by excavating the soil and attempting to treat it ex situ by one of the processes described above, or by properly disposing of the contaminated soil. An alternative to excavation would be to switch to a passive in situ treatment technique such as barometric pumping (as described in the next column) after the bulk of the contaminant has been removed by SVE.

**Cost Estimate—**Table 15 shows the items to be considered when developing a cost estimate for SVE. The assumptions include:

- SVE will be effective in reducing the mass of volatile soil contamination to the regulatory limit.
- The vertical extent of contamination is shallow, allowing the use of horizontal wells.
- The Forest Service owns the backhoe and generator.

Table 15—Items to be included in a cost estimate for treating contaminated soil by soil vapor extraction.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Piping. |
| • Slotted pipe or well screen. |
| • Gravel pack for area around screens. |
| • Blower. |
| • Liner (if required). |
| • Housing for the blower and generator. |
| • Fuel for the generator—Estimated fuel consumption is one-half gallon per hour. |
| • Exhaust gas treatment system. |
| • Sampling of off gas to monitor treatment progress. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

## Barometric Pumping

Barometric pumping is similar to soil vapor extraction but relies on natural variations in barometric pressure rather than blowers to create the flow of soil gas through the subsurface (Looney and Falta 2000). On a daily basis, barometric pressure will vary slightly because of the cycle of the sun. Wider variations in barometric pressure will be seen over a span of days as weather fronts move in and out of the area being monitored. As the barometric pressure changes in the atmosphere, a pressure gradient is established between the atmosphere and air contained in subsurface soil. An airflow is created into or out of the subsurface soil in response to this gradient. This airflow can be used to remove volatile compounds from contaminated soil. Placing screened wells in the region of contaminated soil and adding a check valve to restrict the flow to extraction rather than injection focuses the pressure sink created by the change in barometric pressure, causing air to flow through the contaminated soil to the screened portion of the well or wells. The screened portion of the extraction wells should be placed deep enough to take advantage of the greatest pressure differential. Contaminants are removed as described in the discussion on soil vapor extraction.

**Use in Cold, Wet, Remote Regions—** The section on SVE described the complexities of using in situ venting processes in cold, wet regions. Acknowledging the reduction in the removal rate of volatile compounds because of cold temperatures, there is an advantage to a decrease in the soil temperatures at the ground surface. Ice will begin to form in the pore space in the top few centimeters of soil as temperatures drop below freezing. In soils with moderate to high moisture content, permeability will decrease at the ground surface, establishing a partial barrier to airflow. This partial barrier will increase the time required for the two pressures (atmospheric and subsurface) to reach equilibrium. Once the two temperatures are at equilibrium, subsurface airflow is stopped. Freezing at the surface increases

the time required for these two pressures to establish equilibrium, increasing the rate at which contaminants are removed.

This technique has an obvious advantage in remote regions. After installation, the system can be left alone, except for regular monitoring.

**Cost Estimate—**Table 16 shows the items to be considered when developing a cost estimate for barometric pumping. The assumptions used to construct this table are similar to those used in the section on SVE.

Table 16—Items to be included in a cost estimate for treating contaminated soil by barometric pumping.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Piping. |
| • Slotted pipe or well screen. |
| • Gravel pack for area around screens. |
| • Liner (if required). |
| • Exhaust gas treatment system. |
| • Sampling of off gas to monitor treatment progress. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

## Bioventing

In bioventing, as in SVE, vacuum in a well or wells screened (open to air flow) through the unsaturated soil pulls air though the soil. Even though some volatile compounds are removed by volatilization, bioventing relies primarily on biological degradation to remove contaminants. Petroleum hydrocarbon compounds that are amenable to biodegradation were discussed previously. Figure 16 shows a schematic of a typical bioventing system.

One difference between bioventing and SVE is the desired airflow rate. Because bioventing attempts to reduce the mass of contaminant by biodegradation, lower airflow rates are used, reducing the volatilization of the contaminants. Reducing the volatilization rate reduces the mass of volatile contaminant that will require treatment in the gaseous phase. Figure 16 illustrates a bioventing system designed so that the extracted soil gas does not have to be treated. Barometric pumping can also be used to supply oxygen to the subsurface, assisting aerobic biodegradation.

**Use in Cold, Wet, Remote Regions—** The main limitation to the use of bioventing in cold regions is probably the reduction in biodegradation because of low temperatures. In Alaska, field tests have shown that heating and insulating the soil during bioventing can maintain adequate rates of biodegradation. Bioventing with three

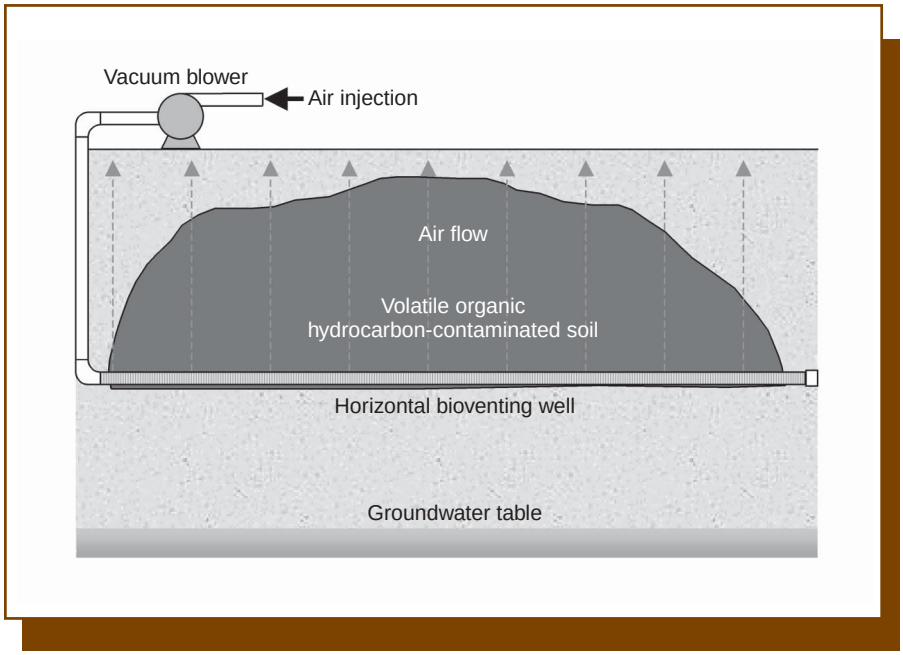


Figure 16—Schematic of a typical bioventing system.

different methods of soil heating was tested on soil contaminated with JP–4 jet fuel near Fairbanks, AK. The soil was heated by circulating extracted heated ground water through the unsaturated contaminated soil, by passive solar heating, and by heating the soil with heat tape. The soil was insulated for all three techniques to help retain the applied heat. Results from these three field tests were compared to a neighboring site where bioventing was attempted with no applied heat. Heating of the soil substantially increased biological activity and contaminant reduction.

Challenges faced for bioventing in wet, remote regions are similar to the challenges faced for SVE. Using barometric pumping to introduce air into the subsurface may make bioventing attractive in remote regions.

**Cost Estimate—**Table 17 shows the items to be considered when developing a cost estimate for bioventing. The assumptions include:

- Bioventing will be effective in reducing the mass of volatile soil contamination to the regulatory limit.
- The vertical extent of contamination is shallow, allowing the use of horizontal wells.
- The Forest Service owns the backhoe and generator.
- Treatment of the off gas is not required.

Table 17—Items to be included in a cost estimate for treating contaminated soil by bioventing.

| Cost estimating factors |
|---|
| • Mobilization and demobilization. |
| • Piping. |
| • Slotted pipe or well screen. |
| • Gravel pack for area around screens. |
| • Blower. |
| • Liner (if required). |
| • Housing for the blower and generator. |
| • Fuel for the generator—Estimated fuel consumption is 2.6 gallons per hour. |
| • Confirmation sampling—The number of samples depends on the size of the contaminated site and on the regulatory agency. |
| • Accommodations at the site during system installation. |
| • Operation and maintenance visits. |

# Summary

Table 18 compares each of the technologies discussed in this report. The applicability of each technology for use in cold, wet, and remote regions is rated on a scale of one to three. The rating criteria for operating in the cold (below 0 °C) are:

**1**—Operates in cold temperatures with minimal difficulty

**2**—Additional controls required to operate in cold temperatures

**3**—Inappropriate in cold temperatures

For operating in wet conditions, the rating criteria are:

**1**—Minimal controls required to operate when the soil moisture content is high

**2**—Additional controls required (covering)

**3**—Inappropriate in wet conditions

The rating criteria for remote operation are:

**1**—Requires minimal equipment and minimal operation and maintenance (O&M) visits

**2**—Requires minimal equipment and frequent O&M visits

**3**—Requires extensive equipment or an extended stay at the site

Other factors are required to make a proper selection of the type of treatment technology or technologies for contaminated soil. Cost is an obvious factor. Time is another factor. For instance, treatment of contaminated soil by barometric pumping will take longer than if the soil was excavated and treated above grade by thermal desorption.

The purpose of this report is to help the Forest Service engineers choose a treatment technology that will reduce the level of petroleum contamination in contaminated soils. The goal of any soil restoration effort is to reduce the risk contamination poses to human health and the environment. It is difficult to reduce the mass of soil contamination in remote regions that receive comparatively high amounts of precipitation, where temperatures that can drop as low as –12 °C, and cold temperatures are sustained for several months. Each of the technologies discussed in this report has been successfully used in Alaska.

Table 18—Ratings of 10 treatment technologies for soils contaminated by petroleum in cold, wet, remote regions.

| Treatment technique | CONDITION | | |
|---|---|---|---|
| | Cold | Wet | Remote |
| **EX SITU** | | | |
| Excavation and proper disposal | 1 | 1 | 3 |
| Incineration | 1 | 1 | 3 |
| Thermal desorption | 1 | 1 | 3 |
| Soil washing | 2 | 1 | 3 |
| Vapor extraction | 2 | 2 | 2 or 1[a] |
| Composting | 2 | 1 | 2 or 1[a] |
| Landfarming | 3 | 1 | 1 |
| **IN SITU** | | | |
| Soil vapor extraction | 2 | 1 | 3 |
| Barometric pumping | 1 | 1 | 1 |
| Bioventing | 2 | 1 | 3 or 1[b] |

[a] A rating of 1 applies if wind-actuated exhaust fans are used.
[b] A rating of 1 applies if barometric pumping is used to supply oxygen to the subsurface.

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# Appendix A—Soil Restoration Vendors

This appendix lists professionals who provide soil restoration services. The table was created from information provided by the Federal Remediation Technologies Roundtable. The Roundtable is a collection of Federal agencies involved in hazardous waste site remediation. The focus of the Roundtable is to exchange information on the use and development of innovative hazardous waste characterization, monitoring, and treatment technologies. Members of the Roundtable include:

- U.S. Department of Defense
- U.S. Environmental Protection Agency
- U.S. Department of Energy
- U.S. Department of the Interior
- U.S. Department of Commerce
- U.S. Department of Agriculture
- National Aeronautics and Space Administration

This information is provided to the reader for reference only. The authors of this manuscript have not evaluated any of the services provided by these companies and do not endorse one company over another.

## Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **In Situ Biological Treatment** | | | | |
| Battelle, Pacific Northwest Division | WA | 6 | 509–372–2273 | Bioventing |
| Phytokinetics, Inc. | UT | 4 | 801–750–0985 | Bioremediation |
| Wasatch Environmental, Inc. | UT | 4 | 801–972–8400 | Bioremediation |
| Parsons Engineering-Science, Inc. | CO | 2 | 303–831–8100 | Bioventing |
| Midwest Microbial, L.C. | NE | 2 | 402–493–8880 | Bioremediation |
| Bio-Genesis Technologies | AZ | 3 | 602–990–0709 | Bioremediation |
| Ecology Technologies International, Inc. | AZ | 3 | 602–985–5524 | Bioremediation |
| In-Situ Fixation, Inc. | AZ | 3 | 602–821–0409 | Bioremediation |
| Billings & Associates, Inc. | NM | 3 | 505–345–1116 | Bioremediation |
| Applied Remedial Technologies | CA | 5 | 415–986–1284 | Bioventing |
| Clayton Environmental Consultants | CA | 5 | 714–472–2444 | Bioventing |
| H2O Science, Inc. | CA | 5 | 714–379–1157 | Bioventing |
| Microbial International | CA | 5 | 714–666–0924 | Bioremediation |
| Praxair, Inc. | CT | 9 | 203–837–2174 | Bioremediation |
| Microbial Environmental Services (MES) | IA | 9 | 515–276–3434 | Bioremediation |
| Keller Environmental, Inc. | IL | 9 | 630–529–5858 | Bioremediation |
| Abb Environmental Services, Inc. | MA | 9 | 617–245–6606 | Bioremediation, bioventing |
| Ensr Consulting and Engineering | MA | 9 | 508–635–9500 | Bioventing |
| Envirogen, Inc. | MA | 9 | 617–821–5560 | Bioventing |
| B&S Research, Inc. | MN | 9 | 218–984–3757 | Bioremediation |
| Terra Vac, Inc. | NJ | 9 | 609–371–0070 | Bioventing |

Continued —>

## Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **In Situ Biological Treatment** (continued) | | | | |
| Waste Stream Technology, Inc. | NY | 9 | 716–876–5290 | Bioremediation |
| Battelle Memorial Institute | OH | 9 | 614–424–5942 | Bioventing |
| Environeering | OH | 9 | 419–885–3155 | Bioventing |
| Ohm Remediation Services Corp. | OH | 9 | 419–424–4932 | Bioremediation, bioventing |
| Dames & Moore | PA | 9 | 215–657–5000 | Bioventing |
| Environmental Remediation Consultants, Inc. | FL | 8 | 941–952–5825 | Bioremediation |
| SBP Technologies, Inc. | FL | 8 | 904–934–9352 | Bioremediation |
| Kemron Environmental Services, Inc. | GA | 8 | 404–636–0928 | Bioremediation |
| Electrokinetics, Inc. | LA | 8 | 504–753–8004 | Bioremediation |
| ESE Environmental, Inc. | NC | 8 | 704–527–9603 | Bioremediation |
| Geo-Microbial Technologies, Inc. | OK | 8 | 918–535–2281 | Bioremediation |
| IT Corp. | TN | 8 | 423–690–3211 | Bioventing |
| Biogee International, Inc. | TX | 8 | 713–578–3111 | Bioremediation |
| Micro-Bac International, Inc. | TX | 8 | 512–310–9000 | Bioremediation |
| Arctech, Inc. | VA | 8 | 703–222–0280 | Bioventing |
| Grace Bioremediation Technologies (Canada) | ON | | 905–272–7427 | Bioremediation |
| Limnofix INC./Golder Associates (Canada) | ON | | 905–567–4444 | Bioremediation |
| **In Situ Chemical/Physical Treatment** | | | | |
| Applied Remedial Technologies | CA | 5 | 415–986–1284 | Soil vapor extraction |
| Geo-Con, Inc. | IL | 9 | 412–856–7700 | Soil vapor extraction, stabilization/fixation |
| Envirogen, Inc. | NJ | 9 | 609–936–9300 | Soil vapor extraction |
| Terra Vac, Inc. | NJ | 9 | 609–371–0070 | Pneumatic fracturing, soil vapor extraction |
| Dames & Moore | PA | 9 | 215–657–5000 | Soil vapor extraction |
| IT Corp. | TX | 8 | 713–784–2800 | Soil vapor extraction |
| Kap & Sepa, Ltd. (Czech Republic) | | | 422–2431–3630 | Soil vapor extraction |

Continued —>

# Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **In Situ Thermal Treatment** | | | | |
| Battelle, Pacific Northwest Division | WA | 6 | 509–376–3638 | Thermally enhanced recovery |
| Western Research Institute | WY | 2, 4 | 307–721–2281 | Thermally enhanced recovery |
| Applied Remedial Technologies | CA | 5 | 415–986–1284 | Thermally enhanced recovery |
| EM&C Engineering Associates | CA | 5 | 714–957–6429 | Thermally enhanced recovery |
| Geokinetics International, Inc. | CA | 5 | 510–254–2335 | Thermally enhanced recovery |
| Praxis Environmental Technologies, Inc. | CA | 5 | 415–548–9288 | Thermally enhanced recovery |
| Sive Services | CA | 5 | 916–678–8358 | Thermally enhanced recovery |
| Thermatrix, Inc. | CA | 5 | 408–453–0490 | Thermally enhanced recovery |
| IIT Research Institute | IL | 9 | 312–567–4257 | Thermally enhanced recovery |
| Bio-Electrics, Inc. | MO | 9 | 816–474–4895 | Thermally enhanced recovery |
| KAI Technologies, Inc. | NH | 9 | 603–431–2266 | Thermally enhanced recovery |
| Terra Vac/Battelle PNL | NJ | 9 | 609–371–0070 | Thermally enhanced recovery |
| R.E. Wright Environmental, Inc. (REWEI) | PA | 9 | 717–944–5501 | Thermally enhanced recovery |
| Hrubetz Environmental Services, Inc. | TX | 8 | 214–363–7833 | Thermally enhanced recovery |
| **Ex Situ Biological Treatment** | | | | |
| Etec | OR | 6 | 503–661–8991 | Bioremediation, solid phase |
| Mycotech Corp. | MT | 1 | 406–723–7770 | Bioremediation, solid phase |
| Yellowstone Environmental Science, Inc. | MT | 1 | 406–586–2002 | Bioremediation, solid and slurry phase |
| Earthfax Engineering, Inc. | UT | 4 | 801–561–1555 | Bioremediation, solid phase |
| Eimco Process Equipment Co. | UT | 4 | 801–272–2288 | Bioremediation, slurry phase |
| J.R. Simplot Co. | ID | 1, 4 | 208–234–5367 | Bioremediation, slurry phase |
| Bio-Genesis Technologies | AZ | 3 | 602–990–0709 | Bioremediation, solid and slurry phase |
| Ecology Technologies International, Inc. | AZ | 3 | 602–985–5524 | Bioremediation, solid and slurry phase |
| Remediation Technologies, Inc. | AZ | 3 | 520–577–8323 | Bioremediation, solid and slurry phase |
| Clean-up Technology, Inc. | CA | 5 | 310–327–8605 | Bioremediation, solid phase |
| Praxair, Inc. | CT | 9 | 203–837–2174 | Bioremediation, slurry phase |
| Microbial Environmental Services (MES) | IA | 9 | 515–276–3434 | Bioremediation, solid phase |

Continued —>

# Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **Ex Situ Biological Treatment (continued)** | | | | |
| ABB Environmental Services, Inc. | MA | 9 | 617–245–6606 | Bioremediation, solid phase |
| ENSR Consulting and Engineering | MA | 9 | 508–635–9500 | Bioremediation, solid phase |
| Bio Solutions, Inc. | NJ | 9 | 201–616–1158 | Bioremediation, slurry phase |
| Waste Stream Technology, Inc. | NY | 9 | 716–876–5290 | Bioremediation, solid and slurry phase |
| OHM Remediation Services Corp. | OH | 9 | 419–424–4932 | Bioremediation, solid and slurry phase |
| Perino Technical Services, Inc. | OH | 9 | 217–529–0090 | Bioremediation, solid phase |
| Etus, Inc. | FL | 8 | 407–321–7910 | Bioremediation, solid phase |
| SBP Technologies, Inc. | FL | 8 | 904–934–9282 | Bioremediation, solid and slurry phase |
| Geo-Microbial Technologies, Inc. | OK | 8 | 918–535–2281 | Bioremediation, solid and slurry phase |
| Bogart Environmental Services, Inc. | TN | 8 | 615–754–2847 | Bioremediation, slurry phase |
| EODT Services, Inc. | TN | 8 | 423–690–6061 | Bioremediation, slurry phase |
| IT Corp. | TN | 8 | 615–690–3211 | Bioremediation, solid and slurry phase |
| Alvarez Brothers, Inc. | TX | 8 | 512–576–0404 | Bioremediation, solid phase |
| Biogee International, Inc. | TX | 8 | 713–578–3111 | Bioremediation, solid and slurry phase |
| Grace Bioremediation Technologies (Canada) | ON | | 905–272–7427 | Bioremediation, solid phase |
| **Ex Situ Chemical/Physical Treatment** | | | | |
| Soil Technology, Inc. | WA | 6 | 206–842–8977 | Soil washing |
| Smith Environmental Technologies Corp. | CO | 2 | 303–790–1747 | Materials handling/physical separation, soil washing |
| Portec, Inc. | SD | 1, 2 | 605–665–9311 | Materials handling/physical separation |
| Applied Remedial Technologies | CA | 5 | 415–986–1284 | Soil vapor extraction |
| Earth Decontaminators, Inc. (EDI) | CA | 5 | 714–262–2292 | Soil washing |
| OHM Remediation Services Corp. | CA | 5 | 510–227–1105 | Soil washing |
| Benchem | IL | 9 | 412–361–1426 | Soil washing |
| Geo-Con, Inc. | IL | 9 | 412–856–7700 | Soil vapor extraction |
| Microfluidics Corp. | MA | 9 | 617–969–5452 | Materials handling/physical separation |
| Integrated Chemistries, Inc. | MN | 9 | 612–636–2380 | Solvent extraction |

Continued —>

## Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **Ex Situ Chemical/Physical Treatment** (continued) | | | | |
| Envirogen, Inc. | NJ | 9 | 609–936–9300 | Soil vapor extraction, solvent extraction |
| Terra Vac, Inc. | NJ | 9 | 609–371–0070 | Oxidation/reduction, soil vapor extraction |
| RECRA Environmental, Inc. | NY | 9 | 716–691–2600 | Materials handling/physical separation |
| Dames & Moore | PA | 9 | 215–657–5000 | Soil vapor extraction |
| Sanford Cohen and Associates, Inc. | AL | 8 | 334–272–2234 | Soil washing |
| Alternative Remedial Technologies, Inc. | FL | 8 | 813–264–3506 | Soil washing |
| Metcalf & Eddy, Inc. | GA | 8 | 404–881–8010 | Oxidation/reduction, soil washing |
| Westinghouse Remediation Services, Inc. | GA | 8 | 404–299–4736 | Soil washing |
| Divesco, Inc. | MS | 8 | 601–825–4644 | Soil washing |
| Advanced Recovery Systems, Inc. | TN | 8 | 423–743–2500 | Acid extraction, oxidation/reduction, soil washing |
| Bergmann USA | TN | 8 | 615–452–5500 | Soil washing |
| IT Corp. | TN | 8 | 423–690–3211 | Acid extraction, oxidation/reduction, soil extraction |
| Hydriplex, Inc. | TX | 8 | 713–370–2778 | Soil washing |
| Radian International LLC | TX | 8 | 713–368–1300 | Materials handling/physical separation |
| Tvies, Inc. | TX | 8 | 713–447–5544 | Soil washing |
| B&W Nuclear Environmental Services, Inc. | VA | 8 | 804–948–4673 | Soil washing, vitrification |
| Technology Scientific, Ltd. (Canada) | AB | | 403–239–1239 | Soil washing |
| Kap & Sepa, Ltd. (Czech Republic) | | | 422–2431–3630 | Soil vapor extraction |
| AEA Technology (England) | | | 123–546–3194 | Soil washing |
| Chemcycle Environment, Inc. (Canada) | PQ | | 514–447–5252 | Soil washing |
| **Ex Situ Thermal Treatment** | | | | |
| Enviro-Klean Soils, Inc. | WA | 6 | 206–888–9388 | Thermal desorption |
| Remtech, Inc. | WA | 6 | 509–624–0210 | Thermal desorption |
| Western Research Institute | WY | 2, 4 | 307–721–2443 | Thermal desorption |
| Hazen Research, Inc. | CO | 2 | 303–279–4501 | Thermal desorption |

Continued —>

# Soil Restoration Vendors

## Ex Situ Thermal Treatment (continued)

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| Smith Environmental Technologies Corp. | CO | 2 | 303–790–1747 | Thermal desorption |
| Soiltech ATP Systems, Inc. | CO | 2 | 303–790–1747 | Thermal desorption |
| Southwest Soil Remediation, Inc. | AZ | 3 | 602–571–7174 | Thermal desorption |
| Carson Environmental | CA | 5 | 310–478–0792 | Thermal desorption |
| Clean-up Technology, Inc. | CA | 5 | 310–327–8605 | Thermal desorption |
| Separation and Recovery Systems, Inc. | CA | 5 | 714–261–8860 | Thermal desorption |
| Mercury Recovery Services, Inc. | IL | 9 | 412–843–5000 | Thermal desorption |
| Midwest Soil Remediation, Inc. | IL | 9 | 847–742–4331 | Thermal desorption |
| Philip Environmental Services Corp. | IL | 9 | 412–244–9000 | Thermal desorption |
| Recycling Science International, Inc. | IL | 9 | 312–663–4242 | Thermal desorption |
| Maxymillian Technologies, Inc. | MA | 9 | 617–557–6077 | Thermal desorption |
| Remediation Technologies, Inc. | MA | 9 | 508–371–1422 | Thermal desorption |
| Carlo Environmental Technologies, Inc. | MI | 9 | 810–468–9580 | Thermal desorption |
| Kalkaska Construction Service, Inc. | MI | 9 | 616–258–9134 | Thermal desorption |
| Conteck Environmental Services, Inc. | MN | 9 | 612–441–4965 | Thermal desorption |
| Roy F. Weston, Inc. | PA | 9 | 610–701–7423 | Thermal desorption |
| Soil Remediation of Philadelphia, Inc. | PA | 9 | 215–724–5520 | Thermal desorption |
| Pet-Con Soil Remediation, Inc. | WI | 9 | 608–588–7365 | Thermal desorption |
| Thermotech Systems Corp. | FL | 8 | 407–290–6000 | Thermal desorption |
| TPS Technologies, Inc. | FL | 8 | 407–886–2000 | Thermal desorption |
| Ariel Industries, Inc. | GA | 8 | 706–277–7070 | Thermal desorption |
| Westinghouse Remediation Services, Inc. | GA | 8 | 404–299–4698 | Thermal desorption |
| Mclaren/Hart Environmental Engineering | NC | 8 | 704–587–0003 | Thermal desorption |
| Soil Solutions, Inc. | NC | 8 | 910–725–5844 | Thermal desorption |
| Rust International, Inc. | SC | 8 | 864–646–2413 | Thermal desorption |
| Covenant Environmental Technologies, Inc. | TN | 8 | 901–278–2134 | Thermal desorption |
| IT Corp. | TN | 8 | 423–690–3211 | Thermal desorption |
| SPI/ASTEC | TN | 8 | 423–867–4210 | Thermal desorption |

Continued —>

## Soil Restoration Vendors

| Vendor | State/ Province | Region* | Phone | Technology |
|---|---|---|---|---|
| **Ex Situ Thermal Treatment** (continued) | | | | |
| Duratherm, Inc. | TX | 8 | 713–339–1352 | Thermal desorption |
| Hrubetz Environmental Services, Inc. | TX | 8 | 214–363–7833 | Thermal desorption |
| Texarome, Inc. | TX | 8 | 210–232–6079 | Thermal desorption |
| Purgo, Inc. | VA | 8 | 804–550–0400 | Thermal desorption |
| Caswan Environmental Services Ltd. (Canada) | AB | | 403–235–9333 | Thermal desorption |
| Someus & Partners Unlimited (India) | | | 91–11–685–6276 | Pyrolysis, thermal desorption |
| Ecotechniek B.V. (Netherlands) | | | 346–557–700 | Thermal desorption |

* Forest Service regions are: 1—Northern, 2—Rocky Mountain, 3—Southwest, 4—Intermountain, 5—California, 6—Pacific Northwest, 8—Southern, 9—Eastern, 10—Alaska

# Appendix B—Remediation Products Summary

This appendix lists remediation products, including the product name, a short description of the product, and an assessment of the product's performance in cold climates. The table was compiled by MCS Engineering (2104 Reserve St., Missoula, MT 59801).

This information is provided to the reader for reference only. The authors of this manuscript have not evaluated any of the services provided by these companies and do not endorse one company over another.

## Remediation Products Summary

- Site maintenance intensity—In situ bioremediation projects require certain environmental conditions to succeed. Any maintenance needs beyond these basic requirements are listed here.
- Mobility—Lists special considerations like road access, power requirements, size of equipment, and other applicable information.
- Approximate cost to treat a cubic yard—WARNING: The information contained in this column is highly variable. The cost estimate provided by the vendor may or may not include pretreatment costs, delivery system installation costs, or consider contaminant type and amount, site access, and other factors. Most cost figures are based solely on the product itself and an arbitrary amount for a contamination level. Site treatment costs are difficult to generalize because of the variability of site-specific characteristics. Check with the manufacturer for a better estimate of your total treatment cost. In general, in situ biological treatment technologies are considered cost effective.

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## Product name: Alken Bio-Nutrient 4

Product category: Nutrient supplement

Manufacturer information:
Valerie Edwards
**Alken-Murray Corp.**
P.O. Box 400
New Hyde Park, NY 11040
Phone: 540–636–1236
Fax: 718–224–0754
Web site: *http://www.alken-murray.com*
*http://alken-murray.hypermart.net/BN4pib.htm*

Manufacturer's claims: Alken Bio-Nutrient 4 is a soluble, dry, rapidly-absorbed nutrient supplement to enhance bacterial metabolism of petroleum-contaminated soil. The product contains urea, potassium, and micronutrients, including dicyandiamide. Dicyandiamide inhibits nitrification of ammonia to nitrate. Ammonia ions will be retained in the remediation zone, while negatively charged nitrate can be removed by groundwater flow through anoxic respiration (in the absence of oxygen), producing inert nitrogen gas.

Site maintenance intensity: Depends on the application technique used.

Mobility: The product comes in 25-, 50-, and 500-pound containers. Repackaging is safe.

Cold climate applicability: Bio-Nutrient 4 is not affected by freezing. The product can be used from 35 to 180 °F. If temperatures fall below 35 °F, the product will not be active, but it will reactivate when the temperature rises above 35 °F.

Approximate cost to treat a cubic yard: 50 cents to $2, depending on nutrient deficiencies.

Manufacturer's comments: Product bulletin, material safety data sheets, dosage charts, and other information are available on Alken-Murray's Web site.

Formal research: None to date, new product.

Field users' contacts: None to date, new product.

## Product name: Alken Clear-Flo 7026

Product category: Microbial cultures

Manufacturer information:
Valerie Edwards
**Alken-Murray Corp.**
P.O. Box 400
New Hyde Park, NY 11040
Phone: 540–636–1236
Fax: 718–224–0754
Web site: *http://www.alken-murray.com*
*http://alken-murray.hypermart.net/860 FrameSet.html*

Manufacturer's claims: Alken Clear-Flo is Alken-Murray's most popular hydrocarbon-degrading formula. It remediates a wide variety of hydrocarbons such as phenol, various solvents, and sulfur-containing components, alcohols, chlorinated hydrocarbons, polynuclear aromatics, and other difficult compounds.

Site maintenance intensity: Depends on the application technique used.

Mobility: Product comes in 25-, 50-, and 500-pound containers. Repackaging is safe.

Cold climate applicability: Product is effective from 42 to 110 °F with pH range from 5.9 to 9.0. Optimal temperature is 75 °F +/– 10 °F. Optimal pH is 7.1 +/– 0.3. Product is guaranteed for a 2-year shelf life. Containers stored more than 2 years should have holes punched in them to allow air to circulate. Freezing will reduce the reactivation rate, but will not kill the product.

Approximate cost to treat a cubic yard: $17 to $20 if a preacclimation device is used to recycle the runoff.

Manufacturer's comments: Guaranteed shelf life of 2 years. A free sample is available for bench testing.

Field users' contacts:
Alberto Morales
A&M Consultants
Phone: 281–980–3184

Additional user contacts are available from the manufacturer.

## Product name: Alken Clear-Flo 7036

Product category: Microbial cultures

Manufacturer information:
Valerie Edwards
**Alken-Murray Corp.**
P.O. Box 400
New Hyde Park, NY 11040
Phone: 540–636–1236
Fax: 718–224–0754
Web site: *http://www.alken-murray.com*
*http://alken-murray.hypermart.net/7036pib.htm*

Manufacturer's claims: Alken Clear-Flo 7036 contains 21 strains of hydrocarbon-degrading microbes designed to degrade heavy and light distilled oil fractions, including crude oil and coal tar.

Site maintenance intensity: Depends on the application technique used.

Mobility: Product comes in 25-, 50-, and 500-pound containers. Repackaging is safe.

Cold climate applicability: Product is most effective from 40 to 100 °F with pH range from 6.0 to 8.5. Freezing will reduce the reactivation rate, but will not kill the product. Prolonged high temperatures could harm the product.

Approximate cost to treat a cubic yard: $17 to $20 depending on application technique.

Manufacturer's comments: Guaranteed shelf life of 2 years. A free sample is available for bench testing.

Field users' contacts:
Alberto Morales
A&M Consultants
Phone: 281–980–3184

Additional user contacts are available from the manufacturer.

## Product name: Alken Enz-Odor

Product category: Nutrient supplement

Manufacturer information:
Valerie Edwards
**Alken-Murray Corp.**
P.O. Box 400
New Hyde Park, NY 11040
Phone: 540–636–1236
Fax: 718–224–0754
Web site: *http://www.alken-murray.com*
*http://alken-murray.hypernet/EZtreat.html*

Manufacturer's claims: Alken Enz-Odor is a blend of a surfactant, four strains of humic acid, humin, lignin, and other organic matter. The bacteria and humic extracts that emulsify the oil-water barrier give the bacteria easier access to the oil. The synergistic blend of this formula makes the product much more powerful than its individual components.

Site maintenance intensity: Depends on the application technique used.

Mobility: Product comes in 25-, 50-, and 500-pound containers. Repackaging is safe.

Cold climate applicability: The product is most effective from 49 to 115 °F. and pH range from 6.0 to 8.5. Freezing will seriously reduce the product's survival rate, but will not kill or harm the surfactant.

Approximate cost to treat a cubic yard: $13, depending on the application technique used.

Manufacturer's comments: A free sample is available for bench testing. The product is used primarily for odor control. It can be used with other products.

Field users' contacts: Over 800 clients.

## Product name: BG-Bio Enhancer 850

Product category: Nutrient supplement

Manufacturer information:
Charles Wilde
**BioGenesis Enterprises, Inc.**
7420 Alban Station Blvd., Suite B 208
Springfield, VA 22150
Phone: 703–913–9701
E-mail: *customerservice@biogenesis.com*

Manufacturer's claims: BG-BioEnchancer 850 is a blend of organic and inorganic nutrients. It accelerates the natural biodegradation of organics, including crude oils, fuels, and chemicals. Besides the basic 850 supplement, the company has more specialized 8501, 8502, and 8503 supplements. The company makes no claims of success for their product in Alaska and advises a test plot before full-scale use. They are willing to send a small sample for testing. They want you to call them and discuss your specific needs before they recommend a specific product.

Site maintenance intensity: Routine monitoring.

Mobility: Shipped as a granular power. Mix it onsite with water and apply it with a sprayer or mix it in as powder. No special personal protective equipment is required.

Cold climate applicability: These products are nutrients for microbes. The limitations are those of the microbes, not the nutrients. Microbes are active at temperatures of 50 °F or above. They don't really work at temperatures below 40 to 45 °F.

Approximate cost to treat a cubic yard: Granular powder runs from $7.24 to $28.43 per pound. 2.33 pounds of powder makes 5 gallons of liquid concentrate. 1 gallon treats 40,000 parts per million of contaminants in 1 cubic yard of soil. Never use less than ¼ pound of powder to treat 1 cubic yard.

Manufacturer's comments: Microbes don't work well when contaminant level is above 5,000 parts per million. At contamination levels higher than 10,000 parts per million, the manufacturer does not advise using microbes.

Formal research: Inhouse studies. Contact the company for this information.

Field users' contacts: Contact the manufacturer with your specific site conditions to get appropriate references. Their Web site shows some successful case studies. One case study was at the Quantico Marine Base in Virginia.

## Product name: BioLuxing

Product category: Delivery system

Manufacturer information:
Alvin Yorke
**FOREMOST Solutions, Inc.**
350 Indiana St., Suite 415
Golden, CO 80401
Phone: 303–271–9114
Fax: 303–216–0362
E-mail: *foremost@earthlink.net*

Manufacturer's claims: BioLuxing enhances and stimulates the growth of biodegradative activity of microorganisms by adding pathways and attachment surfaces for nutrients, oxygen, and other stimulants to the site. This process is completed within a BioNet. A BioNet consists of a series of BioLux fractures. A BioLux is installed by drilling and inserting steel casings to a desired depth and injecting a fluid containing a porous ceramic propellant, Isolite. The injection process causes fractures to open, which are maintained by the Isolite. This also establishes a gallery from which the microorganisms preinoculated in the Isolite can biodegrade contaminants in the vicinity of the BioLux. The steel casing can be used to inject additional microorganisms, moisture, oxygen, or to apply a vacuum (for vapor extraction). The system is effective in tight, low porosity soils. The Isolite-reinforced fractures also increase the rate of conductivity through the subsurface.

Site maintenance intensity: Low maintenance if conditions are met at the layer where the BioLuxes are installed. Monitoring and maintenance may be required for a 2- to 3-year period.

Mobility: Must be accessible by semitruck (for Isolite delivery).

Cold climate applicability: Installation of BioLuxes is hampered when the ambient temperature is below 30 °F. Temperature does not affect the process after it has been installed. Temperature limits still apply to biodegradation.

Approximate cost to treat a cubic yard: $40 to $60

Manufacturer's comments: The product works very well in tight, low-porosity soils such as clays and glacial till. Fractures may not be possible in coarse-grain soils. It may be installed as deep as 50 feet with little aboveground disturbance. It may not be cost effective for very small volumes of contamination.

Formal research: *In Situ Bioremediation of Petroleum in Tight Soils Using Hydraulic Fracturing* by Sandra Stavnes, U.S. Environmental Protection Agency, Southern Region (8). Web site: *http://www.gardenweb.com/isolite/micro.html*

Additional databases: CLU-IN

## Product name: BioSolve

Product category: Surfactant

Manufacturer information:
Stephen LaRoche
**The Westford Chemical Corp.**, BioSolve Group
P.O. Box 798
Westford, MA 01886
Phone: 508–885–1113
Fax: 508–885–1114
Web site: *http://www.wsbiosolve.com/*

Manufacturer's claims: BioSolve is a biodegradable, liquid surfactant formulation that can be used as a stand-alone technology or as an amendment to existing processes, such as pump and treat systems, extraction processes, and others. BioSolve liberates the free-phase organic contaminant from the matrix (soil) by increasing the contaminant's solubility and encapsulating it in a micellular emulsion. BioSolve also reduces interfacial tensions between the contaminants and the matrix, increasing extraction potential. In other words, BioSolve desorbs the contaminants from the soil's particles, allowing easier access by microorganisms or increasing recovery potential.

Site maintenance intensity: Depends on the remediation technology.

Mobility: This liquid is safe to repackage.

Cold climate applicability: Works well in the cold.

Approximate cost to treat a cubic yard: None given.

Manufacturer's comments: BioSolve is designed to mobilize contaminants so the potential exists for unwanted pollution migration unless the proper steps are taken for hydraulic control. Sensitive areas such as wetlands should be taken into consideration.

Formal research: Robert F. Becker, *Accelerating Bioremediation Using a Particular Surfactant/Dispersant Combination*. Abstract—PNWIS & CPANS/AWMA 1995 annual meeting, Spokane, WA (Available from the manufacturer).

Field users' contacts: Contact the manufacturer.

Additional databases: Enviro$en$e, NCP

## Product name: DARAMEND

Product category: Nutrient supplement

Manufacturer's address:
Alan Seech or Paul Bucens
**Grace Bioremediation Technologies**
3451 Erindale Station Rd.
P.O. Box 3060, Station A
Mississauga, ON, Canada L5A 3T5
Phone: 905–272–7480
Fax: 905–272–7472
Web site: *http://www.biogenesis.com*

Manufacturer's claims: A matrix-specific solid-phase organic amendment used to alter sediment structure, nutrient profile, and water-holding capacity. Amendments serve to increase water and nutrient availability and provide a surface where microorganisms and contaminants can interact.

Site maintenance intensity: Depends on application technology.

Mobility: Available in a variety of forms and containers.

Cold climate applicability: Cold temperatures will not affect the product itself, but it will affect the bioremediation process.

Approximate cost to treat a cubic yard: Not applicable.

Formal research: U.S. Environmental Protection Agency report (EPA/540-R-96/503) (*http://www.epa.gov/ORD/SITE/reports/0023.html*)

Additional databases: CLU-IN

## Product name: Dual Auger System

Product category: Delivery system, soil mixing

Manufacturer information:
Richard P. Murray, President
**In-Situ Fixation, Inc.**
P.O. Box 516
Chandler, AZ 85244–0516
Phone: 480–821–0409
Fax: 480–786–3184
E-mail: *info@insitufixation.com*
Web site: *http://www.insitufixation.com/*

Manufacturer's claims: The Dual Auger System can apply in situ bioremediations, stabilization, steam, iron, hydrogen peroxide, and other reagents. This system treats soil by injecting and mixing reagents into the soil without excavation. The dual auger design mixes reagents into the soil in a more efficient process than a similar single auger design.

Site maintenance intensity: Monitoring is done as the system is in use. Power is supplied by the integrated system.

Mobility: Will require road transport by semitrailer.

Cold climate applicability: Operating in below-freezing temperatures will reduce the working efficiency of the injection and mixing systems, but it will not halt the process.

Approximate cost to treat a cubic yard: $40 to $120 per cubic yard

Manufacturer's comments: Refer to In-Situ Fixation's Web site for more detailed information.

Formal research: U.S. Environmental Protection Agency report (EPA/540/S-97/505) and U.S. Department of Energy report *Dual Auger Steam Stripping, Pinellas NE Site, Largo, Florida Innovative Demonstration*.
Mike Hightower, U.S. Department of Energy
Phone: 505–844–5499
Web site: *http://www.em.doe.gov/itrd/rotary.html*

Field users' contacts:
Bob Swale
Argonne National Laboratory
Phone: 630–252–6526

Additional databases: CLU-IN, REACH IT

## Product name: Electrokinetic Injection

Product category: Site enhancement

Manufacturer information:
Laurie Lachiusa
**Electrokinetics, Inc.**
11552 Cedar Park Ave.
Baton Rouge, LA 70809
Phone: 716–886–9762
Fax: 225–753–0028
E-mail: *mlachiusa@aol.com or ekinc@pipeline.com*

Manufacturer's claims: Option One: In-situ Bioelectrokinetic Injection functions as a nutrient transport system to enhance biodegradation. Applying an electrical field to the soil facilitates the introduction of nutrients throughout a heterogeneous soil. Option Two: Micellar-enhanced Electrokinetics Extraction electrokinetically injects charged micellars, which charge noncharged particles. Micelles are then removed by electro-osmotic flow.

Site maintenance intensity: Requires 450 volts of power. Site additives need to be replaced every 3 months. The process can be monitored from company's home office if a data link can be provided.

Mobility: Depends on the type of power-generating equipment and whether drilling equipment is needed for large spills.

Cold climate applicability: This process aids natural degradation. Once the native soil microbes go into hibernation, the process ends. The process may delay or reduce the depth of freezing because of heat generated by the soil's resistance to the power flow.

Approximate cost to treat a cubic yard: More than $100.

Manufacturer's comments: There is minimal site disturbance from the addition of electrodes used to induce power flow. The electrokinetic process is extremely effective in low permeability soils because the migration of ions and pore fluid is governed by electro-osmotic conductivity, not hydraulic gradients.

Formal research: Yalcin B. Acar, M. Fazle Fabbi, and Elif E. Ozsu. *Electrokinetic Injection of Ammonium and Sulfate Ions Into Sand and Kaolinite Beds*. Journal of Geotechnical and Geoenvironmental Engineering. March 1997.
Yalcin B. Acar, Elif E. Ozsu, Akram Alshawabkeh, M. Fazle Rabbi, and R. J. Gale. *Enhance Soil Bioremediation With Electrical Fields*. Chemtech. April 1996.

Field users' contacts:
Randy Parker
EPA Office of Research and Development
National Risk Management Research Laboratory
Cincinnati, OH 45268
Phone: 513–569–7271

Additional Databases: CLU-IN, REACH IT

## Product name: EnviroTech Gold

Product category: Biocatalyst

Manufacturer information:
Herb Pearse
**Eco-Tec, Inc**.
P.O. Box 690
Vaughn, WA 98394
Phone: 425–201–6848
Fax: 425–201–6848
E-mail: *herbpearse@email.msn.com*
Web site: *http://www.eco-tech.com/*

Manufacturer's claims: The biocatalyst suspends contaminant molecules by creating a colloid though micelle formation. It basically suspends the contaminants in an aqueous solution. This colloidal system allows contaminant-degrading microbes much easier access to the contaminant because of the increased surface area.

Site maintenance intensity: Depends on the remediation technique used.

Mobility: This aqueous product can be carried by any means available.

Cold climate applicability: The optimal temperature is from 70 to 80 °F. The product will function between freezing and 200 °F.

Approximate cost to treat a cubic yard: $18 to $45, depending on the concentration and soil type.

Manufacturer's comments: The product can be used with: bioremediation, landfarming, soil washing, and soil filtration. It can also be used for remediation of contamination in water. Please contact the manufacturer for cases relating to your applications. Companies that have used the product include Chevron and the Southern Pacific Railroad.

Formal research: In progress.

Field users' contacts:

Michael lam
Nowicki and Associates
33516 9th Ave. South, Bldg. No. 6
Federal Way, WA 98003

John Reese
Evergreen Enviro Consulting
300 25th Ave. South
Seattle, WA 98144

Additional databases: REACH IT

## Product name: ENVIRONOC

Product category: Microbial cultures

Manufacturer information:
**Biodyne, Inc**.
959 Paschal Place
Sarasota, FL 34232–2847
Phone: 941–377–6621
Fax: 941–379–9896
E-mail: *Biodyne-srq@msn.com*
Web site: *http://www.biodyne-srq.com*

Manufacturer's claims: Blends of microbial cultures with broad degradation capabilities that can enhance the removal of a variety of contaminants from sludge, soil, and groundwater. Microbial blends are freeze-dried, producing high population counts once they are applied in the field. Optimum pH range is 6 to 8. Most strains are aerobic, but some are capable of anaerobic activity.

Site maintenance intensity: Depends on the application technique used.

Cold climate applicability: Blends perform best in a range of 45 to 90 °F.

Approximate cost to treat a cubic yard: $5 to $10 depending on the soil's bulk density and the contamination level.

Manufacturer's comments: The key to successful treatment is giving the microbes an optimum environment in which to work. The company has more than 10 years experience.

Field users' contacts: Contact the manufacturer for field users with similar treatment needs.

## Product name: HLR-80

Product category: Microbial cultures

Manufacturer information:
**NatRx, Inc.**
P.O. Box 735
Muleshoe, TX 79347
Phone: 877–628–7948
Fax: 806–272–5537
Web site: *http://www.natrxinc.com*

Manufacturer's claims: Noticeable remedial activity will occur within 30 to 60 days. HLR-80 has been tested at remote Forest Service sites in Alaska as a surface application under the direction of North Pacific Technology. HLR-80 contains an aggressive strain of hydrocarbon-consuming bacteria coupled with a dissolved oxygen catalyst. This stimulates the introduced and indigenous bacteria by increasing the available dissolved oxygen and energy needed for rapid bioremediation.

Site maintenance intensity: Depends on the application technique used.

Mobility: Any container that holds liquids can be used for transportation.

Cold climate applicability: Field test results indicate HLR-80 may require other technologies such as biopiles to overcome the effects of cold temperatures on the rate of degradation.

Approximate cost to treat a cubic yard: $35.28 to $39.81 per gallon.

Manufacturer's comments: The oxygen supplement (TRX-90) is available separately.

Field users' contacts:
Dave Pflaum
North Pacific Technology
8256 South Tongass Hwy.
Ketchikan, AK 99901
Phone: 907–247–6784

Product name: **Humasol**

Product category: Nutrient supplement

Manufacturer information:
**Agricare, Inc.**
P.O. Box 399
Amity, OR 97101-0399
Phone: 503–835–3123
Fax: 503–835–0605
E-mail: *agrinet@spessart.com*
Web site: *http://www.onlinemac.com/business/agrinet/*

Manufacturer's claims: Humasol is composed of about 85 percent humic substances including: 55 percent fulvic acid and 30 percent remaining 15 percent includes natural minerals and nitrogen. Humasol enhances soil microbes, especially fungi that use lignin to break down hydrocarbon chemicals for a food source. The manufacturer claims that Humasol binds with heavy metals.

Site maintenance intensity: None, if used as an indigenous microbial supplement. Apply it and water. Otherwise, site maintenance intensity depends on the application technique used.

Mobility: Sold in 50-pound or 1-ton bags. It is also available in liquid and granular form. Humasol can be repackaged.

Cold climate applicability: The product is used as a nutrient supplement for soil microorganisms. Cold temperatures will not affect Humasol itself, but they will affect the remediation process.

Approximate cost to treat a cubic yard: Less than $1 per cubic yard.

Manufacturer's comments: Humasol can also be used as a fertilizer substitute to enhance plant growth.

Formal research: None to date, but Dr. Suzanne Lesafe of the Canadian National Water Resource Institute has published information on the use of humate substances in petrochemical bioremediation.

Field users' contacts:

Dr. Suzanne Lesafe
National Water Resource Institute—Environment Canada
867 Lake Shore Rd.
Burlington, ON, Canada L7R 2A6

Pat Randell
Bioenvironmental
160 Mesa Ave.
Newberry, CA 91320

## Product name: M-1000

Product category: Microbial culture, nutrient supplement

Manufacturer information:

Todd Kennedy
**Micro-Bac International, Inc.**
3200 North IH35
Round Rock, TX 78681–2410
Phone: 512–310–9000
Fax: 512–310–8800
E-mail: *mail@micro-bac.com*
Web site: *http://www.micro-bac.com*

Manufacturer's claims: The microbial culture contains specifically selected hydrocarbon and xenobiotic chemical-degrading microorganisms. The liquid-based product comes ready to use. Microbial nutrient packages are also available. These products increase the rate of degradation of the target compounds.

Site maintenance intensity: Normal remediation application maintenance. Micro-Bac recommends monthly monitoring.

Mobility: Liquid form. The product comes in 1-, 5-, and 55-gallon containers.

Cold climate applicability: The M-1000 product line requires liquid water for activity. Freezing will cause a loss of about 50 percent of the microorganisms. Those remaining will continue to function after being thawed. An antifreeze-protected version is available. Product functions best in the range of 10 to 40 °C.

Approximate cost to treat a cubic yard: Less than $10.

Manufacturer's comments: Company is a minority-owned small business.

Formal research: None available.

Field users' contacts: Contact company for references.

Additional databases: Enviro$en$e, NCP

Product name: **Micro-Blaze**

Product category: Microbial cultures, site enhancement

Manufacturer information:
Bill Scogin, President
**Verde Environmental, Inc.**
7309 Schneider St.
Houston, TX 77093
Phone: 800–626–6598
Fax: 713–691–2331
E-mail: bscogin@micro-blaze.com
Web site: http://www.micro-blaze.com/

Manufacturer's claims: Several strains of microbes work synergistically to clean up hydrocarbon-based and organic contamination, such as: diesel, gasoline, glycols, benzene, aviation fuel, hydraulic and motor oils, latrine and septic wastes, and AFFF (aqueous film-forming foams) fire waste. Works aerobically or anaerobically. Micro-Blaze is composed of spore-forming bacteria that can revert to a spore state if conditions become unviable. They will germinate after the correct conditions return.

Site maintenance intensity: Depends on the remediation technique used. It is important to keep the site moist.

Mobility: Concentrated product ships in 5-, 55-, or 250-gallon containers—simply dilute and apply.

Cold climate applicability: Micro-Blaze microbes work best within a temperature range of 60 to 85 °F. Temperature endpoints for remediation are about 35 to 120 °F. Micro-Blaze is composed of spore-forming bacteria that can revert to a spore state if conditions become unviable. They will germinate after the correct conditions return. They will work within a wide pH range of 4.0 to 10.5 and can tolerate temperatures up to 200 °F for a short period.

Approximate cost to treat a cubic yard: $1.90 to $2.60 per cubic yard. "Rule of thumb" is 1 gallon of concentrate for every 10 cubic yards of contaminant.

Manufacturer's comments: When in concentrated form, the product has an indefinite shelf life. When the product is diluted to 3 percent, the shelf life is several years. The same bottle of Micro-Blaze can be used to control odors at restrooms and to clean up gas and oil spills. Verde, Inc., also offers a nontoxic biodegradable firefighting foam design to degrade hydrocarbon contaminants. See Micro-Blaze's Web site for more information.

Formal research: In progress as of November 19, 1999.

Field users' contacts: Please contact the manufacturer for cases relating to your applications.

Product name: **MZC**

Product category: Enzyme supplement

Manufacturer information:
Brian Clark
**Enzyme Technologies, Inc.**
5228 NE. 158th Ave.
Portland, OR 97230
Phone: 503–254–4331 ext. 11
Fax: 503–245–1722

E-mail: *brianc@enzymetech.com*
Web site: *http://www.enzymetech.com*

Manufacturer's claims: Target-specific enzymes and biological enhancements increase degradations rates up to 90 percent. MZC is a unique product including a proven track record with repeatable, consistent results.

Site maintenance intensity: Typical monitoring period is 4 weeks. The period may be shorter or longer, depending on the conditions. Remote systems may operate for up to 2 months unattended.

Mobility: Products are typically supplied in 5-gallon pails. Very portable.

Cold climate applicability: Minimum recommended temperature is about 40 °F—not recommended for freezing conditions. In situ application may be conducted year round.

Approximate cost to treat a cubic yard: About $10 (product application only).

Manufacturer's comments: Many other types of bioremediation supplements are available.

Formal research: None available. Product reviews are covered in commercial and trade periodicals. See the manufacturer for a listing.

Field users' contacts:

Brett Budd
U.S. Army Corps of Engineers
Phone: 605–341–3169

Ed Williams
Southern Pacific Railroad
Phone: 541–883–6518

Contact the company for more references.

Field users' comments: • Worked great and very fast. Important to have experienced personnel onsite to monitor project conditions, such as nutrient levels. • Very successful project, exceeded target goals.

Additional databases: REACH IT

## Product Name: OCLANSORB

Product category: Absorbent

Manufacturer information:
**Sanfransco, Inc.**
P.O. Drawer A
601 South Meadow Lane
El Campo, TX 77437
Phone: 800–392–7736
Web site: *http://www.oclansorb.com/*

Manufacturer's claims: OCLANSORB internally encapsulates hydrocarbons on contact. OCLANSORB will absorb equal amounts of hydrocarbons by volume up to 12 times its weight. Meets leachate standards when used on some oils and pesticides and can be disposed in a landfill or by incineration in accordance with regulatory guidelines.

Site maintenance intensity: Not applicable.

Mobility: Available in a variety of forms.

Cold climate applicability: The more viscous the liquid, the slower the rate of absorption.

Approximate cost to treat a cubic yard: Not applicable.

Manufacturer's comments: Product handling accessories are available.

## Product name: ORC (Oxygen Release Compound)

Product category: Oxygen supplement

Manufacturer information:
**Regenesis**
1011 Calle Sombra
San Clemente, CA 92672
Phone: 949–366–8000
Fax: 949–366–8090
E-mail: *orc@regenesis.com*
Web site: *http://www.regenesis.com*

Manufacturer's claims: ORC is a patented formulation of magnesium peroxide that slowly releases oxygen when hydrated. Very few similar products are available today. This product provides a stable time-released amount of available oxygen and increases "available oxygen" more per pound than any similar material.

Site maintenance intensity: No overhead or maintenance necessary beyond that required for the remediation technique.

Mobility: Packaged in 30-pound buckets.

Cold climate applicability: Effective in cold climates. Extremely cold sites should be field tested before full-scale implementation.

Approximate cost to treat a cubic yard: None given (highly variable, depending on contaminant type, concentration, and so forth).

Manufacturer's comments: Needs a minimum of 3-percent moisture content to activate. A Low pH or a high salinity accelerates the oxygen supplied by ORC.

Formal research: Odencrantz, J., Johnson, J., and Koenigsberg, S. 1996. *Enhanced Intrinsic Bioremediation of Hydrocarbons Using an Oxygen Releasing Compound*. Remediation. Fall. Vol. 6(4). New York, NY: John T. Wiley and Sons. p. 95–109. Web site: *http://www.tri-s.com/article2.pdf*. See *http://www.regenesis.com/tbindex.htm* for additional papers.

Field users' contacts: Interested parties should contact Regenesis, which has closed more than 110 sites.

Additional databases: CLU-IN, REACH IT

## Product name: PDM-7

Product category: Microbial cultures

Manufacturer information:
Darryl Goodchild
**Phase III, Inc.**
916 East Baseline Rd., Suite 101
Mesa, AZ 85204–6603
Phone: 480–503–2847
Fax: 480–503–1077
E-mail: *darryl@phaseiii.com*
Web site: *http://www.phaseiii.com*

Manufacturer's claims: PDM-7 contains a blend of live, synergetic bacteria. These bacteria were specifically chosen for their ability to metabolize petroleum-based products, greases, fats, food particles, hair, cellulose, and detergents.

Site maintenance intensity: Depends on the remediation technique used.

Mobility: Comes in dry powder form that is safe to handle.

Cold climate applicability: Depends on the remediation technique used.

Approximate cost to treat a cubic yard: $13.35 per gallon.

Manufacturer's comments: PDM-7 HC is a strain of microbes specifically developed for the remediation of hydrocarbons.

Formal research: No formal citations were provided.

Field users' contacts: Phase III has a variety of case studies available on their Web site and in their product literature. No end-user contacts were provided.

Additional databases: CLU-IN

## Product name: Phytoremediation

Product category: Site enhancement, revegetation

Manufacturer information:
Ari Ferro
**Phytokinetics, Inc.**
1770 North Research Parkway North
Logan, UT 84341
Phone: 435–750–0985
Fax: 435–750–6296
Web site: *http://www.phytokinetics.com*

Manufacturer's claims: Phytoremediation uses plants to cleanse the site of hydrocarbon-based chemicals. In the zone of soil around the plant root (rhizosphere), there is an abundance of metabolically active microbes that can degrade organic contaminants. Moreover, the plants themselves can take up certain organic contaminants and certain plant enzyme systems can detoxify or degrade contaminants. Additional benefits include soil stabilization and site beautification.

Site maintenance intensity: Depends on weeding, fertilization, and irrigation needs. Once established, very little maintenance is needed.

Mobility: Standard agricultural tools and supplies are needed.

Cold climate applicability: Phytoremediation is most effective during the growing season, although enhanced degradation can extend into late fall and early spring.

Approximate cost to treat a cubic yard: Highly dependent on individual site conditions and objectives.

Formal research: International Journal of Phytoremediation (CRC Press).

Field users' contacts:
Steve Rock
U.S. Environmental Protection Agency
Phone: 513–569–7149

Additional databases: CLU-IN, REACH IT

## Product name: ProZorb

Product category: Absorbent

Manufacturer information:
Gary Snyder, Environmental Director
**Blue Ribbon Environmental Products, Inc.**
6310 North Pittsburgh
Spokane, WA 99217
Phone: 509–489–1704
Fax: 509–489–1785
E-mail: *info@bre-products.com*
Web site: *http://www.bre-products.com*

Manufacturer's claims: A mixture of C, N, P, K, surfactants, water and air designed to encapsulate petroleum hydrocarbons, enhance biodegradation, and be biodegradable. ProZorb will absorb up to 60:1 by weight and 1:1 by volume of target contaminants. Target contaminants are encapsulated inside the capillary tubes and will not leach out or off. ProZorb is composed of natural nutrients and trace elements, making it an effective bioremediation accelerator. ProZorb, along with its encapsulated hydrocarbons, will decompose into water, carbon, and carbon dioxide in 45 to 60 days. ProZorb is also available with REM-3 microbes.

Mobility: 1 cubic foot of ProZorb weighs 2 to 3 pounds. Available in a variety of forms: pillows, loose particulate, fueling bibs, hydraulic hose socks, mats, and so forth.

Cold climate applicability: The more viscous the liquid, the slower the rate of absorption. Optimal temperature range is 40 to 120 °F. The product is effective as long as the hydrocarbon substance is in a liquid form.

Approximate cost to treat a cubic yard: $29 to $40 when used as a remediation agent.

Manufacturer's comments: Works well for marine applications. When using ProZorb in a bioremediation application, the company advises using SoilUTION as a cleaning/wetting agent. ProZorb may also work on heavy metals in limited applications.

Formal research: Study in progress.

Field users' contacts:
Kreg Beck
Idaho Department of Environmental Quality
2110 Ironwood Parkway
Coeur d' Alene, ID 83814
Phone: 208–769–1422

Additional references are available from the manufacturer.

## Product name: REM-3

Product category: Microbial cultures.

Manufacturer information:
Gary Snyder, Environmental Director
**Blue Ribbon Environmental Products, Inc.**
6310 North Pittsburgh
Spokane, WA 99217
Phone: 509–489–1704
Fax: 509–489–1785
E-mail: *info@bre-products.com*
Web site: *http://www.bre-products.com*

Manufacturer's claims: Cultures are specifically designed to biodegrade petroleum hydrocarbons. The REM-3 microbes are acclimated to petroleum-based sludge during their production, allowing them to become very efficient at degrading petroleum hydrocarbons. Populations will grow in the presence of oxygen, nutrients, and oil and can be used as seed stock for bioreactors. REM-3 cultures die off when all hydrocarbons are consumed, leaving no toxic residues or byproducts. Concentration: 5 billion CFU (colony forming units) per gram.

Site maintenance intensity: Depends on the application technique used.

Conditions: Moisture content around 30 percent, oxygen, nutrients/petroleum (food). Otherwise, maintenance should be minimal.

Mobility: REM-3 is best transported in a dry state and can be activated by water or a water-based liquid at the site.

Cold climate applicability: Temperatures below freezing will adversely affect bioremediation. Underground remediation will create some heat, so remediation will be slowed only near the frost line. Optimal temperature 40 to 120 °F.

Approximate cost to treat a cubic yard: $29.99 per pound. For TPH (total petroleum hydrocarbons) levels less than 100,000, $3 per cubic yard, $6 per cubic yard if used with SoilUTION.

Manufacturer's comments: Best used with SoilUTION.

## Product name: Rubberizer

Product category: Absorbent

Manufacturer information:
Ronald A. Woerpel
**Advanced Aquatic Products International, Inc.**
1107 Key Plaza, Suite 201
Key West, FL 33040
Phone: 305–292–3070
Web site: *http://www.rubberizer.com*

Manufacturer's claims: Absorbs hydrocarbons and encapsulates them into an asphalt-like substance.

Mobility: Available in a variety of forms: pillows, loose particulate, fueling bibs, hydraulic hose socks, mats, and so forth.

Cold climate applicability: The more viscous the liquid, the slower the rate of absorption.

Manufacturer's comments: This product passed U.S. Environmental Protection Agency leachate standards. Absorbed oils can be transported as a nonhazardous solid. Once activated, Rubberizer will trap volatile vapors.

Field users' comments: Very effective in absorbing lighter-end oil products.

Field users' contacts:
Commander J.A. Waton
2716 North Harbor Dr.
San Diego, CA 92101

Additional references are available from the manufacturer.

## Product name: SoilUTION and SoilUTION-M with microbes

Product category: Enzyme supplement, microbial cultures, site enhancement

Manufacturer information:
Gary Snyder, Environmental Director
**Blue Ribbon Environmental Products, Inc.**
6310 North Pittsburgh
Spokane, WA 99217
Phone: 509–489–1704
Fax: 509–489–1785
E-mail: *info@bre-products.com*
Web site: *http://www.bre-products.com*

Manufacturer's claims: SoilUTION is a two-part product consisting of SoilUTION and SoilUTION-M. SoilUTION is 1-4 mole nonionic surfactant, biocatalyst, and nutrient. The 100 percent biodegradable cleaning agent can be used to remove hydrocarbons and begin the breakdown digestion of hydrocarbon molecules. SoilUTION-M is the same product with the addition of the REM-3 microbes. Both surfactants serve as enhancers to the ProZorb and REM-3 products. SoilUTION contains no chemical degreasers or emulsifiers.

Site maintenance intensity: Easily applied with a liquid sprayer, then mix in. Site maintenance intensity depends on the remediation technique used.

Mobility: In concentrated form, 8.5 pounds per gallon. The manufacturer recommends diluting SoilUTION with water at a 1:1 ratio.

Cold climate applicability: SoilUTION and SoilUTION-M will freeze at 32 °F and boil at 212 °F. It is not recommended that these agents be used as a cleaning method at temperatures below freezing.

Approximate cost to treat a cubic yard: $29.99 per pound. For TPH levels less than 100,000, $3 per cubic yard, $6 per cubic yard if the product is used with REM-3.

## Product name: Soil Washing Systems

Product category: Soil washing

Manufacturer information:
Charles Wilde
**BioGenesis Enterprises, Inc.**
7420 Alban Station Blvd., Suite B 208
Springfield, VA 22150
Phone: 703–913–9701
E-mail: *customerservice@biogenesis.com*
Web site: *http://www.biogenesis.com*

Manufacturer's claims: The BioGenesis washing process can be used on all types of gravel, sand, silt, and clay, and can clean soil particles as small as 1 micron. The system can remediate almost all types of pollutants, producing only the original contaminants contained in the soil. The systems use biodegradable, low-toxicity chemicals during the washing process.

Mobility: The washing unit is truck mounted. Excavation and loading equipment is needed. At least 10,000 to 20,000 cubic yards of contaminated soil need to be treated to justify this process.

Cold climate applicability: Best done in periods of warming temperatures. Cleanup period is generally short.

Approximate cost to treat a cubic yard: Estimates ranged from $80 to $170 per cubic yard (assuming more than 5,000 cubic yards of sandy or gravelly soils). This estimate is applicable towards Alaska applications. Soil washing in the lower 48 States costs about half of the estimate for Alaska.

Manufacturer's comments: Separated contaminants will need to be removed or destroyed.

Formal research: U.S. Environmental Protection Agency report (EPA/540/R-93/510-Sep93)

Additional databases: CLU-IN, REACH IT

Product name: **The Klean Machine**

Product category: Thermal treatment

Manufacturer information:
**Enviro-Klean Technologies, Inc.**
P.O. Box 4712
Blaine, WA 98231–4712
Phone: 877–292–3584
Fax: 604–534–8033
E-mail: *info@enviroklean.com*
Web site: *http://www.enviroklean.com*

Manufacturer's claims: Thermally processes up to 40 tons per hour of hydrocarbon-contaminated soil. Degrades soils rated up to 50,000 parts per million of contaminants down to nondetectable levels. Much more efficient and economical than similar thermal desorption equipment. System fits on one flatbed semitrailer, including conveyors for soil transfer. Very easy and quick to set up.

Site Maintenance Intensity: The system requires an operator and a front-end loader with an operator. Continuous automatic monitoring is available for air emissions and particulate. Treated product (soil) samples can be taken periodically.

Mobility: The Klean Machine fits on a 40-foot trailer (highway acceptable) and can be transported by truck, barge, or Hercules aircraft. The system weighs about 39,000 pounds.

Cold climate applicability: The Klean Machine is not affected by cold climate conditions. As long as the soil can be excavated, the machine can work.

Approximate cost to treat a cubic yard: From $40 to $85, depending on the level of contamination.

Manufacturer's comments: Unit has its own generator for power. Onsite demonstration sessions are conducted regularly. Call the manufacturer to arrange an appointment.

Formal research: Test results and studies are available from the manufacturer.

Field users' contacts: Past testimonials as well as a list of past and current users is available from the manufacturer.

Additional Databases: CLU-IN, REACH IT, Appendix C—Vendors and Consultants Interviewed

# Appendix C—Vendors and Consultants Interviewed

## Vendors

**Agricare, Inc.**
Product or process: Nutrient supplement, plus a surfactant *Humasol*
Contact: Dr. Zeitoun
Phone: 503–835–3123

**Alken-Murray Corp.**
Product or process: Alken Bio-Nutrients
Contact: Valerie Edwards
Phone: 540–636–1236
E-mail: *valerie@alken-murray.com*

**ATC Assoc., Inc.**
Product or process: In situ biological treatment, landfarming, and biopiles
Contact: Dan Krause
Phone: 206–781–1449

**BioGenesis Enterprises**
Product or process: Soil washing system and BG-Bio Enhancer 850 (nutrient supplement)
Contact: Charles Wilde
Phone: 703–913–9701

**Enviro-Klean Technologies**
Product or process: *The Klean Machine*; thermal desorption
Contact: Phil Wilford
Phone: 877–292–3584
E-Mail: *info@enviroklean.com*

**General Atomics**
Product or process: Circulating Bed Combustor (CBC)
Contact: Bill Rickmond
Phone: 760–420–9102

**Kleinfelder Services**
Product or process: In situ biological treatment, landfarming, and biopiles
Contact: John Lillie
Phone: 425–562–4200, ext. 233

**On-Site Technology**
Product or process: Indirect thermal desorption
Contact: Manny Gonzolas
Phone: 713–641–3838

**Soil Technology, Inc.**
Product or process: Soil washing
Contact: Richard Sheets
Phone: 208–842–8977

**Tech Con, Inc.**
Product or process: In situ biological treatment, landfarming, bioventing, and biopiles
Contact: Chris Edison
Phone: 509–536–0406

## Consultants

**Geosphere, Inc.**
Contact: Lawrence Acomb
Phone: 907–345–7596

**Hartcrowser**
Contact: Bryan Johnson
Phone: 907–451–4496

**Nortech Environmental & Engineering Consultants**
Contact: John Hargesheimer
Phone: 907–452–5688

**Shannon and Wilson, Inc.**
Contact: Dr. Dennis Filler
Phone: 907–479–0600

## About the Authors

**David Barnes** is an assistant professor in the Department of Civil and Environmental Engineering and the Water Environment Research Center at the University of Alaska Fairbanks. He has extensive experience analyzing the movement of contaminants in saturated and unsaturated soils and in developing treatment methods for these contaminants. He also conducts research on water quality, wastewater treatment, and solid and hazardous waste treatment.

**Shawna Laderach** holds a bachelor's degree in civil engineering from the University of Alaska Fairbanks. She is a research associate for the Water Environment Research Center at the University of Alaska Fairbanks and is currently a consulting engineer in Alaska.

**Charles Showers** became engineering program leader at MTDC in the Spring of 2002 after serving 2 years as operations program leader. A licensed professional engineer, Charlie came to MTDC after 9 years as assistant forest engineer on the Payette National Forest. He began his Forest Service career on the Boise National Forest after completing 8 years as a construction project engineer with the Idaho Transportation Department. He has an extensive background in forest engineering.

## Library Card

Barnes, David L.; Laderach, Shawna R.; Showers, Charles. 2002. Treatment of petroleum-contaminated soil in remote, cold, wet regions. Tech. Rep. 0271-2801-MTDC. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Technology and Development Center. 56 p.

Discusses treatment of petroleum-contaminated soils in the Tongass and Chugach National Forests of Alaska, where climate, utility access, and accessibility present serious challenges. The report is not meant to be a "cookbook" for selecting a technology to treat contaminated soils, but provides guidance to help Forest Service engineers select the best technology. The treatment technologies discussed include: excavation and proper disposal, thermal desorption, incineration, soil washing, ex situ vapor extraction, composting, landfarming, soil vapor extraction, barometric pumping, and bioventing.

Keywords: composting, environmental engineering, excavation, incineration, landfarming, petroleum hydrocarbons, pollutants, polluted soils, pollution, pumping, remediation, treatment, washing

**Additional single copies of this document may be ordered from:**

USDA Forest Service, MTDC
5785 Hwy. 10 West
Missoula, MT 59808-9361
Phone: 406–329–3978
Fax: 406–329–3719
E-mail: wo_mtdc_pubs@fs.fed.us

**For additional technical information, contact Charles Showers at MTDC.**

Phone: 406–329–3945
Fax: 406–329–3719
E-mail: cshowers@fs.fed.us

**Electronic copies of MTDC's documents are available on the Forest Service's FSWeb Intranet at:**

http://fsweb.mtdc.wo.fs.fed.us