TECHNICAL
FIELD GUIDANCE

CORRECTIVE ACTION - SOIL REMEDIATION

CONTAMINATED SOIL

GUIDANCE SUMMARY-AT-A-GLANCE

- Contaminated soil at a spill site can present several types of problems. First, it can be a significant source of volatile vapors.

- Second, contaminated soil can act as a continuing source, or reservoir, of contaminants.

- Finally, when contaminated soil is removed from the ground, it becomes a treatment and disposal problem that must be managed carefully.

- Contaminated soils can be removed, treated in place, or isolated from the air or ground water to mitigate risks to human health and the environment. Factors that influence the choice of a particular option include: the nature of the contamination and its toxicity, mobility, and persistence in the environment; the concentration of contaminants in the soil; the extent of soil contamination; potential effect of contaminated soil on the ground water; potential human health or environmental hazards associated with a particular option; and the availability of resources. Some petroleum-contaminated spill residuals, including soils, are also considered to be hazardous wastes. Hazardous wastes must be treated and/or disposed of in accordance with the regulations for these wastes.

- Clean-up alternatives for petroleum-contaminated soils include:

  - Soil excavation;
  - Enhanced volatilization;
  - Passive vapor control;
  - Active vapor control;
  - In-situ treatments (soil washing and bioremediation); and
  - Containment technologies.

1.6.6 Corrective Action - Soil Remediation

Contaminated soil at a spill site can present several types of problems. First, it can be a significant source of volatile vapors. These vapors can migrate through some soils (not all) and seep into subsurface structures like basements, utility conduits, and sewers. In enclosed, poorly ventilated spaces such as these, it is possible for the vapors to accumulate to levels that represent either a safety hazard (i.e., an explosive condition or oxygen-deficiency) and/or a health hazard. Free and dissolved product in ground water also can be source of vapors.

Second, contaminated soil can act as a continuing source, or reservoir, of contaminants. Contaminants can migrate down into ground water (as rainwater infiltrates) or come into actual contact with ground water by virtue of the rise and fall in the water table.[11] In addition, since ground water is often hydraulically connected to surface waters, soil contamination from a spill may also affect the quality of surface water. Contaminated ground or surface water that is used as a source of drinking water or for other beneficial purposes may pose a threat to public health and welfare.

Finally, when contaminated soil is removed from the ground, it becomes a treatment and disposal problem that must be managed carefully. Each of the various management options -- off-site disposal, allowing contaminants to volatilize off the soil pile, thermal treatment -- is subject to several regulatory and/or "good practices" requirements. One or more of these management options may not be feasible at a particular spill site or within a particular region (e.g., there are no nearby landfills that will accept petroleum-contaminated soils) or may be very expensive to implement. If the soil was contaminated by a hazardous material spill or a spill of certain petroleum products, the excavated soil may qualify as a hazardous waste under state regulations and would have to be managed as such.

This subsection contains guidance on BSPR policies for the cleanup of contaminated soil, including guidance on what qualifies as a contaminated soil for the evaluation of health hazards at a spill site. In addition, we provide guidance on: methods to prevent soil vapors from entering subsurface structures, methods and costs for excavating contaminated soil, and options for the treatment and/or disposal of contaminated soil. Other portions of the manual that contain guidance related or relevant to these topics include:

- Part 1, Section 3.1, Fire and Safety Hazards (contains guidance on detection of vapors in enclosed structures);
- Part 1, Section 3.2, Confining and Containing Releases (contains guidance on confining surface spills);
- Part 1, Section 4, Site Investigation Procedures (provides guidance on conducting site investigations to determine the extent of contamination from surface and subsurface spills);

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[11] *Ingestion of contaminated soil can be a significant route of exposure for children with pica (an abnormal craving to eat substances other than food, such as soil or paint), but usually is not a concern with respect to the general population. Inhalation of airborne soil dust can also be an exposure pathway if the soil is dry and exposed.*

- Part 1, Section 6.2, Free Product in Structures, Sewers, and Underground Utility Lines (provides guidance on the assessment and removal of free product in structures, sewers, and underground utility lines);

- Part 1, Section 6.3, Vapor in Structures, Sewers, and Underground Utility Lines (provides guidance on the assessment and mitigation of vapors in structures, sewers, and underground utility lines);

- Part 1, Section 6.4, Free Product on Soil Surface (provides guidance on emergency response and initial corrective action measures pertaining to spills on surface soils);

- Part 1, Section 6.7, Ground-Water Remediation, (provides background and guidance on the movement of free product in soils and the recovery of free product from ground water);

- Part 2, Section 3, Proper Management of Spill Residuals and Debris (provides guidance on options for treatment and/or disposal of contaminated soil and on the permitting requirements that apply to same); and

- Part 3, Section 1, Synopsis of Spill Assessment and Clean-Up Technologies (contains background and descriptive information on the capabilities, costs, operation, and maintenance of commercially available spill management and clean-up technologies, including technologies applicable to the treatment and/or disposal of contaminated soil).

1. Options for the Cleanup of Petroleum-Contaminated Soils

As shown in Exhibit 1.6-40, contaminated soils can be removed, treated in place, or isolated from the air or ground water to mitigate risks to human health and the environment. Factors that influence the choice of a particular option include: the nature of the contamination and its toxicity, mobility, and persistence in the environment; the concentration of contaminants in the soil; the extent of soil contamination; potential effect of contaminated soil on the ground water; potential human health or environmental hazards associated with a particular option; and the availability of resources. Much research has been conducted on various spill clean-up techniques, but there remains much uncertainty about how some techniques work, and what the controlling factors are to achieve maximum effectiveness.

The regulatory status of the contaminated soil, once removed, is also an important consideration. Soils contaminated by a hazardous material spill qualify as hazardous wastes under New York's hazardous waste regulations. Some petroleum-contaminated spill residuals, including soils, are also considered to be hazardous wastes as shown in Exhibit 1.6-41; however, most are not (see also Part 2, Section 3, Proper Management of Spill Residuals and Debris). Hazardous wastes must be treated and/or disposed of in accordance with the regulations for these wastes.

Exhibit 1.6-40

Basic Clean-Up Options for Petroleum-Contaminated Soils

Option	Description
Excavation for Treatment/Disposal	Contaminated soil is dug up for treatment/disposal on or off site.
Enhanced Volatilization	Rototillers and other equipment are used to turn near-surface soils to enhance evaporation of volatile constituents.
Active/Passive Vapor Systems	Gasoline vapors are removed from the soil without excavation by means of venting wells to which a vacuum is applied (active control). Passive vapor control is also possible.
In Situ Treatments	Petroleum constituents are leached from the soil matrix either in-place or after the soil has been excavated (soil washing). Bacteria can also be used to degrade petroleum constituents either in-situ or in aboveground biological reactors (biodegradation).
Containment Technologies	Physical or hydraulic barriers are installed to contain contaminants in place and restrict their migration.

Exhibit 1.6-41

Examples of Hazardous and Non-Hazardous Solid Wastes

Hazardous Solid Waste	Non-Hazardous Solid Waste
Petroleum contaminated solid debris that is contaminated with: # waste oil[1] # any other fuels (gasoline[2] or fuel oils that fail a prescribed ignitability test) and/or fail an Extraction Procedure (EP) toxicity test for lead or other metals[2] # unknown materials until identified otherwise	Contaminated solid debris such as sand, soil, speedy dry, sorbent pads, vegetation, etc., resulting from spills of: # virgin #2, #4, or #6 fuel oil # fuel oil tank bottom waste # diesel fuel # crude oil # vegetable, cooking, or mineral oil # gasoline if not ignitable and/or fails the EP toxicity test[2] # waste oil (if identified as non-hazardous) Contaminated liquid: # diesel fuel # #2, #4, #6 oil # crude oil # vegetable, cooking, or mineral oil # gasoline[3] if not ignitable and/or fails the EP toxicity test[3] # waste oil (if identified as non-hazardous)

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[1] Waste oil is considered hazardous until lab tested and proven otherwise.

[2] Gasoline contaminated debris may be considered a hazardous waste due to the characteristic of ignitability, or if it contains 5ppm or more of lead. As vapors from flammable fuels will dissipate over time, it is recommended that gasoline soaked debris be spread temporarily in a well ventilated location on the property of the spiller until the characteristic of ignitability is eliminated. The debris can then be considered a non-hazardous solid waste to be disposed of properly. This is a temporary action to reduce ignitability and should not be maintained for an extended period of time.

[3] Gasoline contaminated liquid is considered a hazardous waste until the characteristic of ignitability is diminished. A ground-water sample of 0.25ppm or more will fail an EP toxicity test.

(For more information, consult 6 NYCRR Part 371.3 and 371.4)

A number of clean-up alternatives may be combined as appropriate at a given site (i.e., the options listed below are not necessarily mutually exclusive). For example, in areas with particularly high levels of contaminants, a portion of the soil might be excavated and treated and/or disposed of off site while the remaining soil contamination is treated in place.

a. Soil Excavation

Excavation followed by treatment and/or disposal is one of the more common and widely used clean-up alternatives for petroleum-contaminated soil. The principal advantage to this option is that much, if not all, of the contaminated soil in the subsurface can be removed. As such, it no longer serves as a source of contamination to ground water or volatile contamination to the soil gases. Contaminated soil left in place and not treated by other means constitutes a continuing source, or reservoir, of contamination, which can prolong efforts to remedy vapor and ground-water contamination.

The principal disadvantage of this method is the potentially high cost of excavating and managing (i.e., storing, transporting, treating, and disposing of) the contaminated soil. The costs to dispose of large volumes of soil are often prohibitive, especially if the soil qualifies as a hazardous waste and/or if available treatment/ disposal facilities are located at some distance from the site. Furthermore, it is not always true that excavating contaminated soil presents less of a human health risk than not excavating the soil and trying to treat it in place. First, there is the risk to the health and safety of workers who are exposed to the contaminants during their work in and around excavations. Second, there is the health risk to the population in the vicinity of a spill site who may be exposed when the soil is excavated and volatile contaminants are released to the atmosphere in fairly large quantities (unless special measures are taken).

The characteristics of soil largely determine its capacity to retain gasoline liquid or vapors under unsaturated conditions. Excavating soils at or above the point of residual saturation can effectively remove product from the environment.[12] Soil excavation is more effective for removing product spilled onto dry, fine-textured sands rather than coarser-textured sands or those that are at field capacity.[13] Laboratory studies have determined that gasoline residual saturation decreases as the diameter of the soil particle increases and that a soil's capacity to retain gasoline decreases as the soil becomes more saturated or less dry. These experiments also determined that at increased densities, the soil was able to retain more gasoline because of the increase in the total available surface area per unit volume

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[12] *At residual saturation, no additional fluid migration from the soil should occur unless precipitation results in washing of gasoline from the soil profile.*

[13] *Field capacity is the quantity of moisture retained by soil after free drainage.*

and attendant decrease in the average soil pore diameter. Excavations that remove soils saturated with gasoline would, therefore, be expected to effectively minimize further migration of gasoline from the soils to the water table. Soils that are at residual saturation would not be expected to release substantial quantities of product, provided that water does not enter the residually saturated soils because of percolating precipitation or a fluctuating water table.

Notwithstanding the established clean-up criteria for contaminated soils, there are physical limits to how much soil can be excavated. These limits are, in part, a function of the geologic materials encountered. Some very wet soils cannot be excavated to any great depth before the excavation walls cave in. A period of heavy rain can also alter soil conditions such that keeping an excavation open becomes very difficult. Contaminated soils located under paved areas, under buildings, or in areas where substantial underground or overhead utilities exist may not be suitable for excavation. Congested or heavily trafficked areas may also pose constraints against the use of excavation techniques. Excavation operations that interfere with the continuance of business by the property owner may be seen as an unacceptable alternative in some instances. The physical limits are also a function of equipment capabilities unless some special (and expensive) equipment and procedures are used. Depending on the dimensions of the excavation pit, equipment such as backhoes, cranes, and bulldozers can all be used to excavate soils.

Backhoes are generally used for trenching and in other situations where it is best to keep the equipment out of the excavation pit. Smaller, rubber-tired backhoes are useful for fast shallow excavations, but are adequate only if the working surface is stable. A small backhoe with a one-half cubic-yard bucket can excavate to a depth no greater than about 16 feet and has a maximum reach of 26 feet. A larger backhoe unit with a three-and-one-half cubic yard bucket can reach depths of up to 45 feet (at maximum digging angles of 45 degrees) provided measures are taken to prevent cave-ins and the sloughing in of the excavation walls. Because of such limitations and the space taken up by the soil pile, a significant amount of surface area would be disturbed at a typical UST site.

Cranes are used occasionally at sites that have a large amount of contaminated soil and an unrestricted working area. Cranes can also be used as drag-line excavators for large areas of loose soil or to move large volumes of soil once the soil is excavated.

Bulldozers and front-end loaders are frequently used for larger excavations. Bulldozers can be used to quickly remove large areas of surface soil. Front-end loaders can move large quantities of soil -- with buckets that can hold up to 20 cubic yards of soil. Rubber-tire dozers and loaders are faster than machines with treads, but they operate at optimal level only on stable, level terrain. Dozers and loaders are limited by the fact that they must operate at the level of the excavation, and therefore are impractical for excavating small holes. More effort is usually required to decontaminate this type of equipment as well.

When excavating contaminated soil, several worker health and safety precautions must be followed: (1) the walls of the excavation must be shored according to OSHA standards; (2) the air in the excavation area should be monitored continuously for explosive conditions, oxygen deficiency, and volatile organic compound concentrations; and (3) if explosive conditions are indicated, special explosion-proof motors and spark-arresting equipment must be used to excavate soil.

Costs for excavation and disposal can be categorized under the following components of corrective action: site preparation; excavation; material handling/staging; backfill material; final grading; hauling; and disposal. Site preparation costs may be minimal, if the area requires only minor excavation, but may be significant when large areas must be cleared. Site clearing costs can range from $1,500 to $2,300 per acre when grubbing and stump removal is required. If the area to be excavated is paved, site preparation costs may not apply.

Excavation costs also will vary depending on the type of equipment utilized. Use of backhoes/front-end loaders with capacities of 0.5-0.75 yd^3 can incur costs ranging from $3.55 to $5.00/yd^3 and 1-3.5 yd^3 capacity backhoes can incur costs ranging from $1.75 to $3.00/yd^3 [4].[14] Unit costs for operating dozers and loaders used to move soils on site range from $1.20 to $4,50/yd^3. Backfill material will vary in cost from $10 to $20/yd^3, depending on the distance the material is hauled, and grading of the backfill will add an additional $2.50 to $3.50/yd^3 to the costs of the backfill placement. Costs for transporting the soil to the disposal site is largely dependent on the distance traveled but may range from $0.50 yd^3/mi to $1.00 yd^3/mi. Landfill disposal, including transport, of gasoline-contaminated soils typically ranges from $125 to $200/yd^3. Tipping fees as low as $5/yd^3 were reported for "clean soils" and were as high as $120/yd^3 at licensed hazardous waste facilities.

In some states, a significant amount of gasoline-contaminated soil is being disposed of at batch asphalt plants, which use the contaminated soils in their production process. Disposal costs have been reported to be on the order of $55/yd^3, provided the soil passed the EP toxicity test and did not contain chlorinated solvents.

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[14] *Cost data are from 1987 report. Note also that more specific cost data are available from NYSDEC agreements with response contractors.*

b. Enhanced Volatilization

Enhanced volatilization is a term applied to any technique by which volatile organics are removed from unsaturated soil by bringing clean air into contact with the contaminated soils in order to transfer the contaminants from the soil into an air stream. Volatilization can be approved if vapors are treated in accordance with NYS air regulations. There are a number of different methods available that can achieve this effect.

Pneumatic conveyor systems consist of a long tube or duct to carry air at high velocities, an induced draft fan to propel the air, a suitable feeder for addition and dispersion of particulate solids into the air stream, and a cyclone collector or other separation equipment for final recovery of the solids from the gas stream. Several units of this type heat the inlet air to 300^{o}F to induce volatilization of organic contaminants. Pneumatic conveyors are primarily used in the manufacturing industry for drying of solids with up to 90 percent initial moisture content.

Low temperature thermal stripping systems consist of a configuration similar to that of a rotary kiln dryer system except that additional heat transfer surfaces are provided to heat the soil by contact in a screw-auger device or rotary drum system. Induced air flow conveys the desorbed volatile organics/air mixture through a combination afterburner for the destruction of organic contaminants. The air stream is then discharged through a properly sized stack.

Field studies have shown that of the four methods described above low temperature thermal stripping may have the greatest capability of successfully removing from soil contaminants whose properties are similar to those of gasoline (i.e., compounds with high vapor pressures).

The effectiveness of enhanced volatilization, especially low temperature thermal stripping, is limited under the following conditions: soil characteristics limit the mobility of gasoline vapors from the soil to the air, contaminant concentrations may cause an explosion or fire, and dust and organic vapor emissions must be controlled to avoid adverse impacts on air quality.

Enhanced volatilization by rototilling or other mechanical means would not be considered a potentially appropriate corrective action unless the contaminated soil could be spread over a large area and treated for extended periods of time. Such conditions are unlikely to be found at most spill sites. Accordingly, low temperature thermal stripping may be a more feasible technology.

Roy F. Weston, Inc., under contract to U.S. Army, performed an economic evaluation to determine the cost effectiveness of removing volatile organics from the following quantities of contaminated soils by means of low temperature thermal stripping: (1) 1,000 tons; (2) 10,000 tons; and (3) 100,000 tons [4]. Different system configurations were tested, as shown in Exhibit 1.6-42. Based upon their evaluation, it was concluded that System B was the most cost-effective approach for sites with 15,000 to 80,000 tons of soils to be treated. The unit costs for this system ranged from \$74 to \$160 per ton (\$99 to \$213/yd^3) without flue gas scrubbing and from \$87 to \$184 per ton (\$116 to \$245/yd^3) with flue gas scrubbing. Operating costs for stripping 1,000 tons of soil ranged from \$42 to \$89 per ton (\$56 to \$119/yd^3). However, the capital costs for the systems make up a significant portion of the total costs for processing, as shown in Exhibit 1.6-43. Actual costs for processing less than 10,000 tons of soil would therefore be expected to exceed \$200 per ton (\$270/yd^3) using this type of system. Thermal stripping of soils using asphalt batch plants may also range upwards of \$300/yd^3.

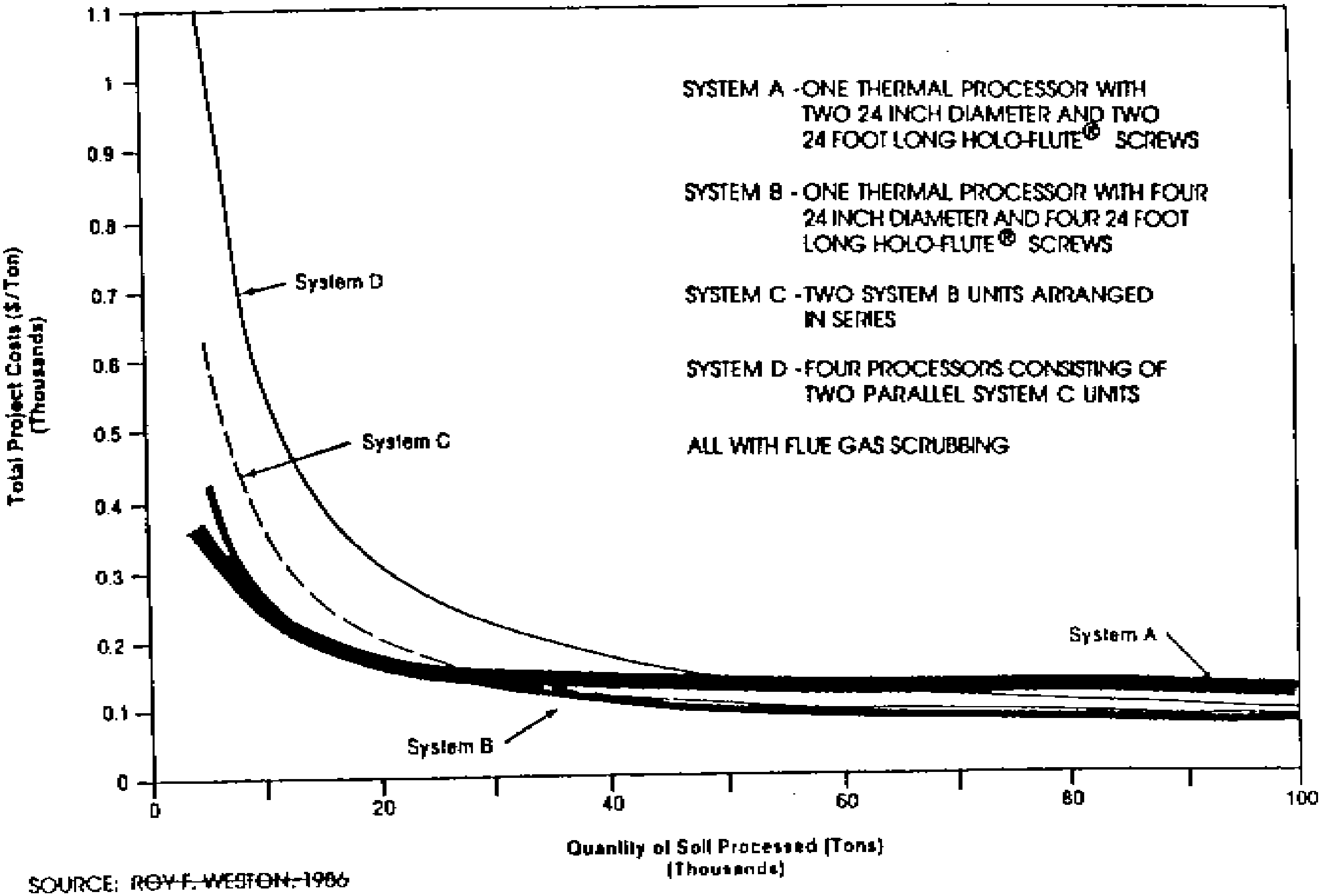
c. Passive Vapor Control Systems

Passive vapor control systems use no mechanical components to intercept the flow of vapor through the soil and vent the volatile constituents to the atmosphere. The general technique is to construct a trench around and down to the depth of the contaminant plume. Therefore, the technique is limited to those settings where the soils can be trenched to the depth of the plume. Limiting factors include the presence of a perched water table or rock layers. Passive venting systems are also less effective in areas of high rainfall or prolonged freezing temperatures. Use of these systems may also require installation of air pollution controls (i.e., vapor phase treatment).

There are two basic kinds of passive vapor control systems: low-permeability and high-permeability. Each of these systems starts with construction of a 3-foot wide trench. The ground surface must be graded to drain water away from the trench so that sediment does not fill up the pore spaces. In a low-permeability system, the downgradient side of the trench is lined with a synthetic membrane or other low-permeability material to effectively block the path of the migrating vapor. The trench is backfilled with crushed stone or river gravel (sizes in excess of one-quarter inch) to provide a more permeable path for the vapors to vent out of the soil. A high-permeability system is constructed similarly, but without a synthetic membrane. Horizontal perforated pipe or vertical solid wall-riser pipes are often installed in the backfill to ensure an open path for vapor flow in the event the ground surface is frozen or otherwise

Exhibit 1.6-42

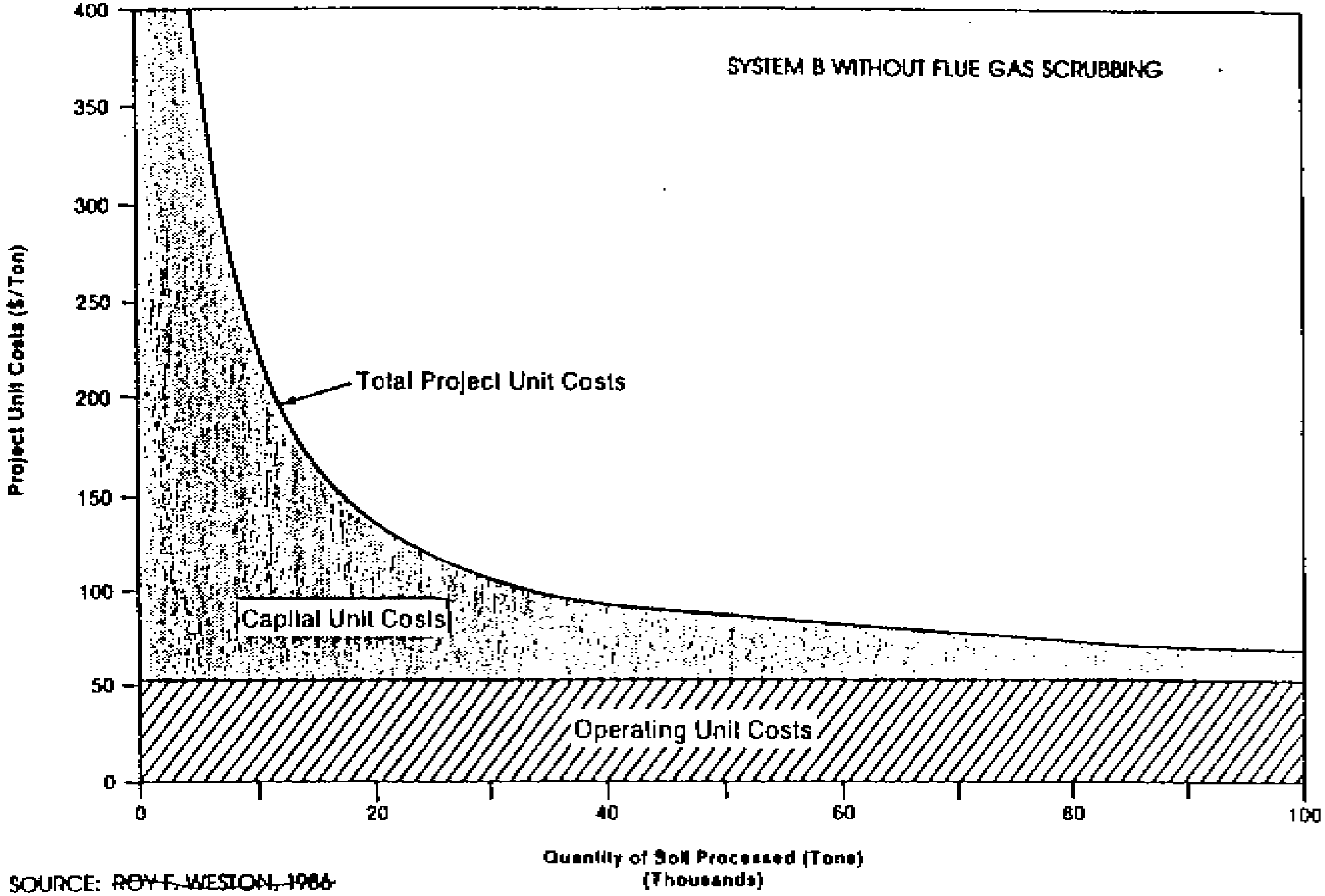
Unit Costs for Low Temperature Thermal Stripping Pilot Plant



SOURCE: ~~ROY F. WESTON, 1986~~

Exhibit 1.6-43

Unit Costs for Low Temperature Thermal Stripping



SOURCE: ~~ROY F. WESTON, 1986~~

sealed. A schematic of both systems is provided in Exhibit 1.6-44.

d. Active Vapor Control Systems

In the subsection on Vapors in Structures, Sewers, and Underground Utility Lines, we discussed methods and procedures for removing vapors from enclosed structures as a means to reduce the safety and/or health hazard. It is possible to install systems that actively keep vapors from migrating out of permeable subsurface soils and into structures such as basements and sewers.[15] The principle behind these systems is that a pressure gradient can be established in the contaminated soil to draw the volatile constituents in the spilled material out of the product that is trapped in the soil pore spaces. Volatile constituents will also be drawn off the layer of floating free product on ground water if the extraction wells are drilled to depths near the water table or if they actually intercept the water table (i.e., they can be used in combination with other clean-up technologies like product recovery wells). These active vapor control systems are frequently referred to as soil venting systems and consist of soil vapor extraction wells, soil vapor collection headers, and blowers or compressors used together to remove volatile components from the soil (see Exhibit 1.6-45).[16] In pressurized venting, air is forced into the soil by use of an infiltrating vent. In vacuum venting, a vacuum is created on the extraction well to remove vapors. Pressure and vacuum systems can conceivably be used in tandem to increase the rate at which gasoline is removed from soils.

Active vapor control is obviously not needed at sites where vapor contamination is not a problem either because the subsurface soils are not very permeable to the vapor phase, because there are no surface or subsurface structures to impact, or because the contaminants of concern are largely non-volatile. Active vapor control is often not practical where drilling through the geologic material and/or drilling to the required depth is infeasible or very costly.

Vapor extraction wells are typically drilled borings, one-to-three feet in diameter, that are backfilled with gravel around a PVC pipe perforated at the depth where vapor is to be collected or along its entire length below ground.[17] The wells are generally installed to the depth of the seasonal low ground-water table or

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[15] *Passive gas control systems are sometimes used but are not as efficient.*

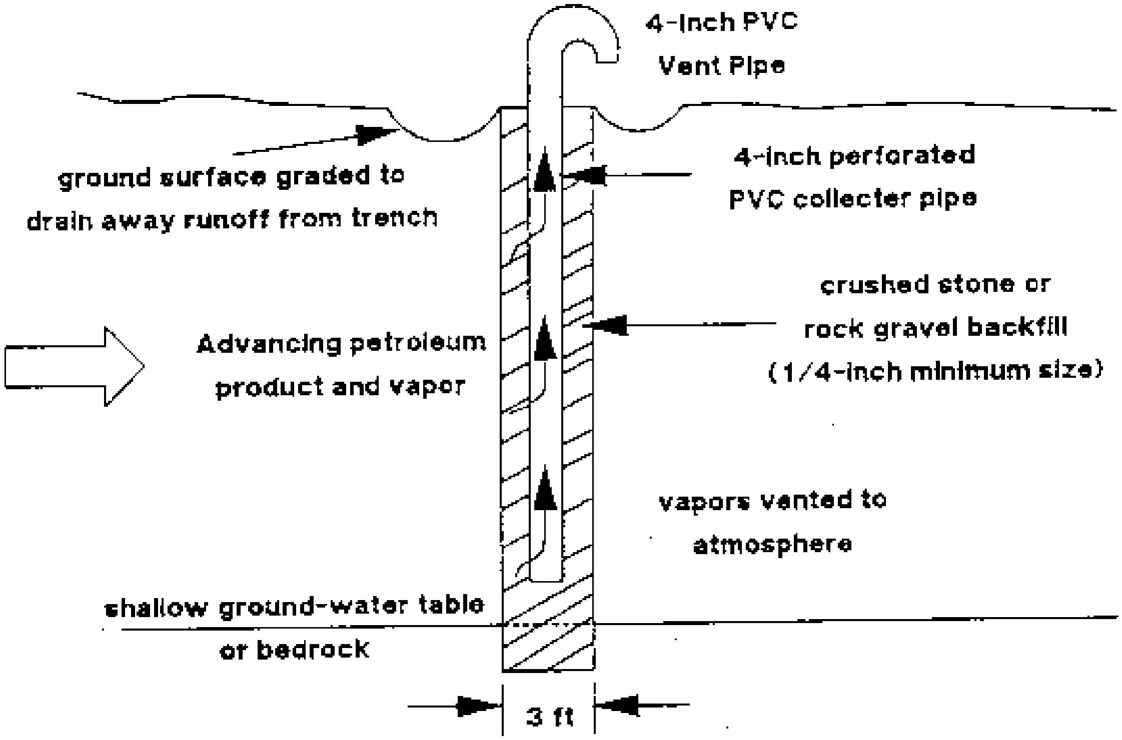
[16] *These systems are often used in conjunction with sealing the surfaces of the interior structural walls or sealing around piping where the vapors can enter the structure.*

[17] *These wells can actually consist of gravel packs extending upwards to the soil surface, slotted or unslotted well casings installed with or without a gravel pack, or any other configuration that allows gases to move from the soil.*

Exhibit 1.6-44

Schematic of Passive Vapor Control Systems

High-Permeability System



Low-Permeability System

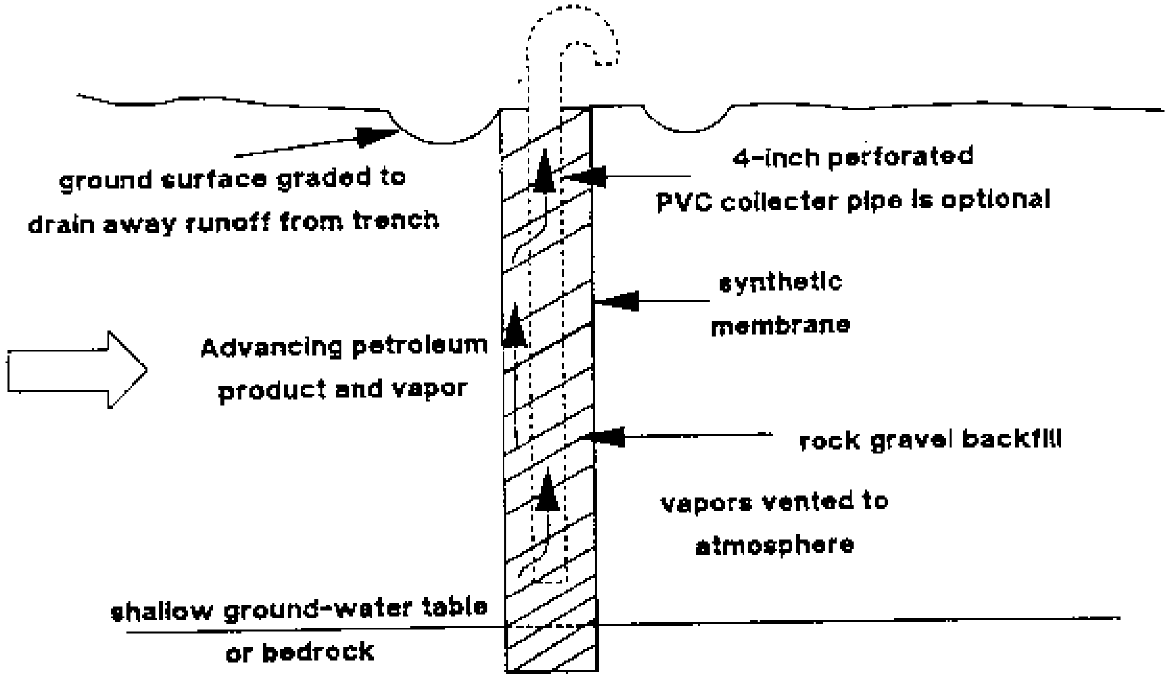
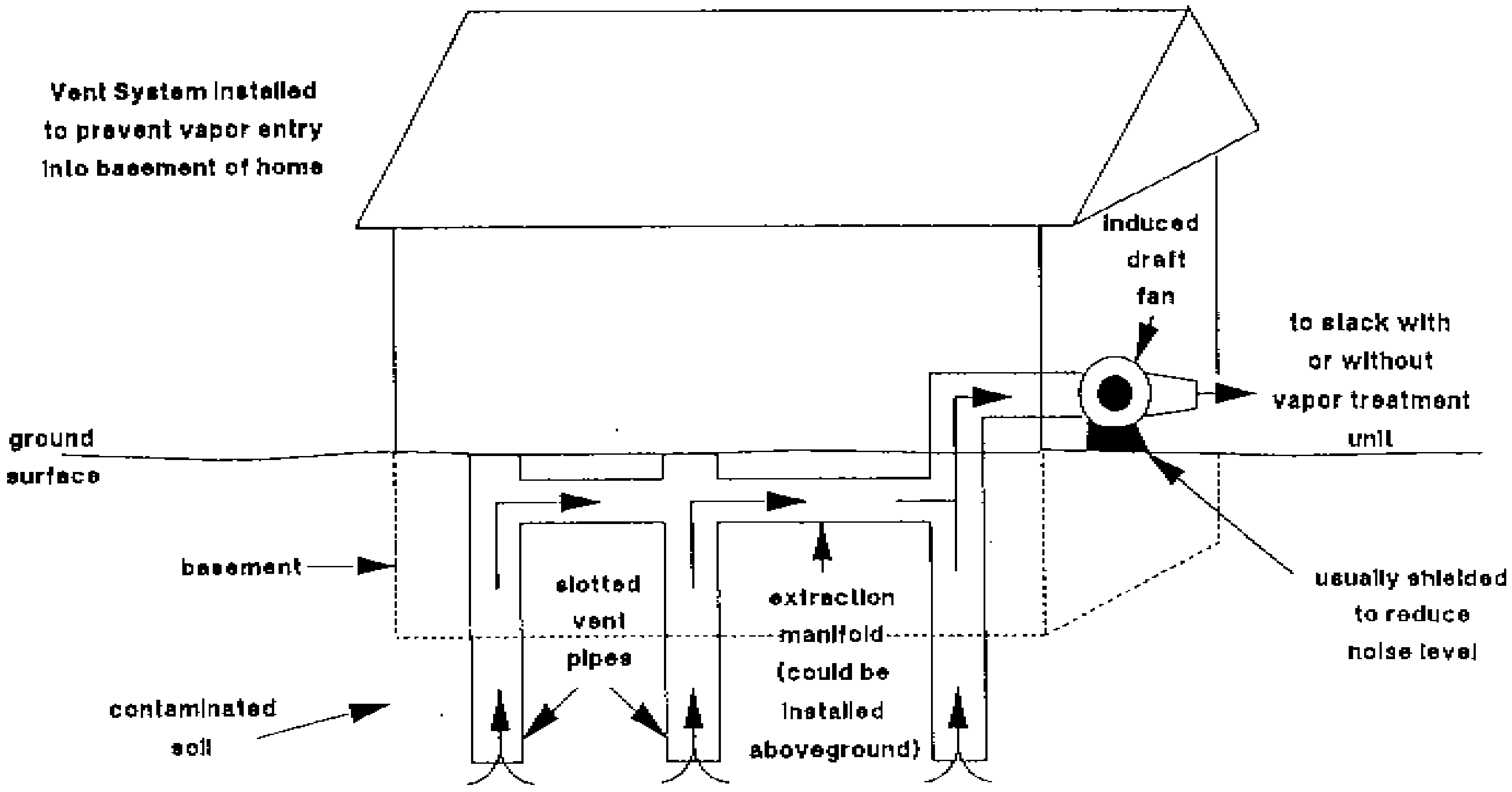


Exhibit 1.6-45

Schematic of a Soil Venting System

(Induced Draft Extraction)



to the bottom of the contaminated area. Well spacing is site-specific, and depends on the well depth, the vacuum applied, the vapor flow rate, and the number and type of structures to be protected (e.g., several homes can be protected with a single network of wells). Specific design parameters are generally developed after on-site pilot tests. Another consideration is where to place the blowers or compressors so that residents are not overly disturbed by their noise during operation, particularly at night, since it is often best to have the system operate continuously for as long as necessary. Occasionally, it will be necessary to build noise shielding around the equipment to suppress noise levels.

There is much uncertainty regarding the effectiveness of soil venting systems because the technology has not been widely applied. Limitations to the use of venting soil gases are associated with soil characteristics that impede the free movement of vapors to the extraction well, emissions of volatiles during venting, and explosion hazards. Soils that have limited pore space because of compaction or fine-grained texture of soil particles tend to restrict the rate at which air passes through and over all soil particles contaminated by gasoline. The limitations imposed by these types of conditions would require the use of more closely spaced venting wells and possibly higher-capacity pumps. Volatiles generated during the venting process can be readily captured utilizing granular activated carbon sources where air quality restrictions apply. Explosion hazards associated with gasoline vapors can be overcome by using intrinsically safe equipment and by ensuring that an adequate amount of air area moves through the system to keep vapor concentrations below the lower explosion limit (LEL).

In order to predict the effectiveness of soil venting, several researchers have attempted to develop theoretical models of vapor movement in soil [4]. However, it is questionable whether this model could be applied to field situations because of the difficulties involved in determining initial values for key variables in the equations. For example, in order to use the equations, an estimate of the vapor phase concentration in the soil pores must be derived. Because of the constant flux of soil air, it may be difficult to estimate an initial vapor phase concentration for gasoline in soil under field conditions. Another reason for the model's development was that experiments had indicated that soil particle size, density, and moisture should have no effect on the mechanisms involved in the venting process. Although this may have been the situation in the experiment, it is questionable whether the model could be applied to field conditions where soil characteristics would be expected to significantly affect the rate at which gasoline vapors could be vented from the soil.

Nevertheless, the experimental results do indicate that over 99 percent of gasoline initially present at residual saturation in sands could theoretically be removed by soil venting under ideal conditions. The model predictions generally compared very well with the experimental data and provided information that led to the following conclusions:

- Removal rates decrease with time during venting as the immiscible phase composition shifts towards a mixture comprised of less volatile compounds corresponding to a lower total vapor pressure of the gasoline;

- The rates at which vapors escape from residual saturation are greater than the maximum rate at which they can be swept from soil above the water table; and

- Depression of the water table would result in as increased rate of removal of vapor phase components by removing the rate-limiting diffusion barrier that results from the presence of water in the soil pores within the capillary fringe.

The findings of these studies have led to the following general recommendations regarding use of soil venting techniques for gasoline removal from unsaturated soils:

- Short slotted sections at the bottom of the import vents may achieve more efficient vapor removal than continuous slot vents;

- Sealing the soil surface of the venting area may optimize venting by helping to ensure that exhaust air is drawn out laterally, not from the soil surface downward; and

- Venting should be initiated at high flow rates (greater than or equal to 16 liters per minute) to remove the majority of vapors, and thereafter reduced to conserve energy.

Major capital costs for soil venting systems are associated with installation of the venting well, the cost of the pump, and any costs associated with air emission control. Conventional drilling equipment and materials are used to install venting wells. Costs for a 20-foot venting well, constructed of two-inch diameter slotted Schedule 40 PVC, would be expected to be in the range of $40 per linear foot installed, and attendant piping would cost approximately $3-5 per linear foot. The size of the vacuum pump would be based upon the area and volume of soil to be vented. Vacuum pumps capable of moving 40-60 standard cubic feet of air per meter at 1.5 inches of water range in price from $500 to $2,000. Pumps capable of moving 1,000 standard cubic feet per meter at 25 inches of mercury vacuum cost approximately $4,000.

Operating costs include costs for power consumption, replacement parts, personnel, insurance, and security (does not include costs to monitor the atmosphere inside the structure). These costs will vary depending on utility costs and time of operation. The need for vapor treatment, such as flaring or carbon adsorption of the emitted vapors, would add to the operating cost. Active vapor control systems do require periodic maintenance and monitoring to ensure continued effective operation.

e. In-Situ Soil Treatment

Contaminated soils can sometimes be treated in place using chemical, biological, and/or physical processes. In general, the available in-situ technologies for contaminated soil (e.g., soil washing/extraction) are not as well developed or tested as some other alternatives, but may be suited to some cases. For more information, see Review of In-Place Treatment for Contaminated Soils, USEPA, 1984.

NOTES

Soil washing is a general term applied to any technique that affects the removal of gasoline constituents from the soil matrix by actively leaching the contaminants off the soil into the leaching medium. The extracted constituents can then be removed from the washing fluid by conventional treatment methods. Soil washing is accomplished either in-situ, as a water flushing system (as shown in Exhibit 1.6-46), or processed through a countercurrent extractor system (shown in Exhibit 1.6-47). The washing fluid most often used for soil flushing is water, which may contain additives such as acids, alkalis, and detergents. However, pure organic solvents, such as methanol, hexane, or triethylamines, are also used as washing fluids.

The soil/washing fluid slurry can be dewatered by means of conventional dewatering techniques such as sedimentation filtration, evaporation, dissolved air flotation or drying beds. The treated soils can then be placed back into the original excavation or sent to a sanitary landfill. The leachate collected from the extraction process can be treated by conventional treatment and recycled in a closed system. Contaminated solvents are separated by physical separation techniques such as distillation, evaporation, or centrifugation.

The effectiveness of a soil flushing/washing system depends in large part on the residual gasoline capacity of the soil. Diesel, kerosene, and gasoline are not as tightly bound to the soil matrix and thus the soil washing system is very effective on these constituents.

Limitations with the use of soil washing and/or soil flushing are associated with soil characteristics that impede the solid/liquid separation subsequent to the washing phase (e.g., soils having a high percentage of silt or clay). In-situ soil flushing using surfactants or other additives can result in decreased soil permeability. However, using water to flush soil residually saturated with petroleum products is not effective in mobilizing the immobile phase; surfactant treatment may be necessary to effectively remove these materials. Field studies have indicated that significantly greater volumes of water than air are required to cleanse residually contaminated soils [4]. Test results have shown the soil wash process will remove up to 99.4% toluene, 99.5% gasoline, 96.7% diesel, 96.1% kerosene, 97.4% TCE, 99.9% tetrachloroethylene, and 99.0% creosote-coal tars (PAHs). The actual percentage of contaminant removed depends on: (1) the relative amounts of clay and sand; (2) the nature of the contaminants; and (3) the concentration and type of reagents.

Processing costs for a commercial soil washing process developed by MTA Remedial Resources, Inc., are about $100 per ton, which includes both capital amortization and operating costs but not excavation or disposal costs [4]. Resource Conservation Co. estimates processing costs for their Basic Extraction Sludge Treatment (BEST) system to be about $120-150 per wet ton, not including excavation or disposal costs.

Exhibit 1.6-46

Schematic of an In-Situ Flushing System

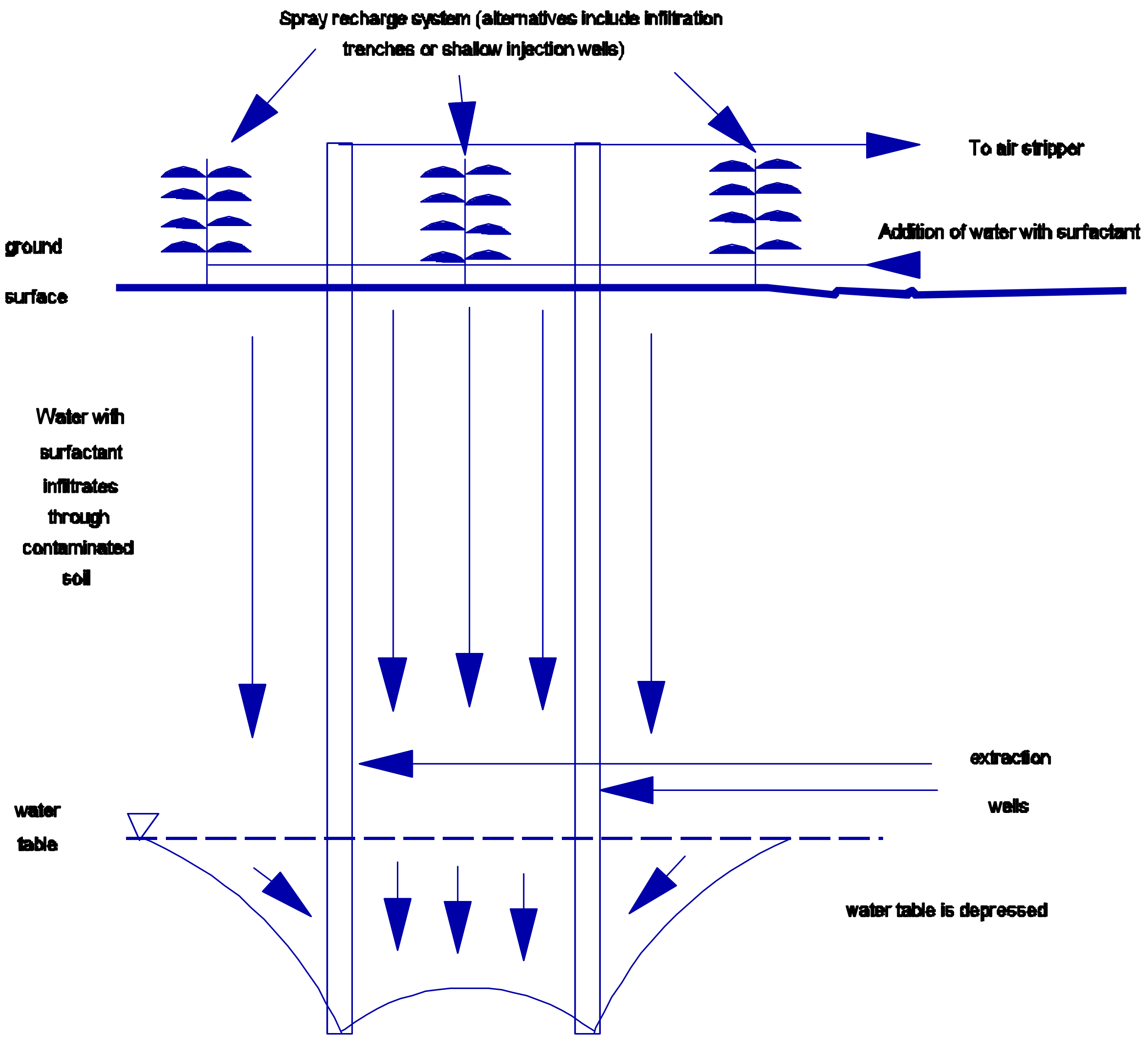
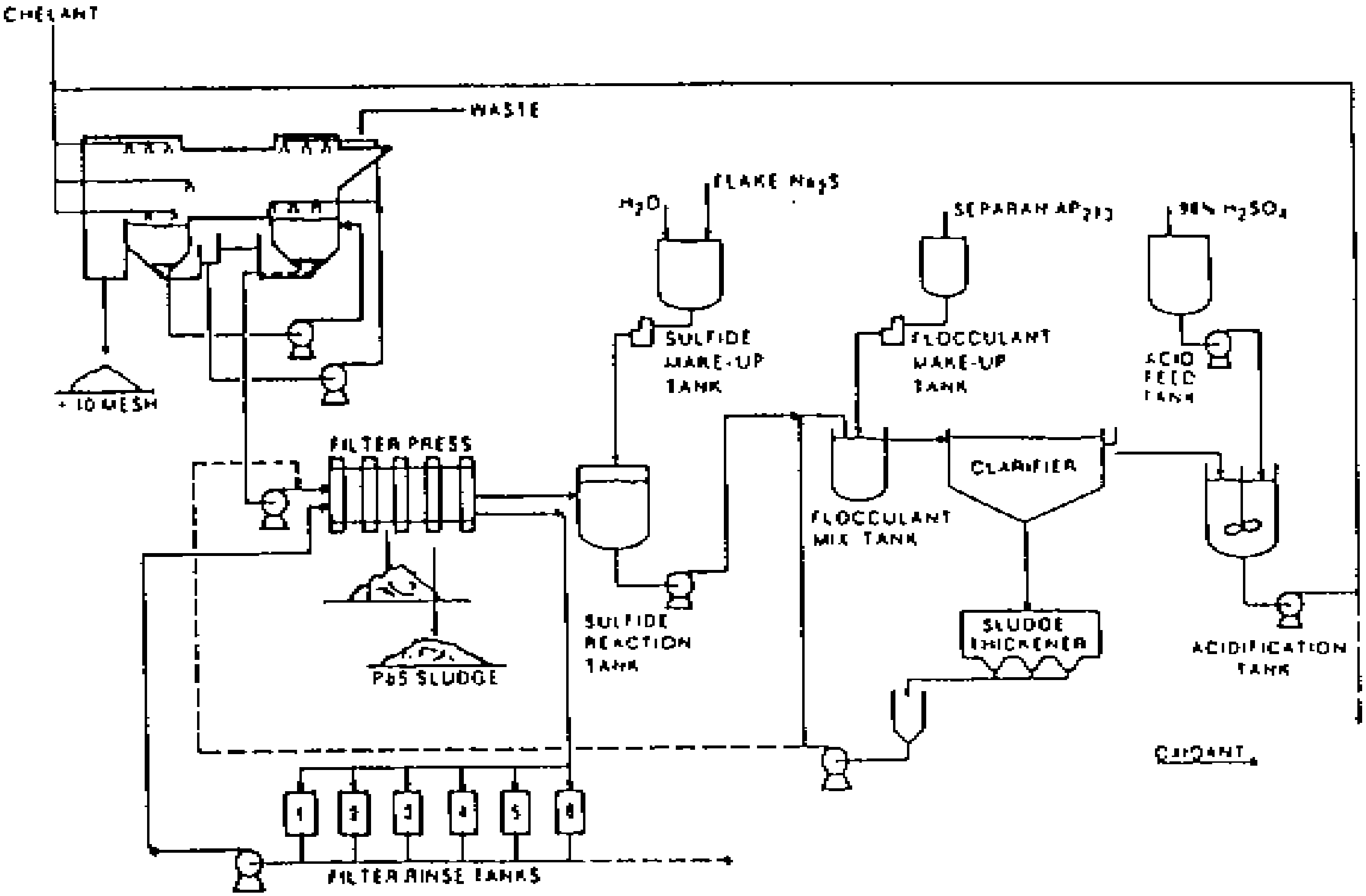


Exhibit 1.6-47

Process Flow Diagram of Counter Current Extractor



SOURCE: EPA, 1986

Bioreclamation is a process whereby natural microorganisms in the soil break down the organic compounds. It is a process that has been used successfully to treat contaminated soils. Factors affecting the usability of this method include the biodegradability of the contaminants, various environmental factors that affect microbial activity, and site hydrogeology. The technique best suited for treating petroleum hydrocarbons in soils relies on aerobic degradation. Oxygen (often in the form of hydrogen peroxide) and nutrients are delivered to the subsurface by means of injection wells or gallery infiltration systems to enhance natural microbial activity.

The n-alkanes, n-alkylaromatics, and aromatic petroleum components in the C10-C22 range are the least toxic and the most readily biodegradable of the petroleum components, whereas those in the C5-C9 range have relatively high solvent type membrane toxicity (see Exhibit 1.4-27 in Attachment 1.4-1 at the end of Part 1, Section 4, Site Investigation Procedures). Those petroleum components in the range above C22 are not readily degradable because of their physical characteristics. Cycloalkanes and branched alkanes in the C10-C22 range are more resistance to biodegradation than aromatics and n-alkanes because of their branched structure. Gasoline composed principally of cycloalkanes and alkanes in the C5-C10 range would, therefore, be expected to be subject to microbial degradation in the soil environment, provided environmental conditions did not hinder the process.

The following environmental factors affect microbial activity: nutrient availability, oxygen concentration, redox potential, pH, soil moisture content, hydraulic conductivity of the soil, osmotic potential, temperature, food source competition, and the types and concentrations of hydrocarbon contaminants. Contamination in permeable sandy soils tends to be easier to treat than contamination in clayey soils.

Optimal quantities of nitrogen and phosphorus required for microbial degradation is related to the organic carbon content of the soil/contaminant mixture. Optimum temperatures for microbial degradation are reportedly above 20^{o}C.

Optimal microbial activity occurs at between 50 and 80 percent of the water-holding capacity; at 10 percent or less water-holding capacity, metabolic activity becomes marginal [4]. As soils become saturated, anoxic conditions result and anaerobic microbial activities predominate. Microbial degradation of gasoline under anaerobic conditions is not significant. Lack of oxygen in aquifer systems has been reported as a major limiting factor for in-situ aquifer microbial degradation of petroleum products [4]. Microorganisms in well-oxygenated ground water containing 4 mg/l of oxygen can degrade only 2 mg/l benzene. The solubility of benzene in water (1780 mg/l) is much greater than its capacity for degradation. Mechanical systems that add air to the aquifer are able to introduce only 10 ppm of oxygen into the ground water. However, injecting hydrogen peroxide into ground water has been found to stimulate microbial degradation.

From studies that have simulated the simultaneous growth, decay, and transport of microorganisms, as well as the transport and removal of hydrocarbon and oxygen, in aquifer systems the following conclusions have been drawn [4]:

A zone of reduced hydrocarbon and oxygen concentration will develop between the oxygenated formation water and the plume in which microbial degradation rates are reduced;

A large microbial population will develop in the region contiguous to the hydrocarbon source in which instantaneous reaction of hydrocarbons and oxygen will take place;

Adsorption to the aquifer material may significantly enhance the biodegradation of hydrocarbon spills; and

Exchange of oxygen and hydrocarbon vertically with the unsaturated zone may significantly enhance the rate of biodegradation.

These studies point out the importance of oxygen exchange to microbial degradation in aquifer materials. In soil materials above the water table, the rate of oxygen exchange will be greater than that associated with aquifer materials. The rate at which oxygen can be brought in contact with the microbial population and gasoline-contaminated soils will be related to the depth of contamination, the soil texture, and the soil's water and gasoline content.

Costs for microbial degradation of gasoline-contaminated soil are not widely reported because these techniques are most often applied in recirculation systems or to restore ground-water systems. A hypothetical spill cleanup of 10,000 gallons of jet fuel in a fine gravel formation using a hydrogen-peroxide-enhanced microbial degradation system was estimated to cost between $400,000 and $600,000 [4]. Others have reported that bioreclamation costs range between $50 and $100 per ton ($66 to $123/yd^3).

Physical methods for immobilizing or detoxifying waste in the subsurface have also been considered, and several are under development. Physical methods include heating, freezing, and vitrification (electric melting). These methods have not been developed sufficiently for widespread commercial application.

f. Containment Technologies

Contaminants in the soil can also be contained and prevented from migrating further. Containment devices include caps and various subsurface barriers. Containment is typically used when the area of contamination is large and soil excavation or the use of other treatment methods would be too costly. Containment tends not to be used for most petroleum spills, but its use for this purpose is conceivable.

Capping involves covering the contaminated area with soil and sometimes with synthetic material of low permeability. The cap prevents direct exposure to the contaminated soil and minimizes water infiltration; therefore, the transfer of contaminants to ground water is minimized. Subsurface containment technologies include slurry walls and grout curtains. These barriers are installed around the perimeter of the contaminated area and work best if extended from the ground surface down to an impermeable layer underlying the contaminated area. Caps are always used in addition to subsurface barriers to minimize water infiltration.

2. Proper Management of Contaminated Soil

The nature of the contamination determines how the excavated soil should be managed. Any soil containing hazardous waste must be managed as such. For purposes of this discussion, however, we will assumes that the contaminated soil does not contain hazardous waste.

If temporary on-site or off-site storage of the contaminated soil is required, the storage area should be diked or bermed to collect run-off, and lined with plastic or low-permeability clay to prevent seepage into the ground. A layer of sorbent material should be placed on the bottom of the storage area and any liquids that accumulate should be pumped into containers and disposed of properly (see Part 2, Section 3, Proper Management of Spill Residuals and Debris). If the soil contains volatile contaminants, the soil pile should be located away from ignition sources. If the treated soil cannot be returned to the excavated area, clean fill material will be required.

The soil may be treated either on or off site, although on-site management, if feasible, is generally significantly less expensive. Typical treatment might involve spreading and discing to allow volatile contaminants to evaporate (land treatment). Other possible treatment methods include solidification/stabilization, soil washing, disposal in a landfill, or some kind of thermal treatment, including incineration, low temperature volatilization, or "burning" in an asphalt plant. For more on the contaminated soil management, see Part 2, Section 3, Proper Management of Spill Residuals and Debris.

TECHNICAL

FIELD GUIDANCE

CORRECTIVE ACTION - GROUND-WATER REMEDIATION

NOTES

Corrective Action -
Ground-Water Remediation

GUIDANCE SUMMARY-AT-A-GLANCE

- The discovery of free product on the ground water surface should always trigger action to remove as much as product as practicable. Prompt removal of product is necessary because (1) free product is a source of vapors, which can migrate into subsurface structures to present a safety hazard, and (2) free product is a continuing source of dissolved contaminants in ground water.

- Free product in contact with ground water will nearly always mean some amount of dissolved contamination will be present. The opposite, however, is not always true. If both free and dissolved product contamination are present, a free product recovery program can be devised to also address the dissolved contaminants. Whether dissolved contamination must be addressed (in the absence of any free production contamination problem) and the degree of cleanup required will depend on the type of contaminants, their toxicity, their concentration relative to health-based or other standards, and on whether the ground water is used as a drinking water supply or for some other beneficial use.

- Because the presence of free product can be determined within a variety of open structures, excavations, or borings, there are a number of options available for delineating the extent of free product in the subsurface. The selection criteria for these options may include:

  - <u>Expediency</u>, or degree of imminent hazard, where time is of the essence;

  - <u>Feasibility</u>, as controlled by depth to the water table and competency of the earth materials; and

  - <u>Cost</u>, usually measured in terms of price per unit foot drilled, or time spent excavating.

- The locations, number, and depths of the excavations, borings, and wells are important considerations in product-plume delineation. The locations will often be constrained by existing structures, the presence of overhead power lines, and property boundaries. Within these constraints, a strategy for plume delineation that consists of starting near the source and then moving away from the source in equal increments of distance is reasonable. In some cases, this strategy can also be applied near and around locations where product has already been discovered. The number and depths of excavations, borings, or wells that will be necessary depend on the magnitude of the release, the depth to water, the absorptive capacity of the unsaturated zone, and the degree of diversity in the earth materials.

Corrective Action -
Ground-Water Remediation

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

\# The placement and design of product-detection wells should take into account the contrast in permeability between the excavation zone and the surrounding earth materials and the diversity of these materials. A high contrast in permeability may form a natural barrier in and around the excavation zone, especially if the surrounding media has a low permeability. Under these conditions, product releases will tend to be confined to the excavation zone, thereby allowing for easy detection and recovery within this zone. If the permeability contrast is small, or if permeabilities of the native soils are large, free product may go undetected as it migrates through the excavation zone into the surrounding materials, bypassing a well in the excavation zone.

\# Placement of product-detection wells outside the excavation zone entails more uncertainty than placement inside because natural earth materials are more likely to be more diverse.

\# The first general guideline is that as the diversity in subsurface earth materials increases, the number of wells should increase to lessen the risk of missing a major preferential flow path. The number and positioning of detection wells could be related to the size of the subsurface features having one or more preferred flow paths. In general, large geologic features, such as an extensive layer of coarse-grained fill, a wide channel sand deposit, or a major fault/fracture zone would vary internally, but could be covered by one well or relatively few. At the other extreme, small features such as widely spaced fractures, randomly located rootholes, and buried utility lines in low-permeability materials are small targets and may not be intersected even when many wells are installed.

\# The thickness and elevation of the free product and water surface should be observed at all monitored locations. These levels will change with time in response to various environmental changes such as water-table fluctuation, precipitation events, and fluctuations in atmospheric pressure.

\# Unfortunately, a precise measurement of product inside the well cannot easily be related to product thickness outside the well. This fact is critical because ignoring it can lead to overestimates of recoverable free product. Some have suggested that a ratio of 4:1 for the thickness of product inside the wells and the sum of thickness of free product and the product capillary fringe outside the well can be assumed.

\# A primary consideration in monitoring well design is chemical reactivity of the casing and screen to different petroleum products. The most widely used monitor-well screen materials include polyvinylchloride (PVC), stainless steel, and Teflon. PVC screens are the most frequently used due to their

Corrective Action -
Ground-Water Remediation

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

low material and installation cost. Stainless steel and Teflon are recommended for casing materials in monitoring for organics. Stainless steel is about three times as costly per lineal foot as PVC. However, it is better suited for long-term applications in corrosive environments, as it can withstand redevelopment and is compatible with most petroleum products and saline waters.

Several technologies may be used to recover or control the migration of free product, including trenches and drains, recovery wells, and barriers. To select the most appropriate free product recovery technology and system design, consider several factors:

-- hydrogeologic conditions, such as the local geology (i.e., soil and/or rock characteristics);

-- the depth and potential fluctuation of the ground water;

-- the possible existence of a perched-water table or perched product conditions;

-- the depth to relatively impermeable boundaries (e.g., clay or unfractured bedrock); and

-- the direction and patterns of local ground-water flow.

Other conditions that may greatly affect the design of product recovery and control systems are the volume, extent, depth, mobility, and physical and chemical characteristics of the free product in the subsurface. All of these conditions should be evaluated prior to designing a product removal/control system, if that system is to be most effective and efficient.

The primary objectives of a product recovery operation are to control product migration, recover as much product as possible, and to complete the recovery operation in as short a time period as possible. Important parameters for the recovery operation include:

-- the rate of discharge;

-- whether water, as well as product, will be pumped;

-- the disposal techniques used to handle the product and water withdrawn;

-- the monitoring procedures for evaluating the effectiveness of the recovery operation; and

-- the criteria for determining when the recovery operation is complete.

Corrective Action -
Ground-Water Remediation

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

Generally, the greater the number of wells used in a recovery operation, the smaller the total discharge required to maintain hydraulic control of the migrating product plume. Using a trench or drain system is essentially equivalent to having placed a very large number of wells along the centerline of the trench.

A common mistake made in operating product recovery systems is "overpumping" the system. Overpumping the system creates an excessive cone-of-depression that is significantly deeper than the low seasonal water table elevation. This leaves behind product above the zone-of-saturation in an immobile pendular product state of residual saturation. In this situation, the product will not be recovered until the water table is allowed to return to more elevated levels such that the product is again mobile.

Proper monitoring procedures will be critical for determining when the product recovery operation is complete. In addition to periodically measuring fluid-level elevations within the monitoring well system, record the quantities of free product collected and on the trend of fluid-level elevations within the recovery system. If the volume of product released to the subsurface is known, it can be compared to the volume recovered to date as an indication of removal efficiency. Well-documented case histories have shown that no more than 25 to 50 percent of the total volume lost can be recovered as free product.

As the recovery operation progresses, the amount of product present in the surrounding monitoring wells should decrease gradually (if the fluid level is constant) as the product migrates slowly to the recovery well(s) or trench(es). Eventually, there should be minimal or undetectable amounts of accumulated free product within the monitoring and recovery systems. The accumulations of product in the wells can cease temporarily, but product recovery may not be complete. Recovery volumes generally decline as a result of a seasonal (or induced) rise in the water table that has trapped previously mobile product beneath the elevated water table. Product may once again appear in this supposedly "clean" system when the water-table elevation falls. Wait for several "cycles" of water table fluctuations (either natural or artificially induced) before judging whether product recovery operations are complete.

Because the amount of free product detected in the well may vary with water-table elevation, the evaluation of the clean-up objective for free product recovery should be made during the low water-table season. If only a small amount of product is detected during a period of low water-table elevation, this could indicate that the practical limits of removal have been reached.

Corrective Action -
Ground-Water Remediation

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

The following exhibit lists the relative costs, hydrogeologic constraints, recovery efficiencies, and problems associated with several recovery technologies.

Whether dissolved product contamination requires cleanup will depend on the type of contaminant(s), the contaminant concentration(s), and whether the ground-water resource is judged impaired relative to its current or projected best use. New York State applies a non-degradation standard to most of its ground-water resources, which presumes that cleanup of dissolved petroleum product in ground water attain an established level.

Once a decision has been made to clean up dissolved ground-water contamination, several factors must be evaluated:

-- The type of contaminants to be removed;

-- The background levels of these contaminants in the ground water;

-- The expected or measured concentrations of these contaminants in the ground water;

-- The clean-up targets or standards for these contaminants;

-- The water-quality parameters that may inhibit removal of the contaminants or affect the operation of the ground-water extraction and treatment system;

-- The anticipated flow rate of the ground water; and

-- The site characteristics that may affect the feasibility of using certain treatment methods.

The selected treatment technology should be capable of removing the contaminant(s) of concern to acceptable levels, cost-effective and reliable, operated in accordance with all regulatory requirements, and tailored to site conditions.

For most petroleum product spills, there are four basic technologies for removing dissolved product from ground water:

-- Air stripping;

-- Activated carbon adsorption;

-- Combined air stripping and carbon adsorption; and

-- Biological treatment.

Relative Costs, Constraints, Effectiveness, and Problems Associated with Selected Product Recovery Technologies

Technology Option	Costs* Capital	Costs* O&M	Hydrogeologic Constraints	Product Recovery Effectiveness	Potential Problems
Open Trench	Low	Low	# Excavatable materials within depth limitation # Shallow water table	# Well-suited for either high-or low-permeability materials # Ill-suited for gradient control	# Slumping of trench walls # Uncontrolled lateral spreading of product # Ineffective product pumps/skimmers due to low product thickness in trench # Large area needed for construction may conflict with existing structures
French Drain	Low-High	Med	# Excavatable materials within depth limitations # Shallow water table	# Well-suited for low-permeability materials # Can integrate otherwise isolated preferential flow zones # Well-suited for gradient control # Ill-suited for maintenance and rehabilitation	# Slumping of trench walls # Overdesign of pumping/treatment system in low-permeability materials # Clogging of drain tile and drain rock # Large area needed for construction may conflict with existing structures
Recovery Well(s)	Low-Med	Med-High	# Not limited by hardness of materials # Not limited by depth of product or water table # Limited to more permeable materials	# Well-suited for high-permeability earth materials # May not integrate preferential flow # Well-suited for gradient control # Better-suited for maintenance and rehabilitation zone	# Excessive spreading of product in a residual saturation state above water table # Clogging of screens and gravel pack # Free product zone (or water table) not coincident with well production # Overdesign of pumping/permeability treatment system in low-permeability materials
Barriers	High	Low	# Excavatable materials within depth limitation # Low-permeability material at base of barrier	# Provides additional control on fluid movement # Can isolate recovery zone from other wells and surface waters	# Rising water table on up-gradient side of barrier can lead to uncontrolled discharge without pumpage control # Leakage through walls that are incompatible with product

* Costs are relative and based on an assumption that all technologies are feasible at any particular site; relative excavation costs for drains/trenches assume no blasting of bedrock materials.

1.6.7 Ground-Water Remediation

The cleanup of ground water contaminated by a petroleum spill may involve the removal of free product and/or the treatment of dissolved product (unless, in the latter case, an alternative water supply is provided). The discovery of free product on the ground water surface should always trigger action to remove as much product as practicable.[18] Prompt removal of product is necessary because (1) free product is a source of vapors, which can migrate into subsurface structures to present a safety hazard, and (2) free product is a continuing source of dissolved contaminants in ground water. The federal UST rule defines free product as "an accumulation of regulated substance in the non-aqueous phase (i.e., liquid not dissolved in water) that is beneath the surface of the ground." In more technical terms, "free product" is any liquid product within earth materials that has a fluid pressure equal to or greater than atmospheric pressure, and that occupies most of the void space within the porous media. Free floating product can be defined as free product that is less dense than water; when it comes in contact with the ground water, it will accumulate on top of the water table.

Free product in contact with ground water will nearly always mean some amount of dissolved contamination will be present. The opposite, however, is not always true. If both free and dissolved product contamination are present, a free product recovery program can be devised to also address the dissolved contaminants. Whether dissolved contamination must be addressed (in the absence of any free production contamination problem) and the degree of cleanup required will depend on the type of contaminants, their toxicity, their concentration relative to health-based or other standards, and on whether the ground water is used as a drinking water supply or for some other beneficial use.

This section discusses the technical issues behind, and the technology options for, the cleanup of free and dissolved product contamination of ground water. Some of the terms and concepts discussed are quite technical, involving some complicated hydrogeological principles. Explaining the flow of an essentially immiscible fluid through the subsurface environment is just not very simple. We do not expect nor do spill responders necessarily need to become hydrogeologists. You do have access to such experts. We do intend, however, to increase your understanding of hydrogeology to improve your ability to consult with clean-up contractors (who can be even less knowledgeable) and to understand the data they generate. Our intent is to be as practical as possible recognizing that time and resources often don't permit extensive hydrogeological studies of spill sites.

For many of the techniques, Part 53 of Title 12 of the Codes, Rules and Regulations of the State of New York (12 NYCRR 53) requires two working days notice before any mechanical digging or drilling can occur.

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[18] *This section deals only with floating free product, that is, product with a density less than water. Petroleum products that come into contact with water will tend to result in floating free product. Products that are more dense than water will sink into the water table (there may be no floating product layer). Many kinds of organic solvents exhibit such behavior; however, the cleanup of such spills is not the responsibility of the Spill Response Program.*

1. Free Product Detection and Recovery

This subsection addresses both practical and technical issues associated with removing free floating product -- how it can be detected, how it moves through the subsurface environment, how it can be removed and recovered, and what problems need to recognized and avoided.[19]

First, it must be noted that free product removal and recovery operations have been and continue to be performed without much knowledge of the various technical terms and concepts we will explain. Many of these operations have been successful -- it cannot be said that an understanding of these topics is a prerequisite for success. Often, however, this success has been achieved largely by chance. For example, a recovery well not installed downgradient of the source because it would involve digging up a roadway or contact with overhead power lines nonetheless influences the free product plume sufficiently to draw it back to the well.

Yet, while many free product recovery operations are effective, others are not. For example, a second recovery well had to be installed because the first was ineffective, or the recovery operation could have taken less time and cost less if a recovery well that had a smaller diameter and a larger drawdown pump was used. Recovery operations also produce confusing or contradictory results, which can be difficult to interpret, such as when free product shows up in a well irregularly or no product is recovered, although nearby wells contain several inches of product. To improve your ability to recover free product from ground water, you must increase your understanding of the way free product moves in the subsurface environment.

a. Free Product Movement in the Subsurface

Under usual conditions, the void spaces in and between soil and other earth materials will contain only air and water.[20] The water content generally increases with depth below ground, reaching full saturation below the water table. After a petroleum release occurs, and with spread of the product above the water table, these voids or spaces will contain air, water, and product. In the field of fluid mechanics, the air, water, and product would be treated as three immiscible fluids separated by sharp boundaries called "interfaces." Energy is required to maintain an interface between the three fluids. This energy, which manifests itself as "interfacial tension," is the source of capillary forces that can move liquids through earth materials that are dry, or only partially saturated.

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[19] *Free product removal from structures, sewers, and underground utility conduits is discussed in Part 1, Section 6.7. The removal of product-contaminated soil is discussed in Part 1, Section 6.6.*

[20] *References to "earth materials" in this discussion include all types of soil, sediments, and rocks (geologic formations), as well as artificially-placed fill.*

More familiar examples of this phenomenon of capillary forces include the movement of water into and within a paper towel. In this case, the fluid pressure within the moving water is less than atmospheric pressure due to the interfacial tension between the liquid and the paper towel. After the paper towel is fully saturated with water, the fluid pressure equals atmospheric pressure, and drops of water can begin to flow out in response to the force of gravity.

The interplay between gravity and capillary forces is of great importance to product migration and accumulation in the subsurface environment. The same capillary forces that spread and retain the water in the paper towel will spread and retain petroleum products in natural earth materials. When the product accumulates to the point where the majority of the available void space of the earth material is filled with the product, gravity forces begin to control movement and capillary forces become inconsequential.

Because many petroleum products are less dense than water, they tend to accumulate above water-saturated zones in the subsurface. These zones occur within the "capillary fringe" above locally perched and regional water tables in earth materials. The "capillary fringe" is defined as the zone of earth material that is saturated by water pulled upward by capillary forces against gravity -- a process analogous to the way in which water is drawn upward within a soda straw sitting in a glass of water. The height to which water is drawn above the air-water interface in the glass is a measure of the capillary force. As the diameter of the straw decreases, the level to which the water rises and the capillary forces that make the water rise both increase. This is a good analogy for what happens in variably-saturated earth materials. The height to which water is drawn above the water table by capillary forces increases with decreasing grain size, that is, a narrower, more constricted void space between the grains (or within fractures, if present) of earth materials.

The accumulation of petroleum product to near-saturation levels above the pre-existing capillary fringe above the water table create a "free product plume." Free product will flow in response to gravity, and will not be influenced significantly by capillary forces. Therefore, any liquid that flows into an open borehole, well, pit, drain, or other similar structure, or from a seep or spring, provides conclusive evidence that the same liquid exists as free product in the adjoining earth materials. Conversely, earth materials above the free product plume having product at less than atmospheric pressures will not yield product to these structures.

NOTES

b. Delineating a Free Product Plume

Because the presence of free product can be determined within a variety of open structures, excavations, or borings, there are a number of options available for delineating the extent of free product in the subsurface. The selection criteria for these options may include:

- Expediency, or degree of imminent hazard, where time is of the essence;
- Feasibility, as controlled by depth to the water table and competency of the earth materials; and
- Cost, usually measured in terms of price per unit foot drilled, or time spent excavating.

Exhibit 1.6-48 summarizes several of the possible options and their use.

A tractor-mounted backhoe is most effective under imminent hazard conditions because it can be used quickly to excavate soil at key locations. The use of a backhoe is limited by depth to which soil must be excavated and the resistance of the earth materials to caving[21]. With moderately consolidated soils and a shallow water table, a backhoe pit also offers a better view of subsurface soil conditions than does a smaller-diameter soil boring. This is particularly advantageous when there is considerable diversity to the subsurface soil layers, i.e., heterogeneous earth materials. It can be a quick way, for example, to spot sand channels where product will flow laterally as "tongues" of spreading product away from the source. The existence of such channels may be missed when drilling small soil borings; knowing that they exist can help an investigator locate observation and recovery wells. Another advantage of backhoe pits is that they can be used as recovery sump pits, which provide a low-cost and expedient means for corrective action especially under emergency conditions.

Shallow boreholes can be drilled in relatively soft soil, sediment, and weathered rock materials using hand and power auger equipment. They provide a ready means for sampling soils for laboratory or field analyses. In most earth materials resistant to caving and in locations with shallow water tables, these boreholes will tend to stay open and can be used as locations from which to monitor for the presence of product and to measure water levels. They are not, however, recommended as locations for collecting product or water samples.

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[21] *Shoring is required to prevent earth from caving in if the pits dug by the backhoe exceed certain depths. This is especially true if personnel plan to enter the excavation to inspect and sample the soils and product-contaminated zones.*

Exhibit 1.6-48

Optional Methods to Delineate Extent of Free Product in the Subsurface

Method/ Technique/ Equipment	*Advantages*	*Disadvantages*
Pit or excavation dug with earth-moving equipment (e.g., backhoe)	# *Can be used quickly to excavate soil when necessary to gain a rapid evaluation of subsurface conditions* # *Offers better view of subsurface soil conditions in moderately consolidated soils and shallow water table conditions than do soil borings* # *Quick way to spot preferential flow paths* # *Excavations can be used for product recovery*	# *Limitations to depth of excavation and resistance of earth materials to caving* # *Not particularly usable in consolidated soils or when water table is at great depth*
Shallow boreholes drilled with hand or power augers	# *Can be used to assess site area relatively quickly and at reasonable cost* # *Allows for sampling of soils and soil gas*	# *Best suited to relatively soft soil, sediment, and weathered rock materials* # *Not recommended as product recovery or water sampling locations unless completed as wells* # *May miss preferential flow paths*
Monitoring wells	# *Better suited for prolonged sampling of ground water* # *More stable structure than open borehole for pumping of product or water*	# *More expensive to install* # *Requires greater accessibility to site* # *May miss preferential flow paths*
Soil vapor monitoring	# *Less intrusive than drilling of boreholes or wells* # *Can be used to quickly screen site for presence of volatiles* # *Can be used to help locate best drilling locations and, therefore, save on cost of drilling program*	# *Results subject to fluctuations in environmental conditions (e.g., temperature)* # *Requires 5 or more minutes of purge time per sampling point to establish level reading* # *Not well suited to heavy clay soils* # *Measures only volatiles* # *Is best used with follow-up confirmatory sampling*
Geophysical survey techniques (e.g., terrain conductivity)	# *Non-intrusive technique* # *Can be used to quickly screen site for presence of metallic objects and for contaminants affecting soil conductivity* # *Can be used to help locate best drilling locations and, therefore, save on cost of drilling program*	# *Subject to interference from other electromagnetic sources* # *Limited depth of penetration (function of technique used)* # *Limited sensitivity to low contaminant levels* # *Is best used with follow-up confirmatory sampling*

Wells are better suited for collecting samples for laboratory analysis and provide a more stable structure that can be pumped before sampling. Much information is now available on proper well design and sampling methods to ensure sample integrity. Concerning the choice of different well screens, several issues deserve special consideration:

- The chemical compatibility between the product and the casing and/or screen materials;
- Well screen design, especially whether the slot size in the screens is large enough to not limit product entry due to capillary effects; and
- The advisability of taking special sampling precautions when attempting to collect water beneath floating product in the well.

These issues are discussed in a later subsection.

Under the right site conditions, soil vapor monitoring and shallow geophysical surveys can delineate the product plume and also help document plume movement and removal. Both vapor monitoring and geophysical technologies are evolving rapidly; several devices and techniques have been proven under certain field conditions. These non-intrusive techniques hold promise for reducing the number of boreholes and wells that must be drilled during site investigations to delineate free product plumes. This can save time otherwise spent waiting for drilling rigs to arrive and can help focus well drilling activity at the site. See Section 3.1 for a discussion of these techniques.

The ideal site conditions for these techniques include a shallow water table, subdued topography, non-heterogeneous earth materials, and an absence of man-made structures or buried utilities that can either provide preferential paths for product and vapors, or introduce geophysical anomalies. Even when these conditions exist, the soil vapor and geophysical data should not be used alone to justify a removal decision, but should be used to supplement more direct observations of free product in borings, wells, and other structures. Although each vapor monitoring or geophysical technique has limited capabilities, several complementary techniques can be used with direct observations to provide a more reliable picture of subsurface conditions.

The locations, number, and depths of the excavations, borings, and wells are important considerations in product-plume delineation. The locations will often be constrained by existing structures (buildings, streets, utilities, other tanks, etc.), the presence of overhead power lines, and property boundaries. Within these constraints, a strategy for plume delineation that consists of starting near the source and then moving away from the source in equal increments of distance is reasonable. In some cases, this strategy can also be applied near and around locations where product has already been discovered (e.g., sump pumps in basements). The number and depths of excavations, borings, or wells that will be necessary depend on the magnitude of the release, the depth to water, the absorptive capacity of the unsaturated zone, and the degree of diversity in the earth materials. Larger-sized free product plumes tend to result from conditions involving a very large release, a shallow water table, and thin permeable soils over fractured bedrock. Smaller-sized free product plumes tend to be associated with smaller releases, finer-grained soils, and a deep water table.

The placement and design of product-detection wells should take into account the contrast in permeability between the excavation zone and the surrounding earth materials and the diversity of these materials. A high contrast in permeability may form a natural barrier in and around the excavation zone, especially if the surrounding media has a low permeability. Under these conditions, product releases will tend to be confined to the excavation zone, thereby allowing for easy detection and recovery within this zone. A large contrast in permeability between backfill and native materials and an elevated water table inside the excavation zone provide for optimum conditions for product detection. If the permeability contrast is small, or if permeabilities of the native soils are large, free product may go undetected as it migrates through the excavation zone into the surrounding materials, bypassing a well in the excavation zone.

Placement of product-detection wells outside the excavation zone entails more uncertainty than placement inside because natural earth materials are more likely to be more diverse. The result is the creation of small-product tongues or fingers migrating along the more permeable channels that may not be easily detected unless the detection wells are intersecting these more permeable zones. The excavation backfill, on the other hand, should offer a more homogeneous engineered material with little or no preferential migration pathways.

If earth materials were homogeneous, the number of detection wells outside the excavation zone could be limited to two -- one upgradient and the other downgradient. Also, the number of borings/wells needed to define a product plume after a release would be small because the plumes shape would be regular and easily predicted with simple equations. Unfortunately, this is rarely the case, and there are no simple rules to guide selection of the optimum number of detection wells at any particular site. A few guidelines can be offered to help form a decision that is based usually on professional judgment and physical constraints.

The first general guideline is that as the diversity in subsurface earth materials increases, the number of wells should increase to lessen the risk of missing a major preferential flow path. The number and positioning of detection wells could be related to the size of the subsurface features having one or more preferred flow paths. In general, large geologic features, such as an extensive layer of coarse-grained fill, a wide channel sand deposit, or a major fault/fracture zone would vary internally, but could be covered by one well or relatively few. At the other extreme, small features such as widely spaced fractures, randomly located rootholes, and buried utility lines in low-permeability materials are small targets and may not be intersected even when many wells are installed.

When significant uncertainty exists over the lateral or vertical extent of a preferential flow path, rely on other indirect methods to identify and map the preferred flow path(s) using the standard tools of field geology, interpretation of the origin (and, therefore, the likely geometry) of strata within a formation, and controlled field pumping tests.[22]

The thickness and elevation of the free product and water surface should be observed at all monitored locations.[23] These levels will change with time in response to various environmental changes such as water-table fluctuation, precipitation events, and fluctuations in atmospheric pressure. There are a number of commercially available methods and equipment for measuring water and product level measurements that are relatively inexpensive and do not require much time to use. Product thickness can be measured, for example, with product/water-sensitive pastes on a steel tape, transparent bailers, and various electronic devices. The first of these methods is probably the most accurate, but may take the most time to do accurately. We suggest using more than one method at the same location.

Unfortunately, a precise measurement of product inside the well cannot easily be related to product thickness outside the well. As shown in Exhibit 1.6-49, product thickness inside the well is generally significantly larger than the thickness of free product outside. This fact is critical because ignoring it can lead to overestimates of recoverable free product. Some have suggested that a ratio of 4:1 for the thickness of product inside the wells and the sum of thickness of free product and the product capillary fringe outside the well can be assumed. Laboratory experiments have shown that this ratio can range from a theoretical value of 1:1 to values of 4:1 or greater.

As shown in Exhibit 1.6-49, the thickness of product is divided into two components: the actual thickness outside the well and a "critical thickness" component inside the well. This critical thickness component is controlled by the height of the water capillary fringe and the density of the free product relative to water. Unfortunately, these various components cannot be determined through field measurements. Moreover, the product capillary fringe component is affected by the particular product, grain size, thickness of pre-existing product and other variables, and can vary among well locations. The result is that the critical thickness can take on a unique value for each well.

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[22] *This latter method involves removing water at a constant rate at one well location and observing the hydraulic response (or lack thereof) at the other well locations. A rapid and significant hydraulic response in another well can be taken as good evidence that both wells are tapping the same preferred flow path.*

[23] *When a floating product layer is present, measurements of depth to the water table need to be corrected to account for the density difference of the product relative to water. For example, gasoline has a density approximately 75 percent that of water. Therefore, if one foot of floating gasoline is present, 0.75 feet should be added to the elevation of the water/gasoline interface to obtain the true water table elevation.*

NOTES

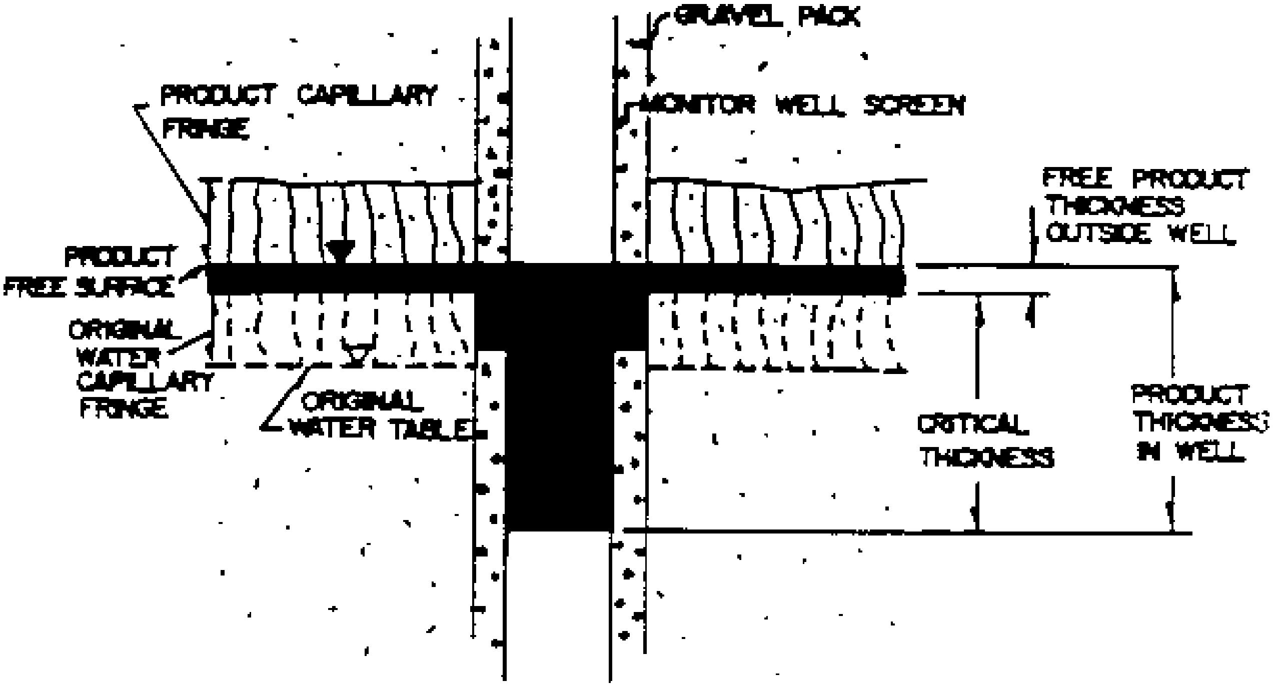
Exhibit 1.6-50 shows conceptually how the critical thickness increases with increasing product density and decreasing grain size (or fracture size, if these are present). No scale is shown for the vertical axis, but it may range as high as about 20 feet for fine-grained materials and high-density products even when the free product thickness outside the well is negligible. For products such as gasoline, the critical thickness may only be a fraction of one inch in very coarse-grained materials.

The thickness of free product will vary spatially and temporally. At any particular well location, a certain sequence of observations would be expected as the product accumulates in earth materials adjacent to the well. This sequence is illustrated with Exhibit 1.6-51 in which the arrows indicate generalized unsaturated flow of product through the earth materials. It is assumed in this description that the earth material is homogeneous, that the water table does not fluctuate during the sequences, and that the well is located in close proximity to the source of product.

Frame (a) in Exhibit 1.6-51 shows the product moving through the unsaturated zone with no accumulation in the well. As product saturation increases, the pressure within the product approaches atmospheric pressure. The capillary fringe is depressed due to product contact with the water and the change in displacement pressure (frame b). Further increases in product saturation can form a discontinuous free-product zone and allow for a small amount of free product to enter the well (frame c). As a continuous free-product zone develops, the critical product thickness is reached inside the well at the lower limit of the free-product zone (frame d). As more free product accumulates, the water-capillary fringe is compressed under the weight of free product, but the critical product thickness remains constant (frame e). Product accumulation outside the well reaches a maximum constant thickness and the capillary fringe is completely depressed in frame (f).

Exhibit 1.6-49

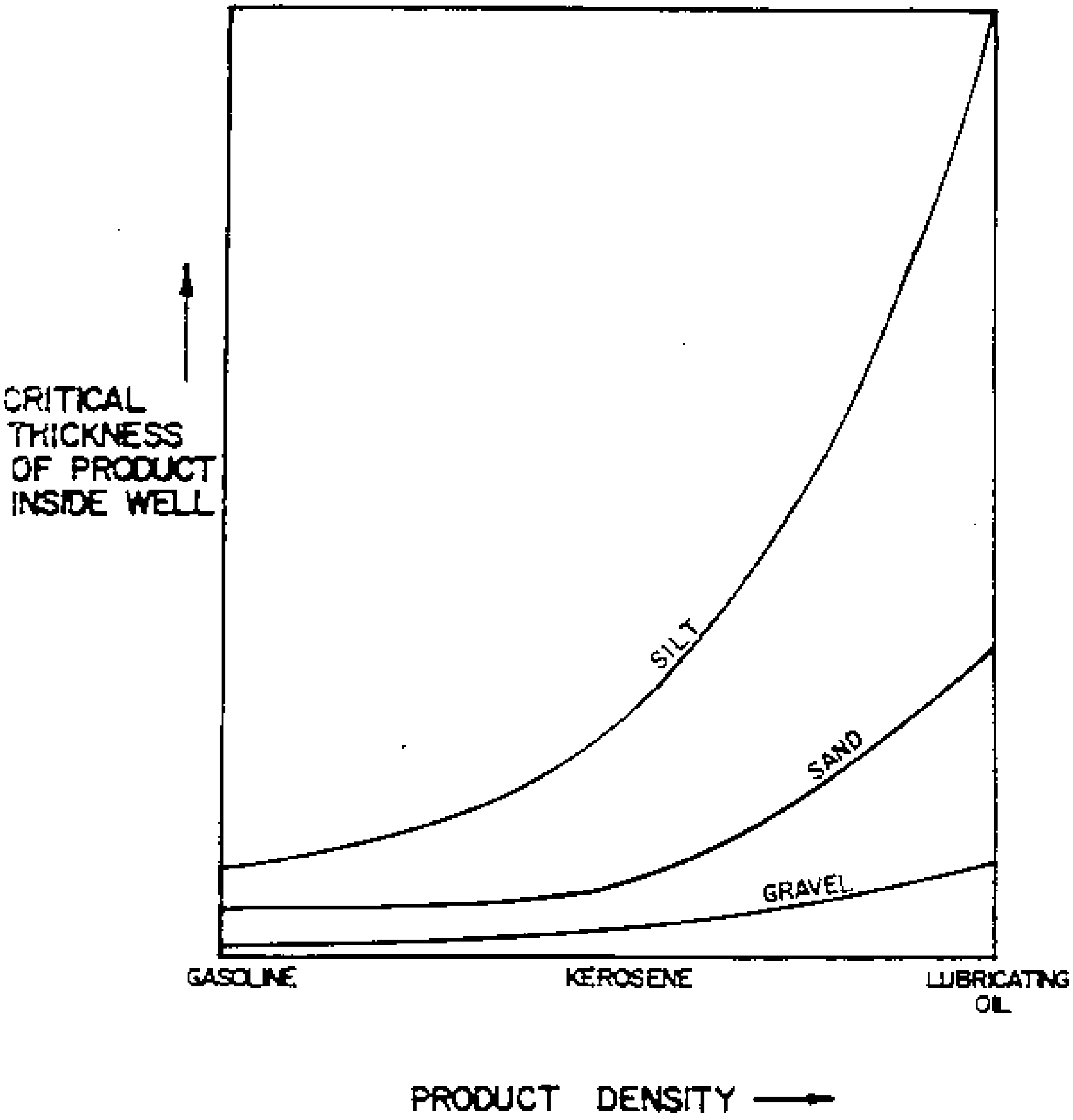
Vertical Section Through a Monitor Well, Gravel Pack, and Earth Materials Showing Thickness of Free Floating Product at Static Equilibrium Conditions



Source: [2].

Exhibit 1.6-50

General Relationship Among Critical Product Thickness in a Monitor Well, Product Density, and Earth Materials of Different Grain Sizes



Source: 2

Exhibit 1.6-51 can also represent simultaneous observations at six separate wells located at different distances along a spreading product plume at the same point in time. The well in frame (a) of the figure would be near the edge of a product tongue. The well in frame (f) would be located near the source of product at the center of the product core. All the remaining wells would represent intermediate locations. This illustrates the importance of well location for estimating the amount of free product in the formation based upon the detected levels of product in the well.[24]

While the product accumulates inside and outside the well, the growing column of product inside the well straddles the water table in a consistent way. As shown in frames (c) through (f) of Exhibit 1.6-51, the ratio of the column height above the water table to the column depth below the water table remains constant. This is the result of a balancing of forces inside and outside the well in the form of fluid pressures associated with two fluids of different densities.

As indicated in frame (c) of Exhibit 1.6-51, the presence of a small amount of product is not necessarily evidence of a significant free-product layer outside the well. Frame (c) shows that free product can enter from a discontinuous free-product zone. Bailing the product from the well and observing its recovery can help to determine if a product layer is discontinuous. If a product immediately flows into the well, the situations depicted in frames (d) and (e) may be present. Differentiating between these two conditions requires more information about the product and characteristics of the earth material.

c. Detection Well Materials and Screen Design

A primary consideration in monitoring well design is chemical reactivity of the casing and screen to different petroleum products. Exhibit 1.6-52 lists the results of chemical reactivity tests for different casing materials in contact with petroleum product.

The most widely used monitor-well screen materials include polyvinylchloride (PVC), stainless steel, and Teflon. PVC screens are the most frequently used due to their low material and installation cost. While chemical incompatibility between PVC and petroleum products is possible, such that dissolution of the screens and casing occurs, such problems do not appear to be common under field conditions.

Stainless steel and Teflon are recommended for casing materials in monitoring for organics. Stainless steel is about three times

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[24] *If the well was drilled after the product was released and migrated, it's only possible to speculate how product levels in the well represent thickness of product in the surrounding media. Your recourse then is to determine product saturations by sampling the soils during drilling.*

Exhibit 1.6-51

Sequence of the Accumulation of Product in a Well and Adjacent Earth Materials Above a Water-Saturated Zone

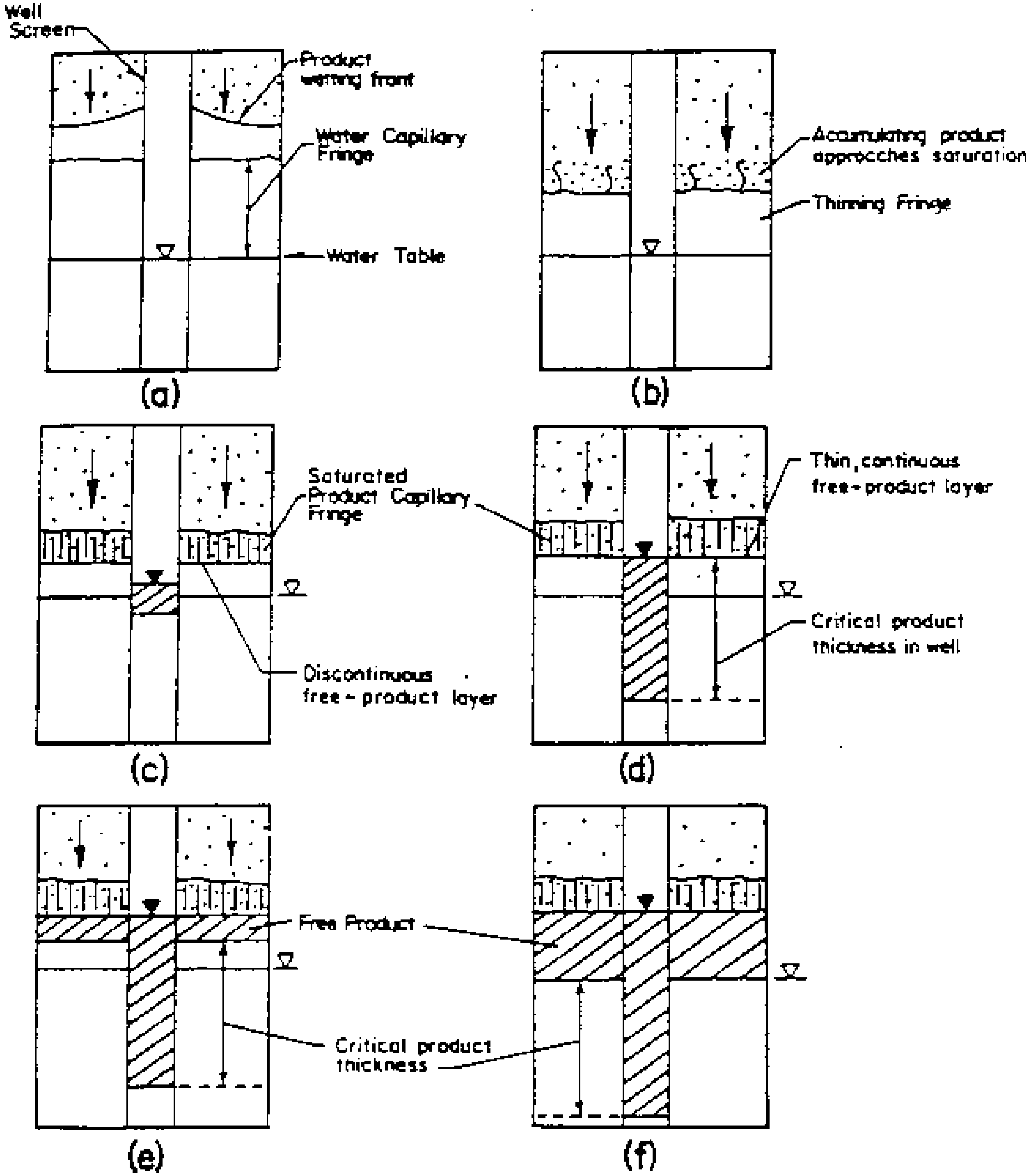


Exhibit 1.6-52

Chemical Compatibility between Selected Well Casing and Screen Materials to Petroleum Product

	Stainless Steel			Cyoloc			Polyvinylchloride		
	316	304	440	Bronze	(ABS)	Kynar	Polypropylene	PVC	Teflon
Benzene	B	B	B	A	D	A	C	C	A
Hexane	A	A	A	A	-	A	B	B	A
Toluene	A	A	A	A	D	A	C	D	A
Xylene	A	A	A	A	D	A	C	D	A
Naptha	A	A	A	B	D	A	C	C	A
Gasoline	A	A	A	A	D	A	C	C	A
Turpentine	A	A	B	C	-	A	B	B	A
Kerosene	A	A	A	A	D	A	A	A	A
Jet Fuel	A	A	A	A	-	A	A	A	A
Diesel Fuel	A	A	-	A	-	A	A	A	A
Fuel Oils	A	A	A	A	D	A	C	A	A
Lube Oil	A	A	A	A	-	A	A	B	A
Creosols	A	A	-	C	D	A	D	D	-
Asphalt	A	B	B	A	-	A	B	A	A

A = No Effect B = Minor Effect C = Moderate Effect D = Severe Effect

Source: Cole Parmer (1987)

as costly per lineal foot as PVC. However, it is better suited for long-term applications in corrosive environments, as it can withstand redevelopment (high-pressure flushing) and is compatible with most petroleum products and saline waters. Because Teflon is the most expensive and most resistant, its use as well screen material is generally limited to severe conditions.

In water supply wells, the well screen and gravel pack are designed for maximum yield. Maximum yield (and minimum drawdown) can be obtained by optimizing the screen length, diameter, and slot size. The slot size must be small enough to retain the gravel pack and yet large enough to obtain the desired yield. The gravel pack should be designed to have a larger hydraulic conductivity than the producing formation. By increasing the conductivity near the well, fluid yield can be optimized by minimizing drawdown in the well. These general design principles can be used in product recovery wells that produce both water and product.

Unlike water supply wells, however, monitoring wells are often installed in formations having wider ranges of particle-size distribution and hydraulic conductivities. In this case, the open area of the screen should generally approximate the natural-formation porosity. Although monitoring wells are not designed for high yields, maximizing flow rate will minimize sampling time. Ideally, slot size should widen inward so that finer formation materials are pulled through the screen during development. The screen slot size must retain a high percentage of the gravel pack and formation materials or effective development can be difficult.

Monitoring well screen lengths are typically much shorter than screens for high-yield water wells and commonly range from five to ten feet in length. Long-term ground-water fluctuations will have to be considered in determining screen length for product detection.

2. Factors Influencing Free Product Recovery

Several technologies may be used to recover or control the migration of free product, including trenches and drains, recovery wells, and barriers. The primary objective in any product-recovery operation, however, whatever the technology selected, is to control the migration of product and to collect as much of the released product as possible.

To select the most appropriate free product recovery technology and system design, consider several factors:

- hydrogeologic conditions, such as the local geology (i.e., soil and/or rock characteristics);
- the depth and potential fluctuation of the ground water;
- the possible existence of a perched-water table or perched product conditions;

- the depth to relatively impermeable boundaries (e.g., clay or unfractured bedrock); and
- the direction and patterns of local ground-water flow.

Other conditions that may greatly affect the design of product recovery and control systems are the volume, extent, depth, mobility, and physical and chemical characteristics of the free product in the subsurface. All of these conditions should be evaluated prior to designing a product removal/control system, if that system is to be most effective and efficient. It is especially important to consider hydrogeologic conditions in order to minimize the potential for contaminating previously "clean" aquifer zones.

The following subsections address many of the factors or issues that should be considered in order to properly design a free product removal system.

a. Earth Materials and Their Influence on Product Recovery

Local geologic conditions greatly affect the design of free product recovery systems, including the soil and/or bedrock characteristics and their stratigraphy (i.e., the sequence and thickness of distinct geologic units or layers). Of primary importance is to identify the stratigraphic unit(s) that contain(s) the free product. The choice of a recovery system design is strongly dependent on whether the product resides in, for example, bedrock, sandy soil, or clay. Also important is the thickness of the unit that contains the free product and what types of other units lie beneath that unit.

To recover free product from fractured bedrock units generally requires the use of recovery well systems. Product recovery from fractured bedrock is particularly difficult because of the complex flow paths (i.e., the product develops a preferential flow along secondary fractures). In addition, rapid and large water table fluctuations and the presence of solution cavities in soluble rocks such as limestone can often hinder product recovery operations.

The success of a product recovery operation in bedrock will depend on whether the pumping well intersects with interconnected product-bearing fractures. Because fracture locations are usually unknown (except for mapped fault zones) the use of several small-capacity wells is often a workable strategy. The interconnectiveness of these fractures and their depth will affect the optimum pumping level for a well intersecting these fractures and for maximizing the rate and efficiency of product recovery. Field pumping tests can be performed to determine the optimum pumping level.

The sequence, thickness, and texture or grain size distribution of the earth materials above, within, and below the free product plume are important because these characteristics control water and product movement. When the product is found in earth materials of low permeability, it is generally more appropriate to use a trench or drain recovery system, particularly if the water table and the product are at a shallow depth below the ground surface. Product within soils that are more permeable (e.g., sandy soils) or product that is at a great depth may be recovered more easily using pumping wells.

b. Ground-Water Conditions and Their Influence on Product Recovery

Consider local and regional ground-water conditions in the design and operation of a product recovery system. These conditions include the depth to the water table and its seasonal fluctuations, ground-water flow patterns and discharge points, and water-table response to pumping.

The depth to the water table may dictate the type of product recovery technology to be used. If the water table is relatively deep (i.e., greater than 15 feet), a pumping-well system may be the most practical recovery method. The efficacy of constructing trenches below these depths will depend on the strength of the materials to resist caving, and this technique is generally more expensive. Trenches, drains, and well systems may all be used with a shallow water table. The recovery technology selected for shallow water-table conditions is likely to hinge on the permeability of the earth materials. Trenches or drains are likely to be more efficient methods for product recovery in settings where fluids are transmitted slowly through the earth materials.

Another water-table condition that can influence the design and operation of a product recovery system is the existence of a perched water table -- a saturated region that is underlain by an unsaturated zone. This type of situation presents limitations for the depth of a well or trench (so that product is not provided a route to uncontaminated materials) and for the minimum obtainable fluid level within the recovery system.

When the slope of the water table directs product plume movement, recovery wells or drains should generally be placed hydraulically downgradient from the product source to capture and control the product plume with the minimum required fluid withdrawal rate. The area exhibiting the greatest product layer thickness in the detection wells is not always the optimal location for siting the recovery system. However, placing wells or drains only at the downgradient end and near the edge of the mapped plume can result in inefficient product recovery. Although this strategy halts any further free product migration of the leading plume edge, it leaves significant amounts of product in the central and uppermost parts of the plume. This is especially true if the water-table gradient is low and the product has a small density-to-viscosity ratio (see subsection 3.3 below).

Seasonal fluctuations in the water table must be considered in the design of recovery systems as well as in locating appropriate monitoring points. The depth of well screens and gravel-filled trenches must be sufficiently shallow to allow product to be collected during anticipated high water-table conditions and deep enough to capture product during periods of low water-table conditions.

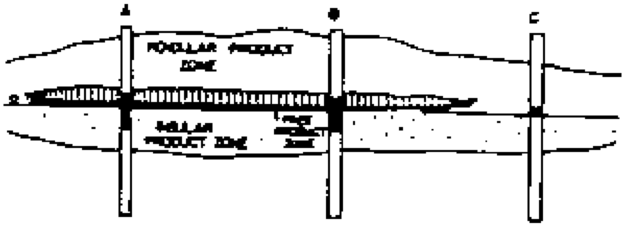
Large seasonal water-table fluctuations may adversely affect product recovery efficiency, particularly during high water-table periods. Prolonged recovery operations or an increased pumping rate may be required during these periods to effectively complete product recovery. Product thickness within the wells will also vary with water-table fluctuations. Generally, a lowering of the water table results in greater collection of product in a well. As the water table rises, product can be left beneath the water table (i.e., in an insular saturation state) and is not available to flow to the open well). The result is a decrease in product thickness within the well. Only abnormally steep hydraulic gradients will mobilize this trapped product.

These observations tend to suggest that the optimal depth for a well or gravel-filled trench (i.e., to maximize the quantity of product collected) is at, or slightly below, the seasonally low level of the water table. These observations also suggest that, without the addition of a surfactant, artificial recharge of "flushing" of the product left in soils above the water table may complicate the recovery operation. Although some product trapped above the water table may be leached down to the water table, the induced rise in the water table may isolate product below the elevated water table. A hypothetical free product removal scenario, shown in Exhibit 1.6-53, illustrates how these mechanisms affect monitoring of product thickness and recovery efficiency.

Drawdown of the water table due to pumping activities during recovery at the well, or at other wells in the area, must also be anticipated in selecting the proper depth for a recovery system. The response of an aquifer to pumping stress is controlled by the permeability of the aquifer and its thickness. The permeability characteristic will determine the discharge rate required to maintain a specific fluid level (or drawdown) within a pumping well or trench. For a given fluid withdrawal rate, the decline of water levels in high permeability materials will be less than that in low permeability materials. A higher rate of discharge is necessary, therefore, to decrease the water level in a high permeability aquifer to the same degree as in an aquifer of lower permeability.

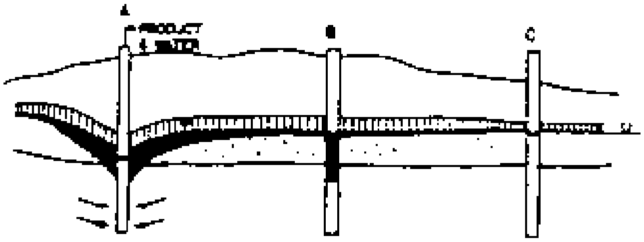
Exhibit 1.6-53

Movement of Free Product Plume in Response to Recovery Showing Changes in Water-Table Fluctuations



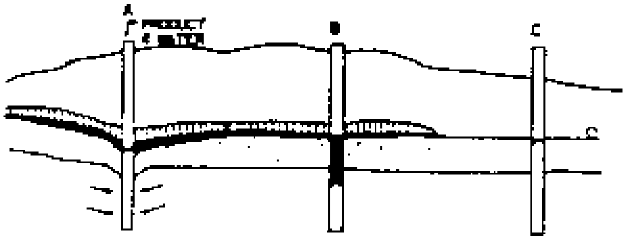
INITIAL CONDITIONS

Free product plume bounded above and below by pendular and insular product zones, latter zone caused by previous fluctuation of water table, trapping the insular product below the water table.



AFTER STARTING PUMPING/RECOVERY

Insular zone thins and transfers product to free product zone as free surface falls. Product thickness increases in Well B and appears in Well C; products thins in Well A due to recovery.

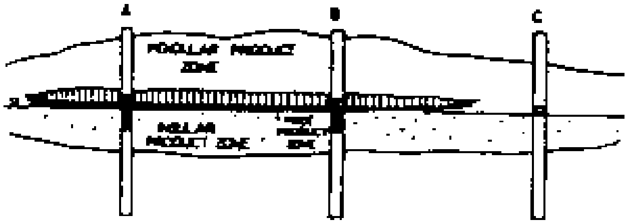


AFTER ONE MONTH

Drawdown of the water levels has stabilized. Insular zone continues to thin and pendular zone thickens. Free product plume shrinks in area, but thickness in wells is unchanged.

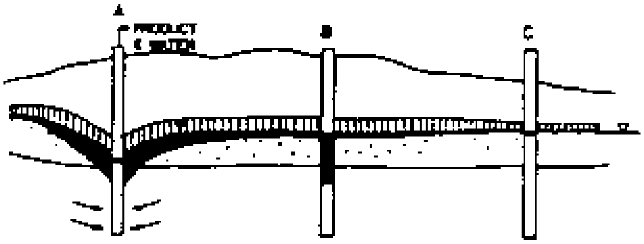
Exhibit 1.6-53

Movement of Free Product Plume in Response to Recovery Showing Changes in Water-Table Fluctuations (continued)



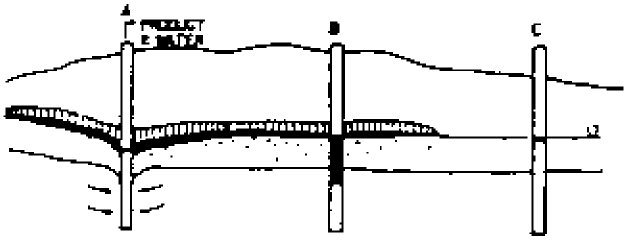
AFTER TWO MONTHS

Water table elevation declines during dry season. Insular zone is virtually gone; pendular zone has increased to maximum thickness. Little or no change at Wells A and B; free product in Well C transferred back into pendular zone. Size of free product plume is stable as product is transferred from insular zone to free zone to recovery well.



AFTER ABOUT SIX MONTHS

Rising water table associated with wet (recharge) season elevates free product zone, which thins as product is transferred back into insular zone. A secondary insular zone at lower bulk concentration results from inundation of pendular zone by rising water table.



AFTER NINE MONTHS

Recovery shut down at 7 months due to low product recovery; as water table declines during next dry season, free product again appears at Wells A and B as insular product is released from underwater storage. Recovery then must resume.

The selection of pumping equipment should be based upon estimated pumping levels from in-the-field pumping tests at one or more existing wells in the vicinity. Water pumps that operate on a suction lift principle will be limited to pumping water from about 20 to 22 feet below the pump (usually at ground surface, but sometimes below grade). For more on pumping equipment, see 4.4, below.

c. Product Characteristics and Their Influence on Product Recovery

Physical and chemical properties of the petroleum product can affect recovery operations and design and the rate and extent of product recovery. Consider these characteristics in selecting the types of materials used to construct the recovery system (including any pumps) and in operating these systems to minimize hazardous conditions. For example, many organic compounds will chemically degrade plastics that may be used in the construction of artificial liners and in various pump components, including electrical connections.

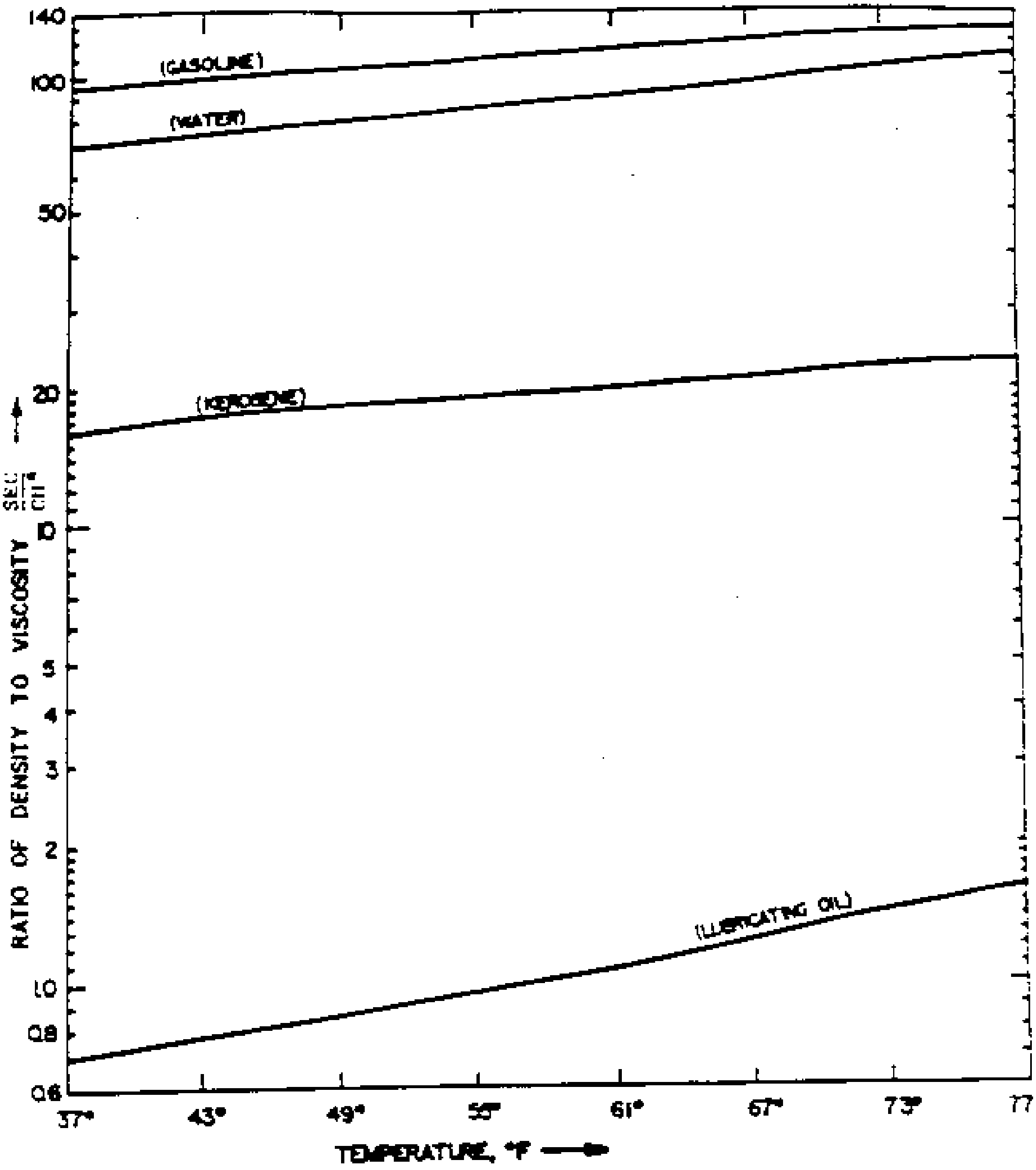
The density and viscosity of the product will have a bearing upon how easily the product will move through earth material (i.e., the hydraulic conductivity). The hydraulic conductivity is directly proportional to the density of the product fluid and inversely proportional to product viscosity. Therefore, a product with a high density-to-viscosity ratio will generally pass more quickly through a given earth material than a product fluid with a smaller density-to-viscosity ratio. Although product density is not sensitive to temperature, product viscosity can decrease significantly with increasing temperatures. The density-to-viscosity ratios for water and three different types of petroleum products over a temperature range representative of ground water in the continental United States are presented in Exhibit 1.6-54. This shows that, with other factors being equal, free gasoline can move at the same rates as the water; however, kerosene and lubricating oils will move at slower rates relative to water.

Another factor affecting mobility of the product through earth materials when more than one fluid is present is the "wettability" of the soil or rock to the product. Air, water, and product may be present within void spaces in the earth materials. Most soil/rock materials are preferentially wet to water rather than to a petroleum product. The result is that the effective hydraulic conductivity for the product is less than what would be predicted. With the free product moving less easily than water through the subsurface, the potential rate of product recovery is affected.

Several maintenance operations for the recovery system are related to product characteristics. Because hydrocarbon products in the subsurface are often a good source of food for microorganisms, bacterial growth is often accelerated in

Exhibit 1.6-54

Density-to-Viscosity Ratios for Water and Hydrocarbon Products as a Function of Temperature



hydrocarbon recovery wells to the point that well screens can become clogged and flow to the well is restricted. In these situations, the well screens may have to be sterilized periodically with a disinfectant, such as chlorine, and/or scraped to physically remove the bacterial growth. Another concern is the adequate maintenance of sensing probes used to control the pumping operations. These probes can become coated, particularly when used in the presence of "heavy" petroleum products.[25]

Another important consideration in product recovery is the potential hazards associated with the handling of flammable fluids and explosive vapors. These hazards are a function of specific chemical and physical properties of the product, including its flammability and volatility. These properties addressed in subsection 5, below, should be considered in devising product-handling and safety procedures for the product recovery system.

3. Operational Considerations for Recovery Strategies

The primary objectives of a product recovery operation are to control product migration, recover as much product as possible, and to complete the recovery operation in as short a time period as possible. Important parameters for the recovery operation include:

- the rate of discharge;
- whether water, as well as product, will be pumped;
- the disposal techniques used to handle the product and water withdrawn;
- the monitoring procedures for evaluating the effectiveness of the recovery operation; and
- the criteria for determining when the recovery operation is complete. Several of these operational issues are discussed below.

a. Water Table Drawdown for Free Product Recovery

Decreasing the water table level locally (i.e., creating a cone-of-depression) by pumping the recovery system induces product to flow towards the system. As discussed in previous subsections, there exists an optimum water-table evaluation for maximizing the collection and recovery of product within a well or trench. In bedrock systems, this water level usually corresponds to the location of the intersection of the well opening and product-bearing fractures. In unconsolidated soils,

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[25] *Though unrelated to product characteristics, a high iron and/or manganese content in the water can also cause operational problems. High iron and/or manganese concentrations will facilitate the growth of bacteria on the packing material causing decreased mass transfer rates and greater drops in gas pressure in an air stripper (i.e., decreased removal efficiency). The presence of toluene in the influent is also thought to be a contributing factor. Pretreatment of the influent water to precipitate out these metals, or chlorination to control bacterial growth, can help to minimize this problem.*

this optimum level is generally at, or slightly below, the seasonal low water-table elevation.

The rate of fluid withdrawal required to maintain the optimum water table within the system depends on the permeability of the earth materials from which the product is being pumped. In this respect, the quantity and spatial distribution of the wells in the pumping-well system or the size and location of a trench or drain system should be considered. Generally, the greater the number of wells used in a recovery operation, the smaller the total discharge required to maintain hydraulic control of the migrating product plume. Using a trench or drain system is essentially equivalent to having placed a very large number of wells along the centerline of the trench. If a trench or several wells is (are) used to spread the pumping stress over a given area, a smaller amount of fluid withdrawn will maintain hydraulic control of the moving free product plume.

A common mistake made in operating product recovery systems is "overpumping" the system. Overpumping the system creates an excessive cone-of-depression that is significantly deeper than the low seasonal water table elevation. This leaves behind product above the zone-of-saturation in an immobile pendular product state of residual saturation. In this situation, the product will not be recovered until the water table is allowed to return to more elevated levels such that the product is again mobile. However, a significant quantity of product can also be trapped below the water table when the water table rises during a wet season (i.e., in the insular product state). It will be difficult to recover this product until the water table declines in the next dry season. Meanwhile, the probability that petroleum constituents will dissolve in the ground water will be increased. Overpumping the system will also produce significant quantities of fluid that must be handled, treated, and/or disposed.

b. Monitoring Free Product Recovery

To monitor the effectiveness of the recovery system usually requires the use of monitoring wells located around the area of the recovery system. Measure the water-table elevations and product thicknesses within each of these wells periodically for the duration of the recovery operation. These measurements may be made using a clear, calibrated, interface bailer, measuring tapes coated with product/water-sensitive pastes, and/or with electronic oil/water interface probes. After these measurements are made within each monitoring well, remove the product from the wells so that a new product layer may collect within the well. Monitor the pumping levels and product thicknesses within the recovery well(s) or trench(es) on a regular basis. All of this information can be used to check whether hydraulic control of the subsurface product is being maintained, and to monitor the extent and movement of subsurface product (i.e., areal product thicknesses).

As was shown in Exhibit 1.6-53, monitoring wells within the cone-of-depression created by the recovery operation will often exhibit an increase in product thickness as drawdown proceeds in response to pumping. In the short term, only a minor part of this increase in apparent thickness is attributable to the lateral movement of free product along the gradients caused by pumping the wells. Rather, the observed increase in product thickness may be more the result of the local transfer of product in the insular zone to the free product zone.

Proper monitoring procedures will be critical for determining when the product recovery operation is complete. In addition to periodically measuring fluid-level elevations within the monitoring well system as described above, record the quantities of free product collected and on the trend of fluid-level elevations within the recovery system. If the volume of product released to the subsurface is known, it can be compared to the volume recovered to date as an indication of removal efficiency. Well-documented case histories have shown that no more than 25 to 50 percent of the total volume lost can be recovered as free product.

As the recovery operation progresses, the amount of product present in the surrounding monitoring wells should decrease gradually (if the fluid level is constant) as the product migrates slowly to the recovery well(s) or trench(es). Eventually, there should be minimal or undetectable amounts of accumulated free product within the monitoring and recovery systems. The accumulations of product in the wells can cease temporarily, but product recovery may not be complete. Recovery volumes generally decline as a result of a seasonal (or induced) rise in the water table that has trapped previously mobile product beneath the elevated water table. Product may once again appear in this supposedly "clean" system when the water-table elevation falls. Wait for several "cycles" of water table fluctuations (either natural or artificially induced) before judging whether product recovery operations are complete.

Because the amount of free product detected in the well may vary with water-table elevation, the evaluation of the clean-up objective for free product recovery should be made during the low water-table season. If only a small amount of product is detected during a period of low water-table elevation, this could indicate that the practical limits of removal have been reached. Two reasons can be cited for stopping recovery operations when very small amounts of product are observed during low water-table conditions:

- Drawing the water table down further to induce flow to the recovery well will transfer product to the immobile pendular state; and

- As the water table rises from the low elevation, it will transfer product into the immobile insular state.

In other words, it may not be practical to continue recovery operations when product thicknesses reach a small fraction of an inch inside monitor and recovery wells.

NOTES

Another issue to consider is the measurable detection level for free product. Residual product on the well casing can be mistaken for free product. The level of free-product removal is dependent on the product removal system. The practical limit of product recovery must be set in accordance with the site conditions and available technologies. When the product has a color contrast with the water in the well, one can detect thicknesses down to the level of a sheen and droplets on the sides of a transparent bailer. These levels are below what some pumping or skimming equipment can achieve.

Generally, recovery structures should be located within the product plume between the product source and any potential exposure point. If the exposure point is a well, obtain information about how the well is constructed, which aquifer it is tapping, the normal operating mode (timing and discharge rates), hydraulic test data, and static- and pumping-water levels at the well. These types of data can be used to determine whether the well is actually downgradient and is, in fact, a potential exposure point. If the well is a potential exposure point, the combined hydraulic effect of pumpage at the supply well and the recovery structures needs to be analyzed to ensure that recovery pumpage will contain the free and dissolved product plumes. The dissolved product plume will usually be a greater concern because it is more mobile.

Exhibit 1.6-55 lists the essential characteristics of three basic recovery strategies and two supplemental strategies. Low cyclic pumping can be used for less permeable materials where increased pumping would not increase relative flow rates. Little or no pumping of water from an open-line trench or well(s) located on the downgradient side of a product plume would characterize this approach. Recovery cycles may be controlled by low-permeable materials, or water-level changes that are, in turn, controlled by pumping, tidal, or seasonal changes. The greatest period of product yield would be during the decline in water-table elevation.

Moderate continuous pumping is popular due to its moderate cost and adaptability to a variety of hydrogeologic settings. Such systems may be designed with one centrally located single or dual-pumping recovery well or trench, or several, if permeabilities are large enough to ensure a steady yield of

Exhibit 1.6-55

Product Removal Strategies Defined in Terms of Energy Level, Recovery Cycles, and Duration to Meet Objectives

Removal Strategy	*Energy Level*	*Recovery Cycles*	*Costs*		*Durations*
			Capital	*O&M*	
1. Low Cyclic Pumping	*Low*	*Seasonal* *Pumping-induced* *Atmospheric* *Tidal*	*Low*	*Low*	*Long-Term*
2. Moderate Pumping	*Moderate*	*Season (Recharge/ Discharge)*	*Moderate*	*Moderate High*	*Mid-Term*
3. Accelerated Pumping	*High*	*One (?)*	*High*	*High*	*Short-Term*
4. Recirculation Enhanced[a]	*High*	*One to seasonal*	*Moderate*	*Moderate*	*Short to Mid-Term*
5. Vacuum Enhanced[b]	*High*	*One to seasonal*	*Moderate*	*Moderate*	*Short to Mid-Term*

[a] *Recirculation of water phase can be used with Option 2 or 3 to hasten recovery.*

[b] *Pulling a vacuum at the recovery well can be used with Option 2 or 3 to hasten recovery.*

water from the recovery well. Seasonal patterns of recharge and discharge may limit product recovery to periods of low or decreasing water-table elevations. Initial recovered volumes may be high and may increase with drainage and accumulation of free product in the insular state.

Accelerated pumping is limited to a subsurface environment characterized by moderate to highly permeable materials with few heterogeneities. This method overrides the effects of natural or pumping-induced water table fluctuations. The water-table elevation is held constant by the pumping rate, which will have to be increased during the recharge season. For an older release, the water table can be drawn down to the base of the insular zone, thereby mobilizing the trapped insular product. This method must be designed, however, in such a way as to not extend the contamination zone much below the insular zone by overpumping. Pumping stresses must be spread evenly with several wells in order to lower the water table uniformly over the contaminated area. When removing new plumes that have no insular product zone, pump stresses could be smaller so that the water table can be lowered to just below the free-product zone.

Recirculation-enhanced recovery can be used to supplement seasonal or accelerated pumping strategies, but is only feasible in moderate to high-permeability subsurface environments. The recirculation of produced water can elevate the water-table thereby increasing product-recovery rates. However, a disadvantage of this approach is that the rise in the water table due to recharge may transfer some product into the insular zone thereby immobilizing it beneath the rising water table.

A relatively new method that can be used to increase the rate of product recovery, without drawing the pumping level below the optimum elevation, is vacuum-enhanced recovery. This technology may also be used when product must be recovered from low-permeability earth materials (where well yields are limited), and in situations where the thickness of the saturated zone is small and the depth to which the water can be drawn down is limited. The use of vacuum-enhanced recovery techniques is limited to conditions where the recovery system will be surrounded by earth materials of sufficiently low permeability to air (e.g., saturated media or clays) so that an efficient vacuum can be induced.

Vapor recovery can be added to the product recovery well that is actively producing water and product. This vacuum enhancement technique can be used to supplement continuous, seasonal, and accelerated pumping schemes. It will not enlarge the area of hydraulic influence, but it will speed up the rate of product removal. It is also particularly effective for thin product and ground-water lenses perched on low-permeability materials above the water table.

4. Selecting Free Product Recovery Technology

Sometimes there is little time to select a free product recovery system, especially when a flammable or combustible condition exists due to the entry of free product into subsurface structures. Alternatively, a fairly large subsurface spill may have occurred very near a domestic or public water supply well. These situations may require the immediate installation of a recovery system. Such a system can be constructed from some commonly available materials. For example, a length of culvert pipe, with some touched or cut slots and wrapped with ordinary screening, can be installed in a hole dug with a backhoe (see Exhibit 1.6-56). Water and product that collects in this "well" can be pumped out using a vacuum truck as a temporary measure, or by installing a single submersible or suction pump.

Once the geologic and hydrologic conditions in the vicinity of the petroleum product release and the extent of free product in the subsurface have been determined, the optimum product recovery technology can be selected.

Some constraints for technology selection have been discussed in previous subsections, and some of the common problems in the design, installation, and operation of recovery systems are summarized in Exhibit 1.6-57. Exhibit 1.6-58 lists the relative costs, hydrogeologic constraints, recovery efficiencies, and problems associated with several recovery technologies. The discussion of technology selection criteria presented in this subsection is restricted to the three basic technologies available for free product recovery: pumping wells,trenches or drains, and barriers. Operational design parameters such as pumping methods and rates are also discussed. We note, however, that barriers are not actually a type of recovery method, but are instead used to control product migration as well as to enhance recovery operations (i.e., limit the quantities of fluid discharge required to recover product). In this discussion, we limit our discussion of the use of barriers for free product recovery to their use in conjunction with other recovery technologies.

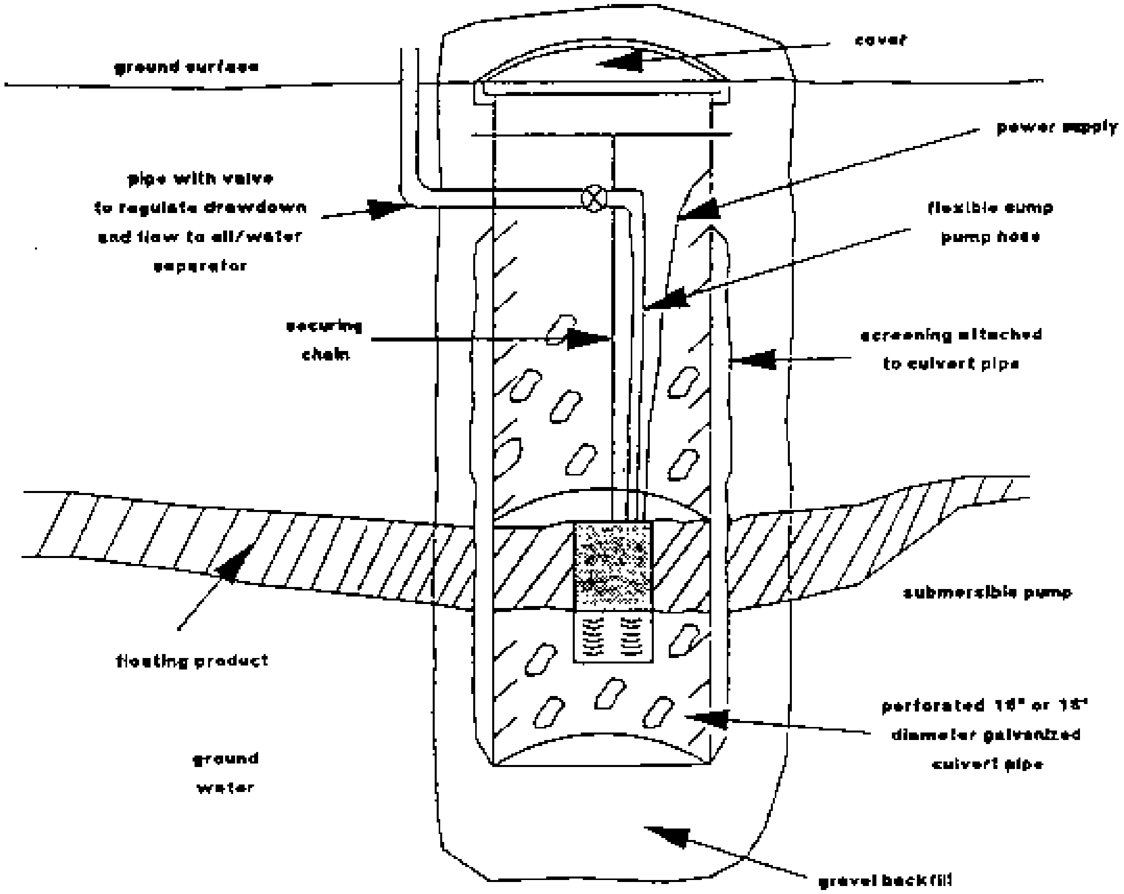
a. Recovery (Pumping) Wells

Unlike with other technologies, the use of recovery wells is not constrained by the depth to the water table and the resistance of the earth materials to caving. Recovery well systems are most suitable for product recovery from fractured bedrock and earth materials with relatively high permeabilities. Pumping wells are also generally the most economic technology for product recovery from depths exceeding 15 feet (approximately) below ground surface.

If a single well, and the cone of influence it produces, is not sufficient to contain the spread of the plume, multiple wells may be drilled. The wells should be positioned with respect to the plume and in proximity to one another in such a way that the

Exhibit 1.6-56

Emergency Recovery Well From At-Hand Materials



Adapted from: American Petroleum Institute. Underground Spill Cleanup Manual. June 1980.

Exhibit 1.6-57

Common Problems in the Design, Installation, and Operation of Free Product Recovery Systems

Problem	Effect
Insufficient characterization of local hydrogeology.	Ineffective systems may be installed or more expense incurred.
Contaminated area not well defined.	Contamination is left behind.
Inadequate testing.	Inadequate characterization of product.
Dual-pump systems installed in areas of low hydraulic conductivity.	Water production rates are low and recovery efficiency is low.
Fouling of recovery system.	Reduced recovery efficiency.
Inadequate O&M program.	System fails or recovery efficiency is low, although design and construction is correct.
Overpumping.	May spread product vertically to a greater degree and trap product below the water table.

Exhibit 1.6-58

Relative Costs, Constraints, Effectiveness, and Problems Associated with Selected Product Recovery Technologies

Technology Option	Costs*		Hydrogeologic Constraints	Product Recovery Effectiveness	Potential Problems
	Capital	O&M			
Open Trench	Low	Low	# Excavatable materials within depth limitation # Shallow water table	# Well-suited for either high-or low-permeability materials # Ill-suited for gradient control	# Slumping of trench walls # Uncontrolled lateral spreading of product # Ineffective product pumps/skimmers due to low product thickness in trench # Large area needed for construction may conflict with existing structures
French Drain	Low-High	Med	# Excavatable materials within depth limitations # Shallow water table	# Well-suited for low-permeability materials # Can integrate otherwise isolated preferential flow zones # Well-suited for gradient control # Ill-suited for maintenance and rehabilitation	# Slumping of trench walls # Overdesign of pumping/treatment system in low-permeability materials # Clogging of drain tile and drain rock # Large area needed for construction may conflict with existing structures
Recovery Well(s)	Low-Med	Med-High	# Not limited by hardness of materials # Not limited by depth of product or water table # Limited to more permeable materials	# Well-suited for high-permeability earth materials # May not integrate preferential flow # Well-suited for gradient control # Better-suited for maintenance and rehabilitation zone	# Excessive spreading of product in a residual saturation state above water table # Clogging of screens and gravel pack # Free product zone (or water table) not coincident with well production # Overdesign of pumping/permeability treatment system in low-permeability materials
Barriers	High	Low	# Excavatable materials within depth limitation # Low-permeability material at base of barrier	# Provides additional control on fluid movement # Can isolate recovery zone from other wells and surface waters	# Rising water table on up-gradient side of barrier can lead to uncontrolled discharge without pumpage control # Leakage through walls that are incompatible with product

* Costs are relative and based on an assumption that all technologies are feasible at any particular site; relative excavation costs for drains/trenches assume no blasting of bedrock materials.

cones of influence overlap and thereby prevent the migration of the plume beyond the influence of the wells (see Exhibit 1.6-59).

Recovery well systems can either be single-pump or dual pump systems. In a single pump system, both gasoline and water are recovered through a single pipeline to above-ground storage tanks or oil-water separators.

Use of a single-pump system will tend to increase the degree of product/water contact and will generate an emulsified fluid as a discharge. This complicates the above-ground product-water separation process. For these reasons, single-pump systems are most commonly employed for smaller spills when gasoline-water recovery rates are relatively low (e.g., less than 500 gallons/hour).

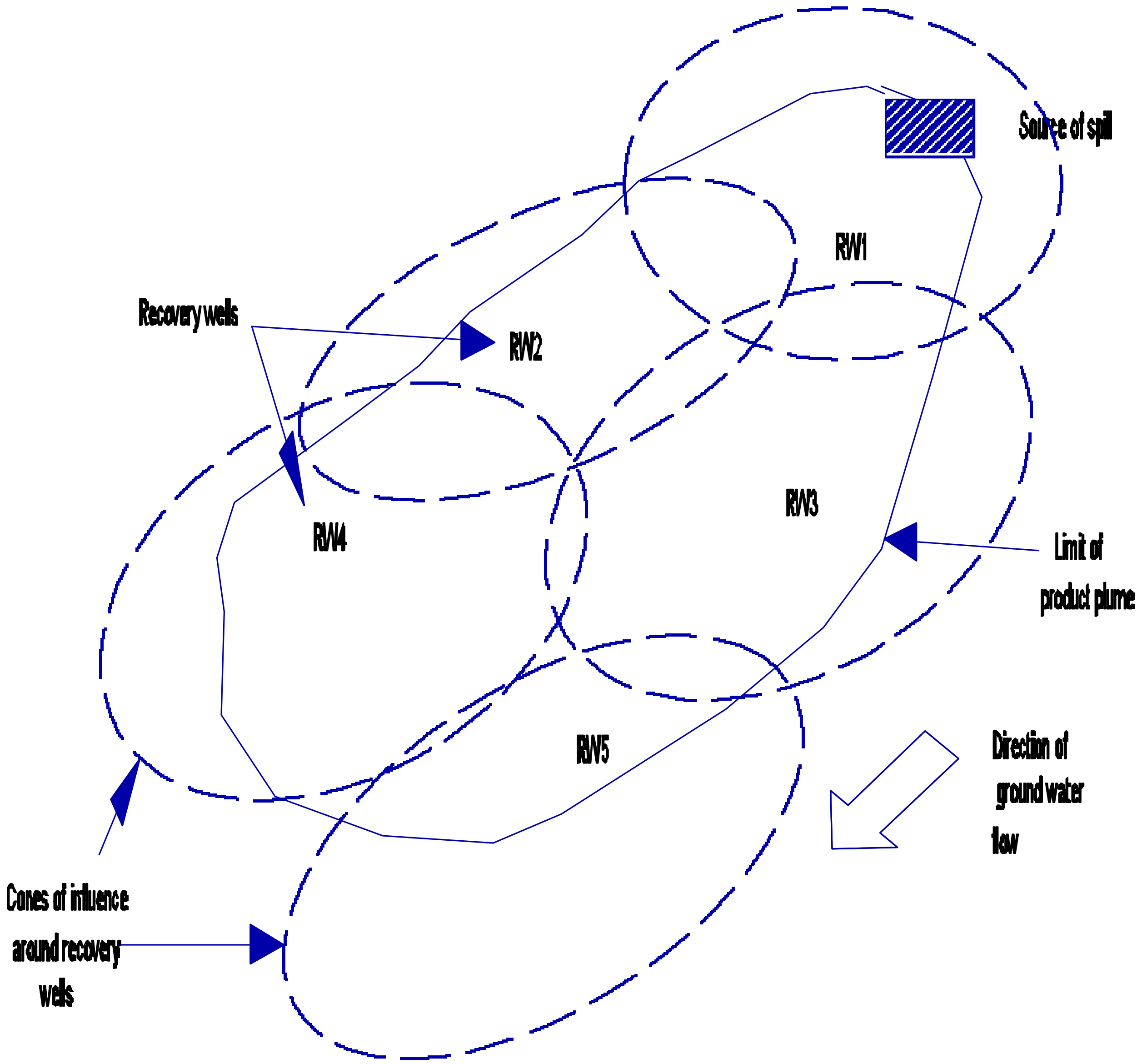
Single-pump systems are, however, simpler to operate and require less complicated control systems than dual-pump systems. In a dual-pump recovery system, one pump is used for removing free floating product and another pump is placed beneath the free product layer to create a cone-of-depression on the water table. Dual-pump systems also require a larger-diameter well (or two smaller-diameter wells located close together) to accommodate both of the pumps. A dual-pump system does have the advantage of minimizing the contact between product and water, which can mean less opportunity for petroleum constituents to dissolve into the water and, therefore, less need to treat the discharge.

Two pump systems are frequently employed in cases where large amounts of gasoline must be recovered. The water pump, or "water table depression pump," should maintain a constant, or nearly constant cone of influence to prevent the migration of the contaminant plume, If a constant depression is not maintained, and the water table and the contaminant plume are allowed to rise, gasoline droplets may adhere to soil particles. As the water table continues to rise, the density differential between the gasoline and water is not great enough to overcome the adhesive forces of the soil particles, and the gasoline droplets remain in the soil. If the cone of depression is allowed to recover completely, the contaminant plume will once again be free to migrate along the natural groundwater gradient.

Dual-pump systems operate in the following way. Initially, the water table depression pump probe is set at an arbitrary depth in the well to which the water table will be depressed. The water table depression pump is then lowered approximately ten feet beyond the probe and pumping is begun. As water is pumped out of the well, the water table and floating gasoline plume are drawn down until the water pump probe detects the presence of hydrocarbons in the plume. When this occurs, the water pump will cease pumping and the depressed water table will rise slightly. However, as soon as the water pump probe detects water again, the water pump will resume pumping and

Exhibit 1.6-59

Overlapping Recovery Well Cones of Influence for Recovery of Product Plume



Adapted from: American Petroleum Institute. Underground Spill Cleanup Manual. June 1980.

the depression will be maintained. Once a constant depression has been established, the product pump is deployed. The product pump's inlet and probe are set at the same depth, a few inches above the water table depression pump probe. As the water table depression pump draws in ground water, gasoline will accumulate in the depression until it is detected by the product pump probe. The product pump probe has the same function as the water table depression pump probe: it activates the product pump when gasoline is present and it turns the pump off when the plume reaches an arbitrary minimum thickness or when the water able fluctuates and water is detected.

Another advantage in using the dual pump over a single-pump system is that the pumps function automatically. Barring equipment failures, water table depression and product removal are constant and the system can operate for weeks or months with only periodic inspections. Once the plume has been drawn down to within a fraction of an inch, the product pump probe will no longer be able to detect the remaining gasoline. At this point, the product pump is turned off, and the water depression pump is elevated to the depression and allowed to pump a mixture of water and the remaining gasoline out of the well.

The disadvantages associated with recovery well systems include the possibility of creating routes for product to migrate to previously uncontaminated zones and increasing the quantity of total fluids that must be withdrawn to collect the product effectively. Exercise care when drilling recovery wells to prevent uncontrolled movement of free product to an uncontaminated zone. For example, if the free product is located in a shallow unconfined aquifer underlain by a confining layer and a confined aquifer, construct and operate the recovery well system to avoid providing a route for product to reach the uncontaminated lower aquifer unit. The potential for downward movement of free product is greatest when the confining layer serves as a perching horizon and the lower aquifer is unconfined. This means that the well should not penetrate the confining (or perching) unit. This is also a consideration when the water table is located in an aquifer consisting of unconsolidated materials overlying a fractured bedrock unit. As noted earlier, product recovery from bedrock is difficult; well penetration (and, therefore, the pumping level) should be limited to the unit(s) above the fractured bedrock unit.

The water withdrawn from a recovery well will usually have to be treated before it can be discharged to surface waters or to a sewer. Effluent from a recovery well must contain less than 50 parts per billion (ppb) of principal organic contaminants (which include benzene, toluene, or xylene) and less than 100 ppb total principal organic and unspecified organic contaminants to be discharged to surface waters in New York State. A large discharge flow can incur significant fees for sewer use. This assumes that there are options for disposing of the discharge. This is not always the case (e.g., there are no receiving waters located nearby or the sewage treatment plant cannot handle the flow volume or the high petroleum constituent concentrations), and the lack of disposal options can represent a significant constraint on free product recovery operations. For more discussion on spill residual disposal options, see Subsection 7 following and Part 2, Section 3.

b. Barriers

The problem of withdrawing large amounts of fluids can be minimized through the use of several wells and/or through the use of a barrier system. Barrier systems used in combination with pumping wells can be effective in enhancing product recovery when the product is confined to depths less than 50 feet in highly permeable, unconsolidated, aquifers. These barriers may be constructed of bentonite, epoxy resins, rubber, lime, or fly ash). The use of a low-permeability barrier is limited to unconsolidated formations with a relatively shallow water table underlain by a low-permeability material such as clay or bedrock. The installation of a barrier within fractured bedrock systems or down to depths greater than 35 feet is very costly. Ideally, the barrier should extend continuously through a shallow aquifer to a virtually impermeable earth material. The continuity of the barrier and the chemical compatibility of the barrier materials with the released product in contact with the wall are critical factors in controlling product migration.

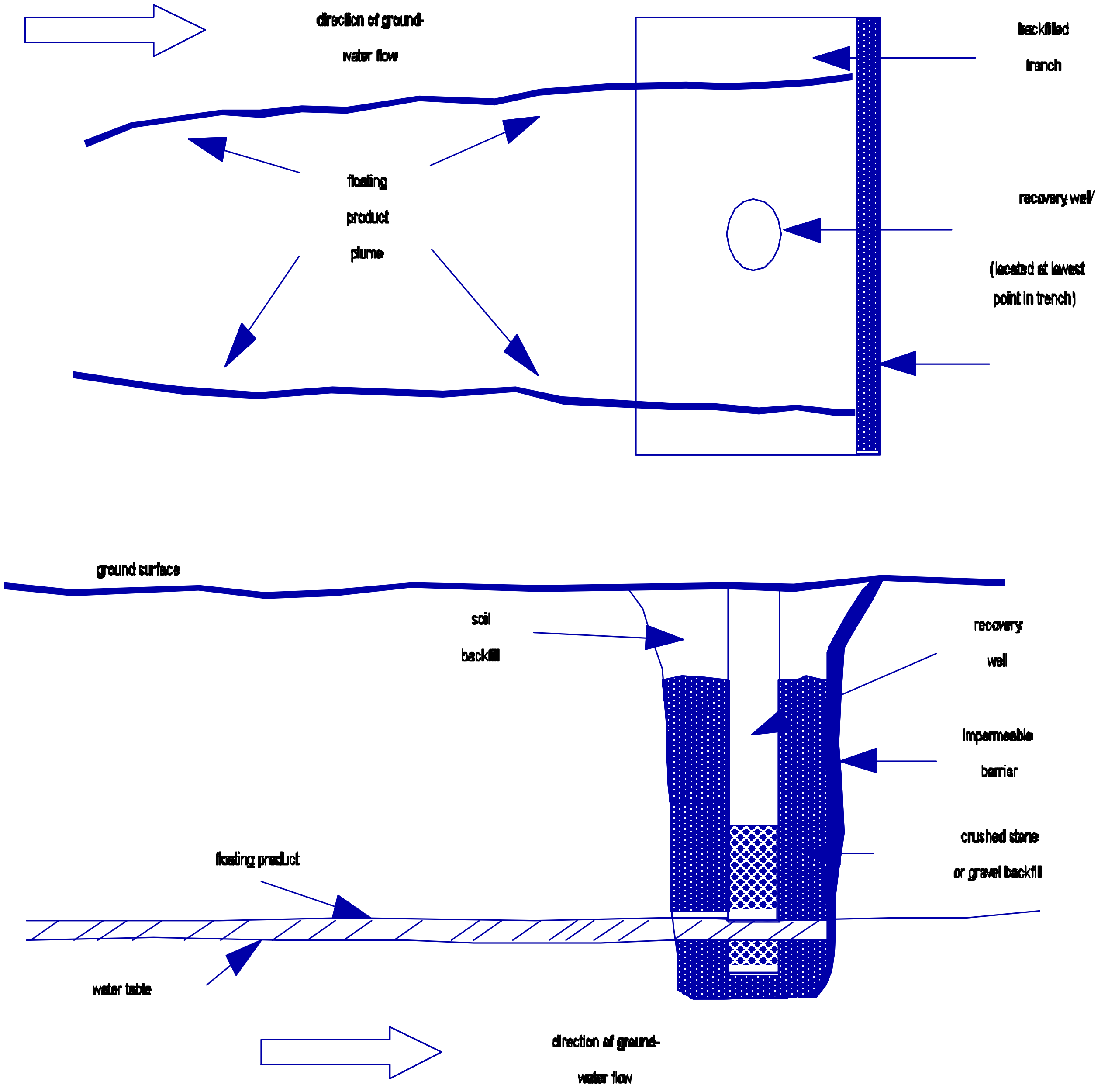
The use of barriers will, however, minimize the rate of fluid withdrawal required to recover the product, and therefore, the associated costs of handling and disposing of the removed product and fluid. However, to determine if the additional expense is warranted, compare the costs of barrier installation to the costs of handling and disposing of the additional fluid that would be withdrawn if a barrier was not used.

c. Trenches or Drains

Product can be recovered effectively from shallow depths (less than 10 to 15 feet below ground surface, approximately) and in low-permeability earth materials through the use of a trench or drain system. A trench or drain can be an effective means of intersecting the preferential flow paths, especially where the water table is shallow. Using recovery drains also has the added advantage of hydraulically influencing a large area with a minimum of fluid withdrawal.

Once the direction of ground-water flow and the plume size have been established, a trench is dug across the entire front and in the path of the migrating plume. If free product has entered a structure, the trench should be constructed as close as possible to that structure. The trench is dug deep enough (usually one to four feet below the water table surface) so that ground-water "ponds" and the floating gasoline is exposed (see Exhibit 1.6-60). Trenches can be constructed to allow gravity to direct the captured product to a recovery point. To increase

Exhibit 1.6-60
Trench System for Recovery of Free Floating Product



Adapted from:American Petroleum Institute. Underground Spill Cleanup Manual. June 1980.

the flow of gasoline to the trench, water in the trench below the plume may be pumped out. In doing so, a hydraulic gradient is created, more ground water is pulled toward the trench, and the aquifer is induced to redirect the movement of the floating gasoline. To ensure that the intercepted gasoline does not escape back into the soil, an impermeable membrane can be

placed on the downgradient wall of the trench. The membrane can serve as a baffle, preventing the flow of gasoline but allowing water to pass under it. If the trench is used as a withdrawal point to draw down the water table, the barrier must be deep enough to intercept product at the lowest water level.

Hydrogeologic settings where the use of trenches or drains might be favorable for free product recovery include the following:

- Where product flows preferentially through randomly occurring and situated zones of earth materials such as channel sands;
- Areas of near-surface water tables and relatively low hydraulic conductivity, where it would be necessary to install a large number of closely spaced wells to effect product recovery; and
- Areas where the aquifer width is thin, such as along streams that are dry during parts of the year, making recovery wells ineffective.

Gasoline ponding in the trench can be removed with a variety of portable, free-floating contaminant recovery devices. Some equipment, such as filter separators, work automatically, separating and removing gasoline from water only when gasoline is present in the trench. Other devices include hand-held skimmers, which are no more than sophisticated floating vacuum cleaners with hydrocarbon sensors. When both gasoline and water are pumped out of the trench, standard gasoline recovery equipment can be used. Large, non-portable oil/water separation tanks, like those used for industrial applications and at gasoline and oil refineries, are commonly used.

d. Recovery System Equipment

There are over 25 companies that design and sell equipment and provide technical advice concerning gasoline recovery from subsurface spills. Many of the companies deal strictly in above-ground oil/water separators such as those typically used at petroleum refineries, wastewater treatment plants, and in industry. Others have created their own lines of in-situ oil/water separation devices, which are specifically designed to separate oil and water underground and recover free product. Commercially available site-specific, state-of-the-art equipment (e.g., narrow pumps for small wells, filter separators which operate passively, and special dual-pump systems for deep wells) can recover free product from a variety of subsurface conditions. The following is a discussion of the different types of oil/water separation equipment that are available for recovering gasoline that has reached the ground-water table. The equipment is evaluated for cost, efficiency, limitations, and ease of operation.

Skimmers. Skimmers are designed to float and automatically pump gasoline off the water surface. They can be used in recovery trenches and wells, but are used more often in trenches. They are used in settings where: (1) water-table depression is not critical for product recovery; (2) earth materials of low hydraulic conductivity are present; (3) periodic water-table fluctuations may interfere with the operation of a stationary pump; (4) free product is confined to the backfill in an otherwise dry excavation; and (5) the fluid-handling, treatment, and disposal capabilities are limited.

The most effective skimmers are equipped with conductivity sensors that detect gasoline. When gasoline-free water is present, an electric signal is passed between the sensors and the gasoline pump does not operate. But when gasoline, which is non-conductive, is present, the electric signal is interrupted and the pump is automatically turned on. Skimmers are deployed easily and may be set temporarily or permanently, or operated manually attached to a handle.[26]

One advantage of skimmers is that they can pass grit and debris up to a quarter of an inch, thus allowing unfiltered gasoline to be recovered. Skimmers can recover water-free gasoline to the limit of their sensor's ability to distinguish gasoline from water (usually a fraction of an inch) and then, with the gasoline sensor turned off, skimmers suck up the remaining gasoline mixed with small amounts of water from the water surface. The average capital cost of a skimmer is $6,000 to $7,000, but with a water-table depression pump to increase the flow of gasoline to the trench, a skimming system could cost as much as $12,000 to $13,000.

Filter Separators for Trenches. Like skimmers, filter separators float on the trench water surface and pump gasoline automatically and continuously. Unlike skimmers, which operate with the aid of conductivity sensors, filter separators have special filters that pass gasoline and other petroleum products but "repel" water. The filter separator floats so that the "oil-loving" - "water-hating" membrane is positioned at the gasoline-water interface. Both gasoline and water come in contact with the filter, but only the gasoline passes through. Once a small amount of gasoline (approximately one liter) has accumulated within the separator's compartment, a floating arm is

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[26] *For skimmer equipment of this last type, the product recovery pump is not attached to the floating section. It is set on the ground above the trench and connected to the skimmer with a synthetic hose to remove the gasoline.*

raised, which activates the gasoline recovery pump and the compartment is drained automatically.

The product recovery pump is located above the trench and is connected to the filter separator with a gasoline-resistant hose. Filter separators of this kind are portable, easily installed, and can reduce a gasoline plume in a trench down to a sheen. They generally cost about the same as skimmers ($6,000 to $7,000), but if a water-table depression pump is required, the filter separator system could cost as much as $12,000 to $13,000.

Filter Separators for Shallow Wells. The same type of filter separators used in trenches may be used in shallow wells.[27] The design and operation of the unit is the same, but there are more variables to consider when using filter separators in shallow wells.

First, filter separators can only be deployed to a maximum depth of 20 feet. Although the separation unit floats on the water-table surface, its surface-mounted pump is physically unable to provide more than 20 feet of lift. In order to achieve greater pumping heads, submersible pumps would be needed. However, submersible pumps cannot be attached to filter separators because the heavy pump would cause the floating separator to sink. Therefore, filter separators can only be used with surface-mounted pumps in shallow wells.

A second consideration when using a filter separator is maintaining a steady flow of gasoline to the separator. Filter separators are more difficult to deploy in shallow wells than in trenches because a water-table depression pump is required. A cone of influence must be maintained to trap floating gasoline and, as a result, the system is more expensive and more time and supervision is required to provide and maintain conditions amenable to the filter separator.

The gasoline removal efficiencies of filter separators in shallow wells are comparable to those of filter separators in trenches. In both cases, the filter separator is capable of reducing the plume to a sheen on the water table.

Surface-Mounted Pumps. Surface-mounted pumps that rely on atmospheric pressure to provide suction lift have a theoretical maximum lifting capacity of 34 feet. Beyond 34 feet, the pull of gravity exerted on the rising liquid column exceeds the capacity of the pump to provide lift. In practice, the 34-foot theoretical maximum is never achieved--20 feet is the highest lift that can be expected with surface-mounted pumps. As a result, in wells where pumping water depths exceed 20 feet, submersible pumps must be used. Submersible pumps do not rely on suction lift; rather, they are submerged in the well, and, with the aid of

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[27] *Shallow wells are defined as wells in which the depth from the top of the well to the liquid surface is less than 20 feet.*

pistons, rotors, vertical turbines, jets or compressed air, push the liquid out of the well.

Surface-mounted pumps have three distinct advantages over submersible pumps: (1) because surface-mounted pumps are above ground they are easier to operate and maintain than submersible pumps; (2) because submersible pumps must be made explosion-proof due to the presence of volatile hydrocarbons and must be able to pump in corrosive environments, they are generally more expensive than comparable surface-mounted pumps; and (3) because submersible pumps are exposed to gasoline, oil, and other corrosive chemicals, they generally have a shorter lift span than surface-mounted pumps (on the average surface-mounted pumps last two to three years longer than submersible pumps).

A wide variety of pumps are available for use in a product recovery system. Commercially available pumps vary widely in operation mode, maintenance, and cost. Most recovery systems remove water and product; the water pump will need to provide sufficient energy to provide the necessary drawdown in the water table so that product flows to the recovery system. In general, the considerations in choosing a pump are sufficient horsepower, correct diameter, intake elevation, minimum intake submergence depth, and location of control valves and switches. Pumps should be ordered with the maximum gallons per minute flow rates anticipated for water-table drawdown and the desired product recovery rate.

Dual-pump systems come in a range of sizes and pumping capacities to meet a variety of well diameter, depth, and pumping conditions. Water pumps come in sizes as small as 3-1/2 inches in diameter for 4-inch wells and as large as 10-inches in diameter for 12-inch and 24-inch wells. Water pumps range in pumping capability from 1/3 horsepower (HP) units, which have a maximum pumping rate of 15 gallons per minute (gpm) and a maximum total displacement head (tdh) of 130 feet, to 7-1/2 HP units, which have a maximum pumping rate of 230 to 500 gpm and a maximum tdh of 300 feet. Product recovery pumps come in similar sizes and pumping capacities. Generally, pump capacity is less of a concern when selecting a product pump due to the low pumpage volume and rate usually encountered in recovery systems. The mobility of the product pump will need to be considered, however, especially in areas that have relatively large water-table fluctuations. A preferentially wet-to-product pump intake may eliminate or reduce water intake and water emulsification with product. Consideration should also be given to the operation and maintenance costs of the recovery equipment. The use of less sophisticated equipment has the advantage of being more reliable and may yield more product in the long run by being operable for greater durations of time.

Dual-pump systems for deep wells operate in the same manner as dual-pump systems for shallow wells with certain exceptions. Two pumps are still used and are set some distance apart (usually 10-15 feet) to ensure adequate drawdown and to ensure that the water-table depression pump will not come in contact with free gasoline. The main difference is that in deep wells greater pumping distances and more extreme pumping conditions are found, requiring that more powerful, durable pumps be used. Water-table depression pumps and product recovery pumps are available that can pump from depths as great as 500 feet and can withstand the corrosive effects of pumping salt water and water laden with sediments. Two- and three-horsepower water-table depression pumps commonly used in deep-well recovery operations are rated to pump a maximum of 60 gpm and have a maximum dynamic head of 150 feet.

Only submersible pumps can be used in deep wells. Moreover, due to their greater pumping capabilities and other features that allow submersible pumps to operate under adverse deep-well conditions (i.e., explosion-proof drive units, water-tight seals, electric cables), deep-well submersible pumps are more expensive than surface-mounted pumps. On the average, submersible pumps are 10-15 percent more costly than surface-mounted pumps. And, as a result, dual-pump systems for deep wells are more expensive than dual-pump systems for shallow wells.

Single-Unit Pumps. In wells that have limited access, such as small-diameter wells, single-unit dual-pump systems can be used. Single-unit systems, equipped with both water-table depression and product recovery pumps, are available to fit wells as small as four inches in diameter. The product recovery pump is attached above the water-table depression pump, and both pumps are equipped with sensors that control pumping in the same manner as described above for dual-pump systems. Single-unit dual pumps for narrow wells have low pumping rates (i.e., 0.6 gpm at a maximum depth of 160 feet), but they sell for as little as $12,000. Exhibits 1.6-61 through 1.6-65 summarize additional information on some of the commercially available pumps and recovery equipment.

Oil/Water Separators. Oil/water separators are little more than large tanks into which a hydrocarbon/water mixture is pumped. Their main function is to allow the flow of the incoming water and to allow gravity separation of less dense hydrocarbon emulsions. Separators have been successfully used at many sites, but seem to be most effective when the hydrocarbon spill is relatively small -- large spills cause water disposal complications -- and the rate of water flow through the separator is slow enough to allow for complete separation.

Exhibit 1.6-61

Trench Product Recovery Equipment
Pumping Rate/Dynamic Head

Product*	Dynamic Head (ft.)	Pumping Rates (gal/min)	Degree of Oil/Water Sep.	Advantages	Disadvantages	Cost
"Scavenger"	<20	<5	Sheen	Light-weight, portable, passive filter separator (does not require energy inputs for separation), automatic product pump	Maximum pumping distance = 20'	$6,850.00
"Tramp Oil Scavenger"	<70	<2.8	99%+	Pumps product automatically, can be operated manually or deployed permanently, pneumatic pump can pump thick oil and grit		$6,850.00

*Both products by ORS (Oil Recovery Systems, Inc., Norwood, MA).

Source: U.S. Environmental Protection Agency. Office of Underground Storage Tanks. April 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.

Exhibit 1.6-62

Shallow Well (Water Table ≤ 20 Feet) Product Recovery Equipment Pumping Rate/Head

Product	Dynamic Head (ft.)	Pumping Rates (gal/min)	Degree of Oil/Water Sep.	Advantages	Disadvantages	Cost[a]
"Scavenger"[b]	<20	<50	Sheen[c]	Light-weight, portable, passive filter separator, (does not require energy inputs for separation), automatic product pump	Requires 24" diameter well, maximum pumping distance = 20'	$6,850.00
"Probe-Scavenger"[b]	15-80	8-38	99%+[d]	Smaller than scavenger, submersible, greater pumping capacity	Requires 8" diameter well	$6,750.00
"Shallow Well"[b]	20-90	5-35	99%+	Can be used in wells as small as 3-1/2" diameter, submersible		$6,750.00
VP-1075-VCP[e]	6-50	10-74	99%+	Can withstand adverse pumping conditions. Can be used in wells as small as 6" diameter		$6,560.00
"Petropurge"[f]	5-85	0.5/40	99%+	Submersible, minimum well size = 4" diameter		$5,950.00

[a] Costs are for equipment only. Does not include installation.

[b] Oil Recovery Systems, Inc., Norwood, MA.

[c] Less than 1 mm.

[d] 99% of the hydrocarbons floating on the water table can be recovered, and some water containing dissolveds can also be recovered, but it is impossible to remove all the dissolveds from the ground water.

[e] EMTEK, Inc., Amherst, NH.

[f] NEPCCO, Foxboro, MA.

Source: U.S. Environmental Protection Agency. Office of Underground Storage Tanks. April 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.

Exhibit 1.6-63

Shallow Well (Water Table ≤ 20 Feet) Water Table Depression Equipment Pumping Rate/Dynamic Head

Product	Dynamic Head (ft.)	Pumping Rates (gal/min)	Advantages	Disadvantages	Cost
"Probe/Pump"[a]	15-35	10-70	Submersible designed for "Probe-Scavenger"		$3,950.00
"Stainless Steel Water Table Depression Pump"[a]	50-100 (1/2-hp) 50-125 (3/4-hp)	12-50	Can be exposed to salt water, maintains uniform depression	Requires 8" diameter well	$4,850.00
"Shallow Well Water Table Depression Pump"[a]	15-26	10-30	Can fit in 3-1/2" diameter well, can be used in corrosive environments, surface-mounted	For shallow water table ≤ 20 feet	$4,150.00
WP-1075 (3/4)[b]	6-50	10-74	Surface-mounted, can withstand adverse pumping conditions, minimum well size = 6" diameter		$3,736.00
HP 1-9[c]	93-190	1-7	Submersible, minimum well size = 4" diameter		$3,950.00
HP 4-6[c]	60-130	10-28	Submersible, minimum well size = 4" diameter		$5,950.00

[a] ORS (0il Recovery Systems, Inc.), Norwood, MA.
[b] EMTEK, Inc., Amherst, NJ.
[c] NEPCCO, Foxboro, MA.

Source: U.S. Environmental Protection Agency. Office of Underground Storage Tanks. April 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.

Exhibit 1.6-64

Deep Well (Water Table > 20 Feet) Water Table Depression Equipment Pumping Rate/Dynamic Head

Product	Dynamic Head (ft.)	Pumping Rates (gal/min)	Advantages	Disadvantages	Cost
"Probe/Pump"[a]	15-35	10-70	Submersible	Maximum pumping distance 40'	$3,950.00
"Stainless Steel Water Table Depression Pump"[a]	50-150	25-60 (2-hp) 5-100 (3-hp)	Can be exposed to salt water. Submersible	Requires 8" diameter well	$6,950.00 $7,850.00
WP-1075-SHH[b]	80-160	11-28 (3/4 hp)	Submersible, multistage certified pump, can withstand corrosive environments	Requires 8" diameter well	$3,291.00
HP 1-9[c]	93-190	1-7	Submersible, minimum well size = 4" diameter	Low pumping rates at high heads	$3,950.00
HP 4-6[c]	60-130	10-28	Submersible, minimum well size = 4" diameter		$4,175.00

[a] ORS (Oil Recovery Systems, Inc.), Norwood, MA.
[b] EMTEK, Inc., Amherst, NH.
[c] NEPCCO, Foxboro, MA.

Source: U.S. Environmental Protection Agency. Office of Underground Storage Tanks. April 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.

Exhibit 1.6-65

Deep Well (Water Table > 20 Feet) Product Recovery Equipment Pumping Rate/Dynamic Head

Company/Product	Dynamic Head (ft.)	Pumping Rates (gal/min)	Degree of Oil/Water Sep.	Advantages	Disadvantages	Cost
4" Scavenger[a]	10-60	0.6-0.8	99%+	Water and gasoline pumps are together in one unit, can operate in 4" diameter well, can be deployed as far as 180 ft., submersible	Rates low pumping	$12,000.00
"Probe-Scavenger"[a]	15-80	8-38	99%+	Is also used for shallow wells, submersible	Requires 8" diameter well	$ 6,750.00
PPSA-112[b]	6-80	5-40	99%+	Submersible pump	Requires 8" diameter well	$ 5,950.00
Petropurge[c]	5-85	0.5-40	99%+	Submersible minimum well size = 4" diameter		
Narrow Well Petro Purge[c]	Not Available	Not Available	99%+	Submersible, pump is 3" in diameter		$ 6,375.00

[a] ORS (Oil Recovery Systems, Inc.), Norwood, MA.
[b] EMTEK, Inc., Amherst, NH.
[c] NEPCCO, Foxboro, MA.

Source: U.S. Environmental Protection Agency. Office of Underground Storage Tanks. April 1988. Cleanup of Releases from Petroleum USTs: Selected Technologies. EPA/530/UST-88/001.

Oil/water separators are composed of two or more chambers. The first (the inlet or pre-separation chamber) is for the deposition of settleable solids, and the second (the separation chamber) is for the separation of

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liquids of dissimilar specific gravities and the removal of the lighter liquid from the heavier liquid. Gasoline emulsions and water recovered from a well are pumped into the separator through the inlet nozzle. The high velocity flow is directed against a baffle that is sloped at a 45 degree angle to the inlet. The baffle slows and disperses the incoming flow into a diffuse cascade that tapers outwardly and spreads across the entire width of the separator. Once the flow moves beyond the baffle its turbulence is significantly reduced and gravity separation and settling can begin.

Primary coalescence of hydrocarbon emulsions occurs in the pre-separation chamber. Separation will continue as long as turbulence is minimized. Turbulence interferes with coalescence and separation by breaking large globules of hydrocarbons into smaller globules, which are more easily dispersed into water.

In some separators the pre-separation chamber is separated from the separation chamber by coalescing tubes or coalescing plates. Coalescing tubes stand vertically, across the width of the tank, and are coated with an oil-attracting petroleum-based chemical. As hydrocarbon droplets coalesce on the tube surface, larger droplets form, which rise to the water surface. Coalescing plates are composed of a stack of corrugated metal plates that rise at an angle up to the water surface and extend across the width of the tank. Water containing hydrocarbon droplets flows between the plates, which are an inch or so apart. Droplets rising with the density gradient accumulate and coalesce on the underside of the plates, forming larger droplets, which have faster rising rates. At the same time, solid particles suspended in the water settle onto the top sides of the plates and move by gravity to the bottom of the separator.

As the separated hydrocarbons begin to accumulate on the water surface, emulsion-free water is directed away from the corrugated plate pack or coalescing tubes and enters the separation sections. This quiescent zone provides for further gravitational separation of the remaining hydrocarbon emulsions. Once a distinct product layer has developed, it can be recovered with either filter separators, product recovery pumps, or with rotary pipe skimmers. A rotary pipe skimmer is essentially a pipe with the top quarter removed. The pipe is bolted to the side of the separation chamber and runs across its width. The pipe is rotated manually into the flow causing the layer of hydrocarbons to enter the pipe opening.

Some oil/water separators are built with an outlet zone for the discharge of clarified water. The third chamber is separated from the separation chamber by a partition that extends across the width of the tank and down a few inches below the water surface. It is designed to block the flow of the hydrocarbon layer while emulsion-free water is allowed to move underneath the partition to the discharge pipe.

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Oil/water separators range from 100 gallon units to 50,000 gallon units, and are sized to treat specific volumes of water. Typically, separators are built to hold ten times the extraction rate of the well. Water is retained in the separator for at least 10-12 minutes. This is the minimum time in which complete gravity separation can be achieved. Under optimum conditions, an oil/water separator can reduce the amount of hydrocarbon emulsions in water to 15 parts per million (ppm).

The cost of oil/water separators is a function of the design capacity of the tank. For instance, a 1,000 gallon separator (which is designed to handle a well extraction rate of 100 gpm) costs between $5,500-$6,000; a 5,000 gallon separator costs between $10,500-$12,000; and a 10,000 gallon separator costs between $15,500-$17,500. The overall costs will vary depending on what additional features are purchased. Exterior corrosion protection, for example, will increase separator costs by 10 percent. Additional coalescer units will increase costs by 20-30 percent, and sensors and automatic product recovery equipment will cost an extra $5,000-$7,000.

A recent innovation in using oil/water separators has been to install the separator unit below ground, flush with the water table. The main advantage of this technique is that the plume, moving with the ground-water gradient, can be intercepted and recovered with minimum energy input. The plume is trapped and directed to the separator influent nozzle with either a subsurface drainage network -- similar to an aboveground municipal storm drain system -- or with a dike and an impermeable membrane, which retard the flow of the hydrocarbon plume. Both water and the intercepted hydrocarbons move by gravity flow through the separator inlet and into the separator chamber. Once separation of emulsions from water has occurred and the hydrocarbon plume has redeveloped at the top of the separator, it is recovered with a product recovery pump, and the emulsion-free water is allowed to flow through the discharge back to the ground water.

Because underground installation of oil/water separators is a relatively new technique, little cost information is available. There are, however, several non-economic considerations that may make underground installation advantageous. For example, installation underground prevents water from freezing in the separator, eliminates the evaporation of potentially dangerous volatile and flammable collected hydrocarbons, and saves aboveground space for other uses. The disadvantages include the problem of excavating a hole large and deep enough to install the separator at the water table, and the quality of the separator effluent, which normally has a residual dissolved concentration of 15 ppm.

5. Product-Handling and Safety Concerns

Other major issues in the handling of recovered product include the separation of the product and water. If recovered product and water are discharged to the same holding tank, some form of product/water separation technology will have to be used. The less-dense petroleum product may separate through simple gravity separation in an oil/water separator. If the product is emulsified in the water, however, a "breaking" treatment step is required to generate product that can be separated from the water.

After the product is separated, it can be removed with some type of a skimming device and stored in drums on site. If the product has not been altered or contaminated while in the subsurface environment, it can be blended with "cleaner" product and reused. If the product cannot be reclaimed, it should be burned in a permitted facility. The water may be discharged directly to surface water if it meets the state's effluent quality limits. Direct discharge to a municipal wastewater treatment plant may be possible, or the water will need to be pretreated (e.g., using carbon adsorption) before it is discharged. Because pretreatment costs of sewer charges can be a major expense, it is distinctly advantageous to minimize the quantity of water removed through the recovery system and to limit the degree of product/water contact.

Safety features should also be incorporated into the design, installation, and operation of any hydrocarbon recovery system. Before any drilling or excavation work begins, local utilities should be contacted to identify the location of possible underground lines that might be encountered. Any machinery capable of producing heat or a spark that might ignite flammable vapors should be kept upwind, as far removed from the well as possible. Heavy equipment should be grounded to prevent the possibility that static electricity produces a spark. All control panels, power supplies, and storage containers containing flammable product should be grounded properly. It is recommended that all electrical equipment and enclosures and gasoline-powered engines meet explosion-proof specifications (i.e. NEMA 7, Division 1, Class 1, Group C and D) if they are to be used within five feet of the recovery well opening. Other safety guidelines for electrical equipment and connections are included in Attachment 1.6-2 at the end of this section. Smoking should be prohibited within the area surrounding the well, and fire extinguishers that are approved for use on petroleum fires should be available. Air-rotary drilling of hydrocarbon recovery wells should be avoided, especially in areas of large product accumulations: the injection of air can produce an extremely flammable mixture.

During the drilling and development of a well, the borehole and mud pit should be tested with a combustible gas detector for the presence of flammable vapors. If high-pressure jetting and air-lifting are being used in developing the well, the well and air-lift discharge should be checked routinely for vapors. If flammable concentrations of hydrocarbon vapors are detected, this method of well development should be abandoned immediately, as the aeration of the hydrocarbon vapors and the static charges that build up in the air-lift system will present an explosion hazard.

6. Dissolved Product Remediation

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The presence of free product on the ground-water surface will always mean some degree of dissolved product contamination. The opposite is not always true. Therefore, the cleanup of dissolved product from ground water may occur in conjunction with free product recovery or as an entirely separate operation. As a general rule, dissolved product remediation usually takes longer to complete than free product recovery.

Whether dissolved product contamination requires cleanup will depend on the type of contaminant(s), the contaminant concentration(s), and whether the ground-water resource is judged impaired relative to its current or projected best use. New York State applies a non-degradation standard to most of its ground-water resources (see also Part 1, Section 7, Closing-Out a Spill), which presumes that cleanup of dissolved petroleum product in ground water attain an established level.

Once a decision has been made to clean up dissolved ground-water contamination, several factors must be evaluated:

The type of contaminants to be removed;

The background levels of these contaminants in the ground water;

The expected or measured concentrations of these contaminants in the ground water;

The clean-up targets or standards for these contaminants;

The water-quality parameters that may inhibit removal of the contaminants or affect the operation of the ground-water extraction and treatment system;

The anticipated flow rate of the ground water; and

The site characteristics that may affect the feasibility of using certain treatment methods.

The selected treatment technology should be capable of removing the contaminant(s) of concern to acceptable levels, cost-effective and reliable, operated in accordance with all regulatory requirements, and tailored to site conditions. A treatment system may consist of one technology or several used in combination to increase removal efficiency.

For most petroleum product spills, there are four basic technologies for removing dissolved product from ground water:

Air stripping;
Activated carbon adsorption;
Combined air stripping and carbon adsorption; and
Biological treatment.

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Exhibit 1.6-66 summarizes the capabilities and limitations of each of these technologies.

a. Air Stripping

In the air stripping process, contaminated ground water is brought in intimate contact with a clean air stream, usually in a countercurrent flow pattern. Volatile constituents in the ground water will pass into the air stream, thus reducing the contaminant concentrations in the water that exits the air stripper.

An air stripper is usually a tower design. Contaminated water is fed into the top of the tower and flows down over an internal system of baffles or packing material (see Exhibit 1.6-67). The packing material spreads the water flow out, increasing the surface area for volatiles in the water stream to be stripped out by the upward moving air stream. Contaminated air exits the top of the tower and the cleaned water is discharged out the bottom of the tower.

The design and performance of an air-stripping system is a function of several factors:

- Characteristics of the packing material;
- Temperature of the air and water;
- The air-to-water ratio;
- Characteristics of the petroleum constituents to be removed; and
- The inorganic quality of the water to be treated.

Selection of a proper design is completed in two steps. First, the cross-sectional area of the tower column must be determined from the physical properties of the air flowing through the column, the characteristics of the packing, and the air-to-water flow ratio. The second step involves determining the proper tower height from the physical properties of the contaminant and the air stream adjusted for site conditions. Key in the first step is establishing the proper air velocity. This will usually be 60 percent of the air velocity necessary to hold up the water in the tower column.

A properly designed air-stripping tower can remove more than 99 percent of the dissolved BETX compounds in ground water. Petroleum product constituents other than BETX are harder to

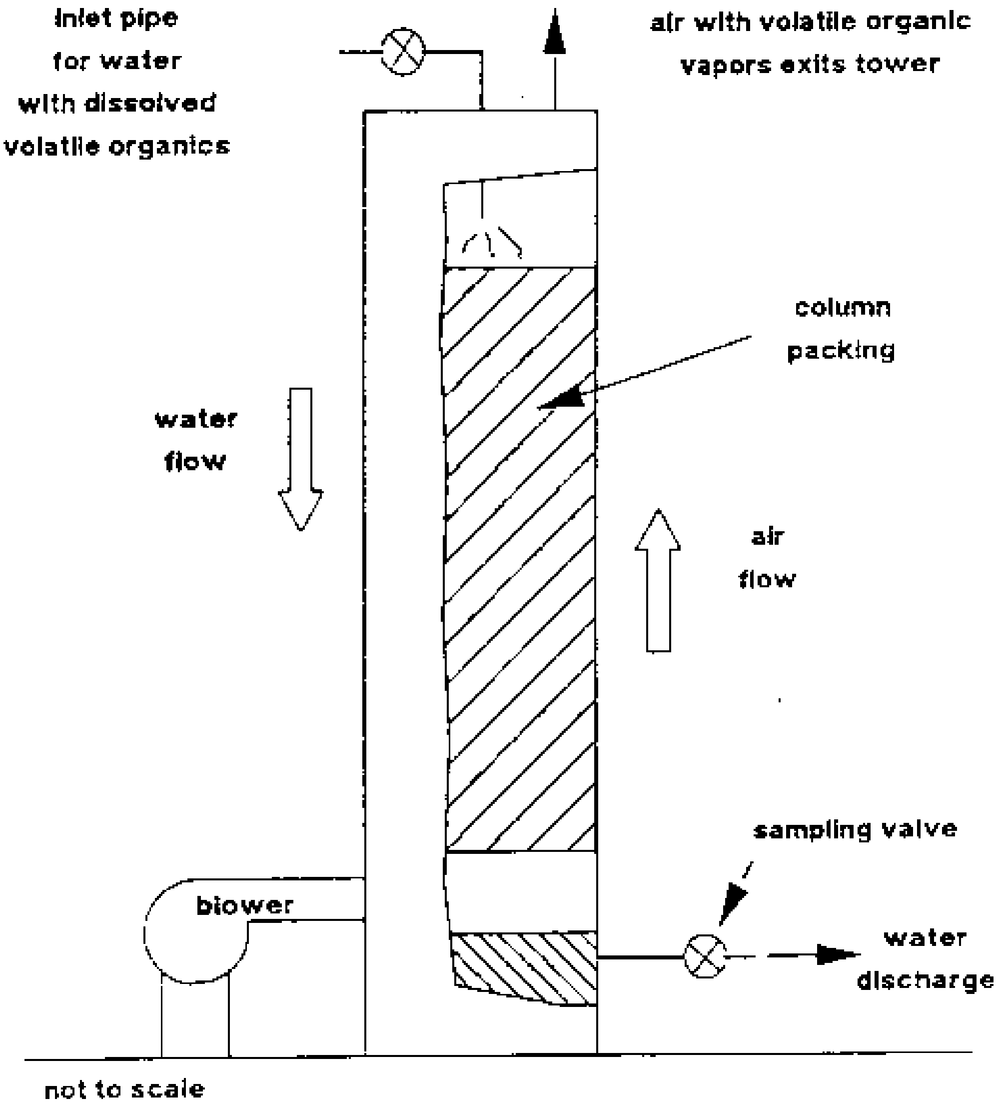
Exhibit 1.6-66

Comparison of Treatment Technologies for Dissolved Product in Ground Water

Technology	Advantages	Limitations
Air Stripping	# Proven technology for volatiles removal. # Simple technology; fairly easy to operate. # Readily available technology. # Low capital and O&M costs.	# Sensitive to fluctuations in hydraulic loading. # Low temperatures result in poor removal efficiency. # Air emission standards may require treatment of vapors. # Packing material can foul as a result of high iron concentrations.
Activated Carbon Adsorption	# Proven technology and readily available. # Can be used in combination with a variety of technologies. # Minimizes air emissions problem. # Tolerant of some fluctuations in contaminant and hydraulic loading. # Well suited as a mobile technology.	# Spent carbon must be replaced or regenerated. # Carbon replacement costs can be high. # Intolerant of high suspended solids levels. # Requires oil and grease pretreatment where concentrations exceed 10 ppm.
Combined Air Stripping and Carbon Adsorption	# Proven technology and readily available. # Cost-effective as less carbon is used to remove contaminants.	# Higher capital costs. # More complicated operation.
Biological Treatment	# Can remove contaminants not removed by other methods. # Minimizes air emissions problem. # Proven technology.	# Higher capital and O&M costs. # Requires more monitoring. # Reliability is variable.

Exhibit 1.6-67

Schematic of an Air Stripper



remove with air strippers for varying reasons. Six of the more difficult constituents to remove would be naphthalene; tetraethyl lead; phenol; dimethylamine; ethylene dibromide (EDB); and ethylene dichloride (EDC). The first four of these constituents either do not readily move through the subsurface (naphthalene and tetraethyl lead) or readily biodegrade (phenol and dimethylamine). Therefore, one would expect none of these chemicals to be found in ground water at significant concentrations; further percentage reductions would be difficult.

Because EDB is one order of magnitude less volatile than benzene, higher air-to-water ratios would be required to remove comparable levels of EDB. EDC has properties similar to those of EDB. It is twice as soluble as EDB and is about as volatile. Thus, the costs to remove EDB or EDC with an air stripper to levels comparable to benzene removal efficiencies would be somewhat higher. The size of the packed air tower would also necessarily have to be larger to remove EDB levels to the same extent as benzene. Consider the following example: Assume a benzene influent concentration of 1,000 ppb and an EDB influent concentration of 100 ppb. Suppose it is necessary to achieve effluent concentrations of 5 ppb for benzene and EDB. To achieve 99.5 percent removal of benzene (from 1,000 ppb to 5 ppb), the packed tower would need a volume of 198 cubic feet with an air-to-water ratio of 22:1. To achieve a 95 percent removal of EDB (from 100 ppb to 5 ppb), the volume of the tower would have to be increased 70 percent and the air- to-water ratio would have to be increased by 400 percent. EDB removal efficiencies of up to 95 percent can be achieved with packed air towers (assuming an influent concentration of 100 ppb) by using an air-to-water ratio of 35:1 and packing depths greater than 40 feet. To achieve high removal efficiencies for EDB or EDC, therefore, it is usually necessary to use activated carbon adsorption. Initial investment costs and annual operating costs for removing EDB or EDC by activated carbon adsorption were actually estimated to be less than costs for removal by air stripping.

b. Activated Carbon Adsorption

Activated carbon adsorption technology is a proven method for the removal of BETX compounds and other less soluble organics, and is well suited for the removal of mixed organics from ground water. It is based on the principle that certain organic compounds will preferentially absorb to organic carbon (an electrical attraction phenomenon in which organic molecules are attracted to the pores of the carbon granules). The less polar or soluble the compound is, the more readily the compound is adsorbed. Oxygenated compounds, like alcohols, are not easily removed with activated carbon.

The most common application of carbon adsorption is passing ground water under pressure through two or more fixed beds of carbon linked in series. The fixed-bed series configuration has been found to be the most

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cost-effective and to produce the lowest effluent concentrations relative to other configurations. Several factors must be considered in the design of an activated carbon adsorption system:

- Influent composition and concentrations;
- Characteristics of the activated carbon;
- Characteristics of the constituents to be adsorbed, especially if they can be destroyed in the carbon regeneration furnaces;
- Temperature, pH, and presence of other competing constituents in the influent;
- Flow rate and resulting carbon contact time; and
- Pressure losses.

Adsorption is not particularly sensitive to influent concentrations or flow rates, but it is sensitive to suspended solids (clog the carbon bed) and oil and grease concentrations. Concentrations of oil and grease in the influent should be limited to 10 ppm. Suspended solids concentrations should be less than 50 ppm in most system configurations.

The following data are required to be able to properly size the carbon beds:

- Hydraulic retention time (in hours);
- Flow (in gallons per minute);
- Hydraulic capacity of the carbon (in gallons of contaminant per pound of carbon);
- Collected volume (in gallons) of treated ground water at breakthrough (i.e., when the carbon bed is saturated and no longer adsorbs the contaminant); and
- Carbon density (in pounds of carbon per cubic foot).

These data are usually collected during field pilot-plant tests.

The largest cost in operating an activated carbon adsorption system is replacing and disposing of, or regenerating, the spent carbon. As a result, an activated carbon adsorption system is usually employed when ground water contains low concentrations of organics, when the flow and loading rates are low, when the compounds cannot be removed by air stripping, and/or to provide final treatment for air-stripped water.

c. <u>Combined Air Stripping and Carbon Adsorption</u>

Air stripping and activated carbon adsorption are often used together to treat contaminated ground water. Used together, these technologies can achieve higher removal efficiencies than either technology used alone. This may be an important benefit in situations where the treated effluent must meet very stringent quality limits before it can be discharged.

Usually, a treatment system employing both technologies will be configured to pass contaminated ground water through the air stripper first. The more volatile constituents are removed first; the design considerations are the same as for an air stripper used alone. The effluent from the air stripper is then sent through an activated carbon adsorption unit for a final polishing treatment. Vapors from an air stripper may also be treated with an activated carbon unit in order to meet emission limits.

Capital costs for a combined air stripper-carbon adsorption system are high. However, the operational costs for such a system are generally lower than would be incurred when an activated carbon unit is used by itself, as the air stripper reduces the contaminant load on the carbon beds.

d. Biological Treatment

Biological treatment for dissolved product remediation can involve extraction of the ground water and treatment in an aboveground, scaled-down, biological system, or treatment in-situ by injecting oxygen and nutrients to stimulate biological growth. Most of the aboveground treatment systems utilize methods/processes borrowed from municipal wastewater treatment facilities that are down-scaled to a mobile system.

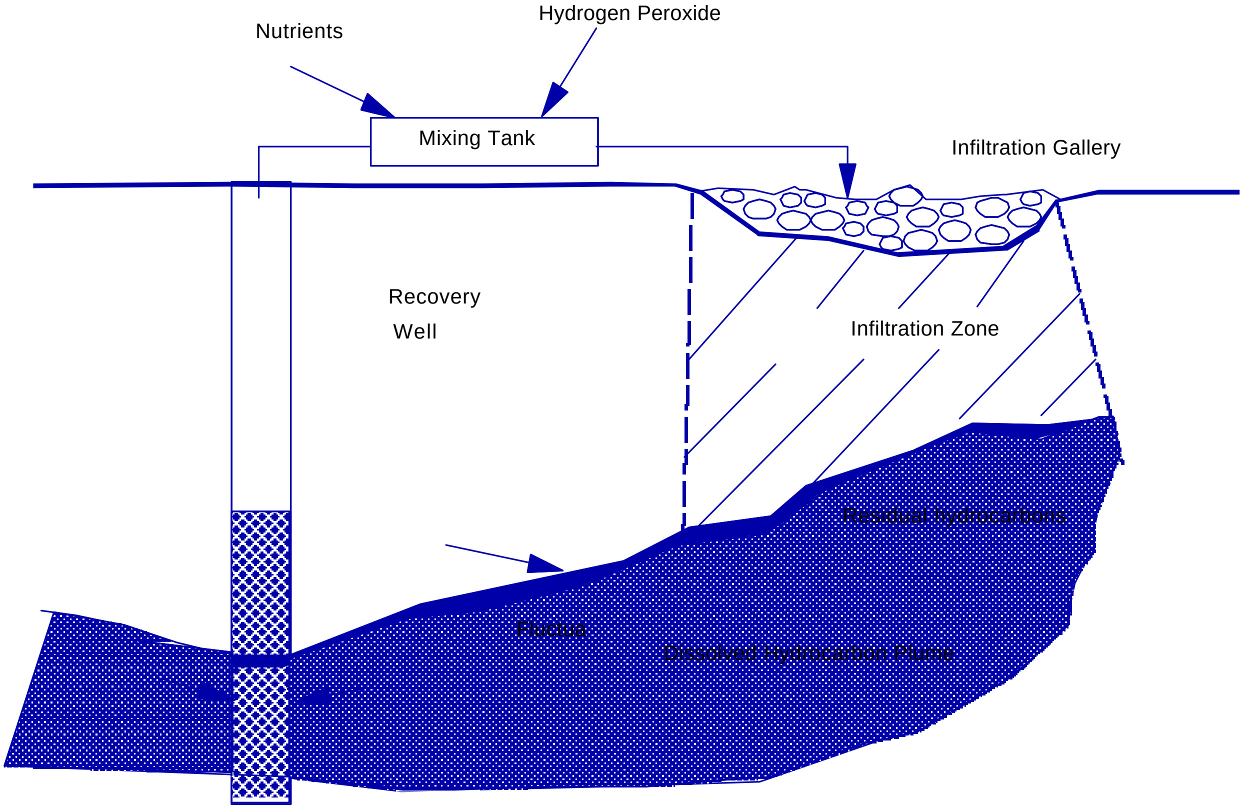
Biological treatment processes can degrade a wide range of contaminants, although the presence of toxics can adversely affect the bacterial population. These systems usually are more expensive to install, operate, and maintain.

Exhibit 1.6-68 is a schematic of an in-situ bioremediation system using infiltration galleries. A recovery well is used to control the dissolved product plume and to drive the flow of water through the mixing tank to the infiltration galleries. Nutrients such as phosphorous and nitrogen are added in the mixing tank. Oxygen, usually in the form of hydrogen peroxide, is injected.

Successful bioremediation requires that nutrients and oxygen are delivered to microorganisms in the contaminated zone. In areas of low hydraulic conductivity, there may not be sufficient contact between the microorganisms, nutrients, and oxygen, and the rate of water extraction and injection is restricted. The result is biodegradation occurring in more limited areas and at a slower rate.

Exhibit 1.6-68

Schematic of an In-Situ Bioremediation System Using Infiltration Galleries



e. Other Treatment Systems

There is another treatment system--chemical oxidation with ultraviolet light--under consideration for ground-water treatment, especially when air emissions from the more traditional technologies are a concern. This system has not been applied widely for the cleanup of subsurface petroleum spills.

Ultraviolet Chemical Oxidation

Ultraviolet (UV) light used together with hydrogen peroxide can chemically oxidize organics in water [2]. Many organic chemicals absorb UV light and undergo a change in their chemical structure or simply become more reactive to chemical oxidants. In the presence of UV light, hydrogen peroxide is transformed into a chemical oxidant, which transforms chemical contaminants into products like carbon dioxide and water. The few commercial applications of this treatment system have indicated it may be more cost-effective than the air stripping process when vapor emission control is required.

7. Handling of Treated Ground Water

Treated ground water discharged from an air stripper, carbon adsorption unit, or biological treatment system must be handled in accordance with local, state, and federal requirements. Effluent disposal may not be a problem at most sites. However, at other sites, physical, geological, and/or political constraints may complicate an increase the expense of effluent disposal.

Effluent from a ground-water treatment system can be handled using one or some combination of the following options:

- Discharge to a nearby positive drainage system like a creek, stream, river, or lake;
- Discharge to a nearby municipal or county sanitary or storm sewer;
- Discharge to an on-site infiltration trench or basin where the water can percolate into the soils;
- Discharge to an on-site injection well where the water can be reintroduced into the saturated zone; or
- Collection for transport to an off-site disposal location where one or more of the options above may be available or feasible.

Some ground-water remediation sites will present circumstances where one or more of these disposal options are available. Your choice of one option over another becomes a question of technical feasibility, local acceptance, cost, and whether effluent quality meets the prescribed limits to receive the necessary approvals/permits. You may be confronted at another site, however, with a situation where no on-site option is feasible, and only the off-site disposal option is available. In these situations, especially if the volume of treated ground water is large, effluent handling represents a significant cost. This cost may be so significant, in fact, that ground-water treatment is viewed as infeasible and other remedies (e.g., alternative water supplies) must be implemented.

The following subsections describe the available effluent disposal options, what conditions must be met for their use, and what problems or complications can arise with each.

a. Discharge to Surface Water

If a surface water body is located near to a site and access to it can be secured, effluent from a ground-water treatment system may be piped above or below-ground and discharged to it. The quality of this discharge must meet certain limits before it can be allowed under the requirements of the State Pollution Discharge Elimination System (SPDES). The effluent must contain less than 50 parts per billion of principal organic contaminants (which include benzene, toluene, or xylenes) and less than 100 parts per billion total principal organic and unspecified organic contaminations. This discharge will be subject to a SPDES permit, which will often require monitoring effluent quality at a specified frequency for the duration of the permit.

The feasibility of this option, of course, first depends on the presence of a positive drainage system in reasonable proximity to the site. Reasonable proximity, in most cases, would translate into distances of less than one mile certainly, and probably less than one-half mile. Even so, there may be other complications that can render this option as infeasible. Chief among these is the inability to secure property owners' permission to lay piping through their property reach the discharge point. Another complication that can arise is the need for additional chemical treatment to eliminate bacterial problems or iron precipitation. The volume of effluent may also be too great for a small drainage system to handle.

b. Discharge to a Sewer System

Many urban and suburban sites will have a sanitary or storm sewer available to receive effluent discharged from a ground-water treatment system. Discharge to the sanitary sewer may be acceptable to the local city or county authorities provided the volume flow and effluent quality can be handled by the receiving wastewater treatment plant. The specific approval of the local authority will usually be needed. The local authority may impose more stringent effluent quality limits and sewer use fees. In general, these local conditions are to be met unless adjustments are negotiated.

The discharge of effluent to the storm sewer is equivalent to a direct discharge to surface water for all intents and purposes. SPDES requirements will be imposed and a SPDES permit will be required. Special approval from the local authority may also be necessary and, again, sewer use fees may be applied.

This option may be feasible only if: (a) there is a sewer system located in reasonable proximity to the treatment site; (b) the sewer system is accessible; and (c) local approval and other permits are secured. Even when these conditions are met, however, the costs incurred in the payment of sewer use fees can be excessive, especially when large flow volumes must be discharged. Other effluent disposal options may prove more cost-effective in these cases.

c. Discharge to Infiltration Trench or Basin

The use of this option is very dependent upon the geologic conditions found at a site and effluent quality. If feasible, this option can represent a low-cost, low-maintenance choice for effluent disposal. In addition, its use can be incorporated into the design of the ground-water remediation system. For example, the treated ground water can be returned to the subsurface at a location(s) hydraulically upgradient of the contamination site. This recirculated flow can help leach contaminants out of the unsaturated zone and speed contaminant flow toward the recovery/extraction well(s). Nutrients and hydrogen peroxide (as an oxygen source) can also be added to the returned flow to enhance biological degradation of the contaminants int he subsurface. A portion of the treated ground water is not recirculated, but instead is discharged to surface waters on the sewer. This helps the system operate at a net hydraulic deficit and prevents pollutants from migrating beyond the contaminated area.

The underground recirculation or injection (see subsection d. below) of treated ground water requires a SPDES permit and is subject to the effluent standards contained in 6 NYCRR, Part 703.b. The SPDES permit requirement will not apply if (per the requirements of TOG 2.1.2):

- The area in which purging (or injection) is taking place is contained, either by a physical barrier (e.g., a slurry wall) or a hydraulic barrier (e.g., a large number of overlapping purge wells), so that contaminated ground water is prevented from migrating beyond the boundaries of the containment zone. Containment must be complete to the extent measurable and the system must operate at a sufficient

NOTES

hydraulic deficit so as to maintain a hydraulic gradient into the containment area; <u>OR</u>

- The site is being remediated pursuant to an order. Any conditions that are necessary to satisfy the substantive technical requirements of the SPDES program can be incorporated into the order which, in effect, serves as a substitute for a permit. To allow this, it is necessary that a full agreement be reached with the responsible party on the appropriate conditions.

The recirculated (or injected) ground water will be required to meet the ground-water effluent standards of Part 703.b unless:

- The recirculation/injection is into a "contained" area as defined above; <u>AND</u>
- There is no net increase in the concentration of any chemical pollutant in the discharge prior to recirculation/injection; <u>AND</u>
- The remedial plan for the site includes ground-water monitoring, both inside and outside the contained area, sufficient to ensure that no degradation of ground-water quality will result.

When the conditions are all met, the effluent quality limits are to be specified to be representative of "best available technology."

The problems or complications that can be encountered with the infiltration option are many. First, the geologic conditions at the site must not preclude fairly rapid infiltration of the treated ground water into the soil. While the infiltration trench or basin itself is filled with a permeable material like gravel or rip rap, the permeability of the underlying soils may be insufficient to handle all but the smallest discharge flow volume. Second, particularly in areas where the iron content of the ground water is high, chemical pretreatment may be necessary to limit bacterial growth. Otherwise excessive bacterial growth clogs the pore spaces and limits the infiltration rate. Third, there may be insufficient site area or access to space to locate the infiltration trench or basin, especially at a location upgradient of the contaminated area. Fourth, it is difficult to demonstrate the net hydraulic deficit for the system required under the provisions of TOG 2.1.2. Finally, this option tends to be a warm temperature option as freezing temperatures tend to preclude its use.

<u>d. Discharge to an Injection Well</u>

The provisions of TOG 2.1.2 discussed above also apply to the injection of treated ground water. With this option, one or more injection wells are used, instead of infiltration trenches or basins, to return the treated ground water directly to the saturated zone usually upgradient of the contaminated area. This induces the flow of contaminants towards the recovery well(s).

Many of the same problems or complications mentioned for the infiltration option also can occur with the injection option. In addition, you have the technical aspects of installing a properly functioning injection well. Like monitoring wells, injection wells must also be constructed carefully to avoid the possibility of cross-contamination or providing a route for contaminants at or near the surface to reach ground water. Therefore, many of the construction requirements discussed for monitoring wells also apply to injection wells. Unlike monitoring well,s however,r injection wells often require screen lengths two to three times the length of the typical monitoring well screens. This larger screen length provides for more area over which to introduce the injected water flow into the saturated zone.

e. Collection for Off-Site Disposal

At some ground-water remediation site, none of the effluent disposal options will be available or feasible to implement. In these cases, you may elect to: (1) collect the treated ground water for disposal at an off-site location, or (2) implement an alternative remedy that does not involve ground-water withdrawal and treatment.

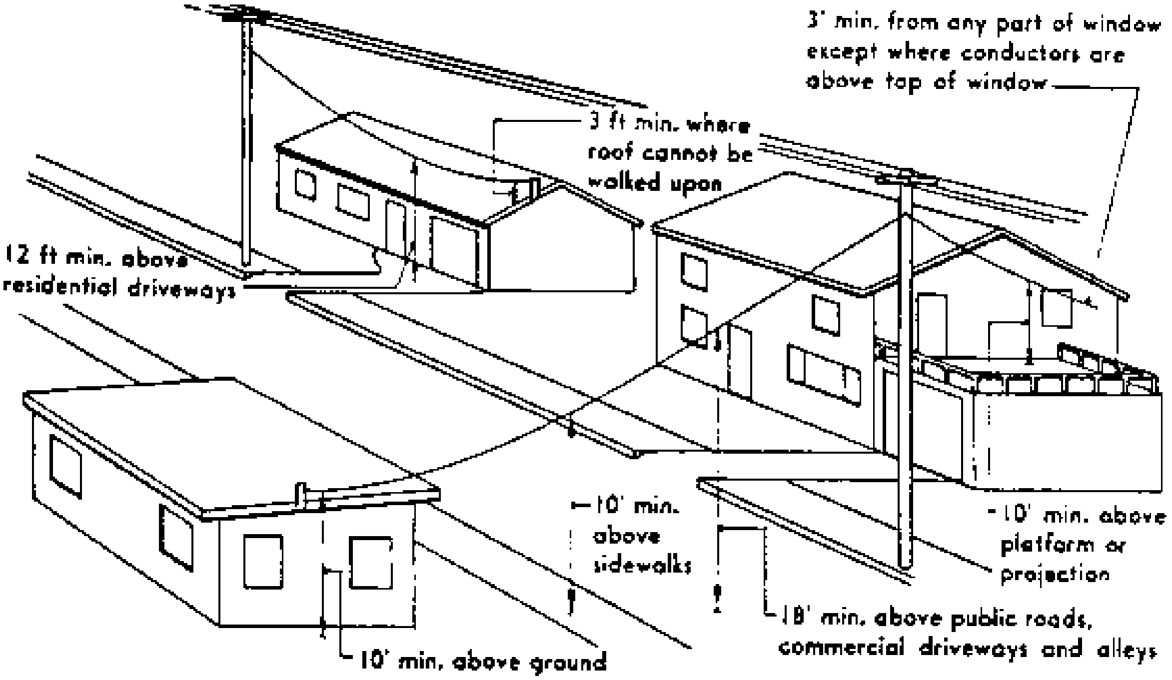
The first option -- off-site disposal -- may be feasible technically, but is likely to be very expensive. The expense will be considerable in cases where the flow volume is large and/or the off-site disposal location is at some distance from the site. However, this may be the only option in situations where other remedies are not available and the ground-water resource is important to the drinking water supply.

Alternatively, the technical difficulties and expense of a ground-water remediation program may dictate selection of a different remedial option. For example, it may prove more feasible and less expense to provide whole-house treatment systems or provide an alternative water supply. These alternative remedies must be selected cautiously as leaving significant ground-water contamination unaddressed is our least preferred option.

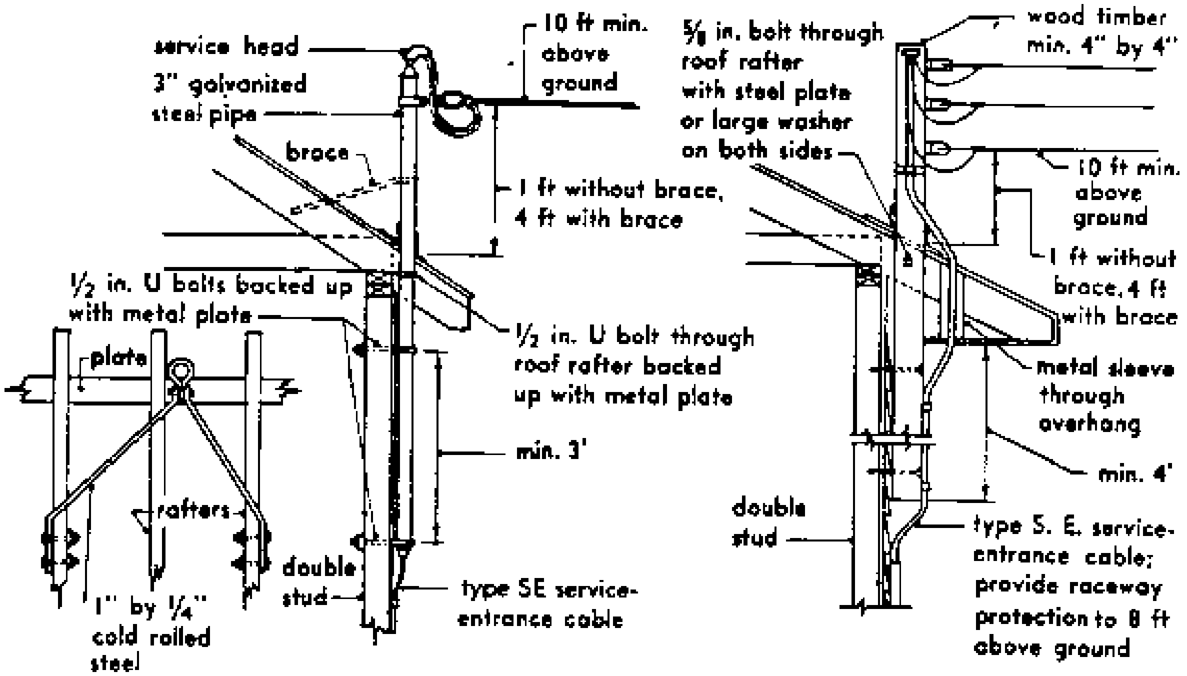
Attachment 1.6-2

Electrical Wiring and Equipment

Overhead Electrical Service



MINIMUM CLEARANCES OF OVERHEAD SERVICE CONDUCTORS



DETAIL OF BRACE

ARRANGEMENT OF SERVICE ENTRANCE CONDUCTORS TO OBTAIN REQUIRED CLEARANCE ABOVE GROUND

Attachment 1.6-2
(continued)

Hazardous Locations

Classification of Equipment

Explosion-proof equipment approved for use in locations where a flammable gas, such as acetylene, is used or stored, is not necessarily approved for use where flour dust is present. In addition to considerations of ignition of flammable materials, equipment for use where flammable dust is present must be able to operate without exceeding its allowable temperature rise when coated with a thick film of dust. Electrical equipment approved for installation in hazardous locations is designated in ULI, *Hazardous Location Equipment List* by class number and group letter.

The class number and group letter for equipment approved for use in a particular hazardous location may be determined from the following two tables. The class number depends on the type of hazardous material present and is determined from table 1.

Table 1
CLASSIFICATION BY CLASS NUMBER

Class	Type of hazardous material present
I	Flammable gases or vapors
II	Combustible dust
III	Ignitable fibers

The group letter depends on the specific hazardous material present and is determined from table 2.

Table 2
CLASSIFICATION BY GROUP LETTER

Group	Specific hazardous material present
A	Acetylene
B	Hydrogen, manufactured gas, carbon monoxide, ethylene oxide, or formaldehyde
C	Ethyl ether, ethylene, cyclopropane, or carbon disulphide
D	Gasoline, hexane, naphtha, benzine, butane, propane, alcohols, acetone, benzol, paint solvent, or natural gas
E	Metal dust of aluminum, magnesium, or alloys of such metals
F	Dust of carbon black, coal, or coke
G	Dust of flour, starch, or grain

Switches, pilot lights, wall receptacles, and motors installed within five feet of the floor in a hospital operating room are approved for installation in a class I, group C location. To check such equipment for approval, proceed as follows: first, from the nameplate or carton, obtain manufacturer's name and catalog number; second, refer to ULI, *Hazardous Location Equipment List*, and under the name of the equipment, such as "switches," look for manufacturer's name, catalog number, class number, and group letter.

The following examples indicate how the above tables may be used to obtain the class number and group letter for electrical equipment installed in various hazardous locations:

EXAMPLES OF CLASS NUMBER AND GROUP LETTER DESIGNATION

Location	Type of hazardous material present	Specific hazardous material present	Class number and group letter
Foundry	Flammable gas	Acetylene	I-A
Gas plant	Flammable gas	Manufactured gas	I-B
Hospital operating room	Flammable gas	Ethyl ether	I-C
Dry cleaning plant	Flammable gas	Benzine	I-D
Aluminum bronze plant	Combustible dust	Aluminum bronze dust	II-E
Coal pulverizing plant	Combustible dust	Coal dust	II-F
Flour mill	Combustible dust	Flour dust	II-G
Textile mill	Ignitable fibers	Cotton lint	III[1]

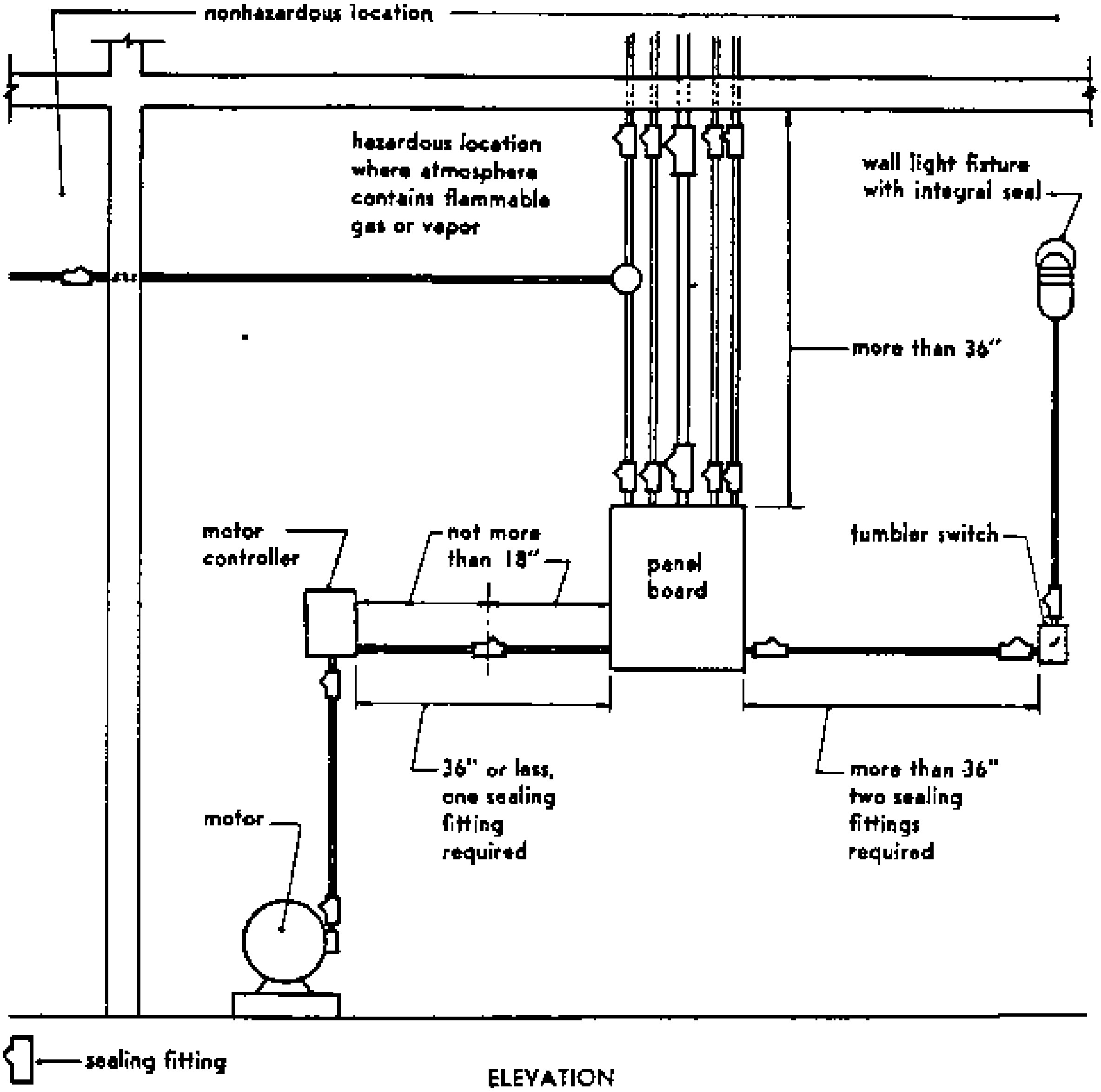
[1] Equipment listed for class II, group G hazardous locations (except fan-cooled type motors), shall be used in class III location.

Attachment 1.6-2
(continued)

Hazardous Locations

In hazardous locations designated as class I, groups A, B, C, or D (see preceding page), a sealing fitting should be provided in each conduit entering an enclosure for equipment which may produce arcs, sparks, or high temperatures.

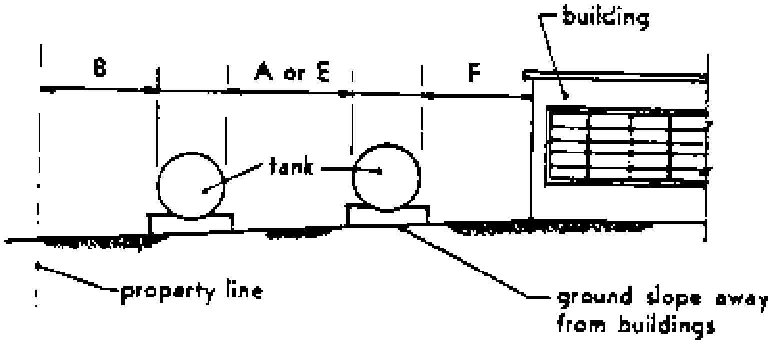
A sealing fitting should also be provided in each conduit leaving such location. Such fitting may be located in the conduit on either side of the boundary between the hazardous and nonhazardous locations.



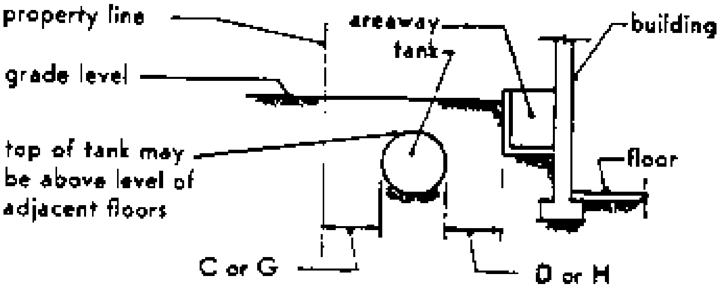
ELEVATION

Equipment for Flammable Liquids

Storage Tanks for Flammable Liquids Located Outside of Buildings



TANKS ABOVE GROUND



TANKS BELOW GROUND

Individual tank capacity, in gallons	Above-ground and below-ground tanks, distances in feet[1]									
	Liquid flash point of 70° F. or less					Liquid flash point over 70° F.				
	Above ground			Below ground		Above ground			Below ground	
	Between tanks	From property line	From building on same premises	From property line	From building on same premises	Between tanks	From property line	From building on same premises	From property line	From building on same premises
	A	B	F	C	D	E	B	F	G	H
0– 275	3	5	5	3	1	3	5	5	1	1
276– 750	3	10	5	3	1	3	10	5	1	1
751–12,000	3	15	5	3	1	3	15	5	1	1
12,001–30,000	3	20	5	3	1	3	20	5	1	1
30,001–50,000	3	30	10	3	1	3	30	10	1	1

[1] Applies to tanks vented to prevent development of pressure exceeding 2.5 pounds per square inch gage.

TECHNICAL
FIELD GUIDANCE

CORRECTIVE ACTION - ALTERNATIVE WATER SUPPLIES

Corrective Action - Alternative Water Supplies

GUIDANCE SUMMARY-AT-A-GLANCE

- *Local and/or the state health departments are* responsible for deciding that an alternative water supply is needed to protect the public health, either on a temporary or permanent basis.

- NYSDEC *spill response personnel* have the discretion, on an emergency basis, to advise a homeowner not to use his tapwater until such time that the local and/or state health department can be consulted to make their determination of the health hazard.

    - While spill responders don't decide whether to provide an alternative water supply, you assist by providing health officials with information about the extent and degree of water supply contamination based upon your investigations. Once the decision is made, however, you are responsible for choosing the type of alternative water supply to be provided, although health officials may express a preference.

- *Potable Water Criteria* used to judge the quality of the water and the need for an alternative water supply are DOH standards to be applied to delivered tap water. The criteria are contained in the two parts of the New York State Codes, Rules, and Regulations (NYCRR) listed below:[28]

    - 10 NYCRR Part 170 (Appendix G)
    - 10 NYCRR Part 5 (Appendix H)
    - If a standard for a certain chemical constituent does not exist, you should consult Technical Operating Guidance (TOG) 1.1.1 (included as Appendix E on Ambient Water Quality Standards).

- *Temporary Alternate Water Supply* is recommended when the contamination problem is expected to be short-lived given the remedial measures being taken to clean up the spill or as an interim measure during the initial stages of cleanup and remediation. If a cleanup/remediation is approaching two years, then a permanent water supply alternative should be considered. When a temporary supply is provided, you are to work with health officials to monitor its efficacy. Temporary alternative water supply options include the following:

    (1) Bottled water:

    - easily distributed
    - cost-effective as a short-term option when a limited number of households have been affected by the spill and cleanup is short term.

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[28] *Program policy is to meet the most stringent criteria where different standards for the same chemical parameter appear in each source.*

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

(2) Whole house-water supply filters:

- easily installed
- cost-effective as a short-term option when a limited number of households have been affected by the spill and cleanup is short-term
- use of this option requires solicitation of water treatment vendors.

A permanent alternative water supply is recommended when, in your judgment, these methods are more technically feasible, more cost-effective, and more permanent a solution relative to other methods of long-term corrective action to clean up a spill. Permanent alternative water supply options include the following:

(1) Household water supply filters:

- easily installed
- most cost-effective as a long-term option when a limited number of households have been affected by the spill and other options are more expensive to implement.
- can be expensive over time due to the expense of frequently monitoring the filtered water's chemical quality
- use of this option requires solicitation of water treatment vendors.

(2) Well replacement:

- requires authorization from the Chief of the Spill Response Section and the approval of the Director of the Bureau of Spill Prevention and Response.

- normally chosen when:

    - o a more permanent solution is desired (relative to installing filters)
    - o one can be reasonably certain that he new well will not be affected by the contamination
    - o the hookup to or extension of a municipal water supply system is not possible or prohibitively expensive.

- special vendor solicitation requirements and design specifications apply to this option (see Appendix J).

NOTES

GUIDANCE SUMMARY-AT-A-GLANCE
(continued)

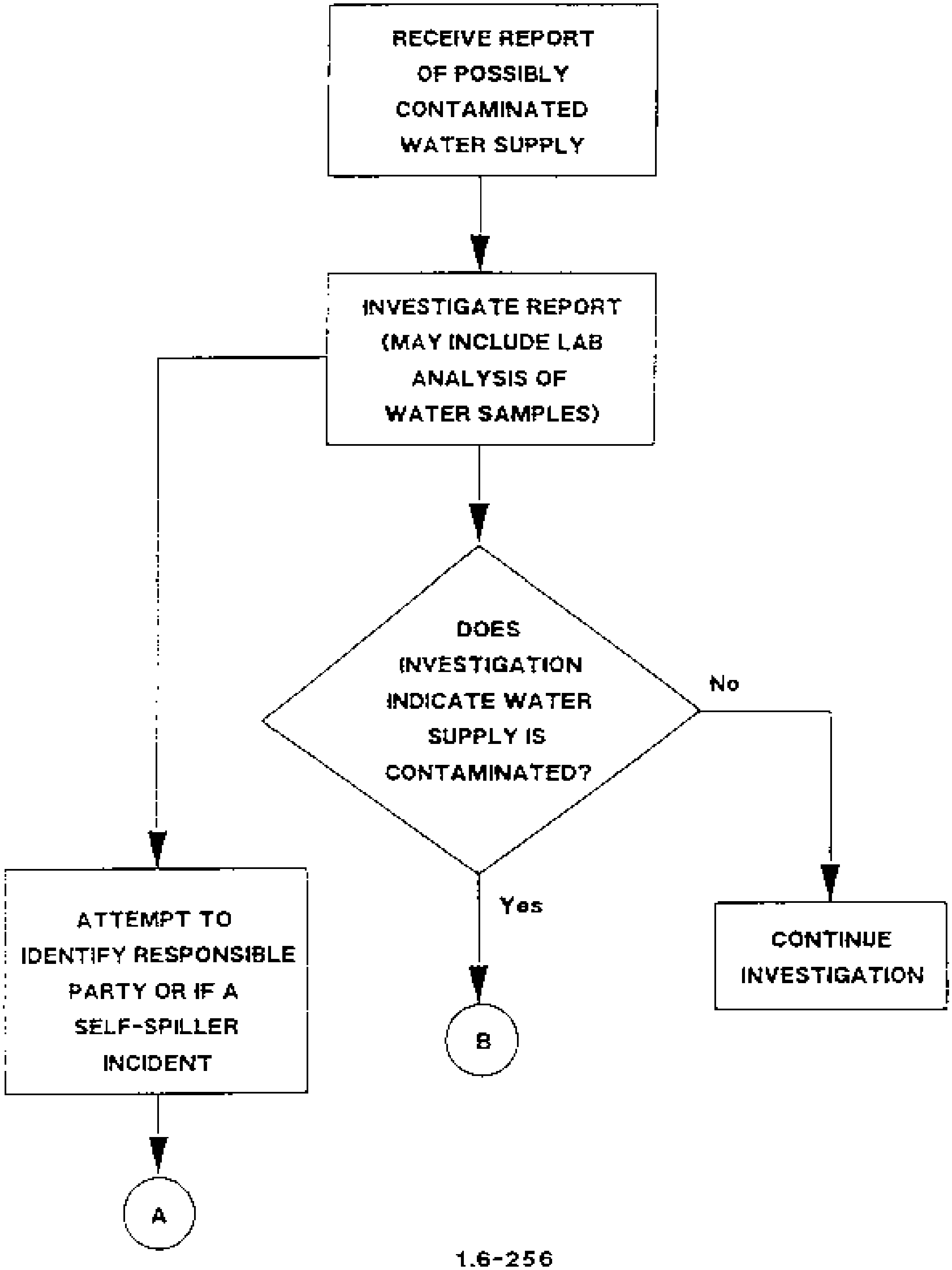
(3) Hook-up to or extension of a municipal water supply:

- the most permanent alternative water supply solution
- normally offers the least amount of health risk compared to installing filters and replacement wells. It is for these first two reasons that health officials often push for this option.
- Implementation requires:

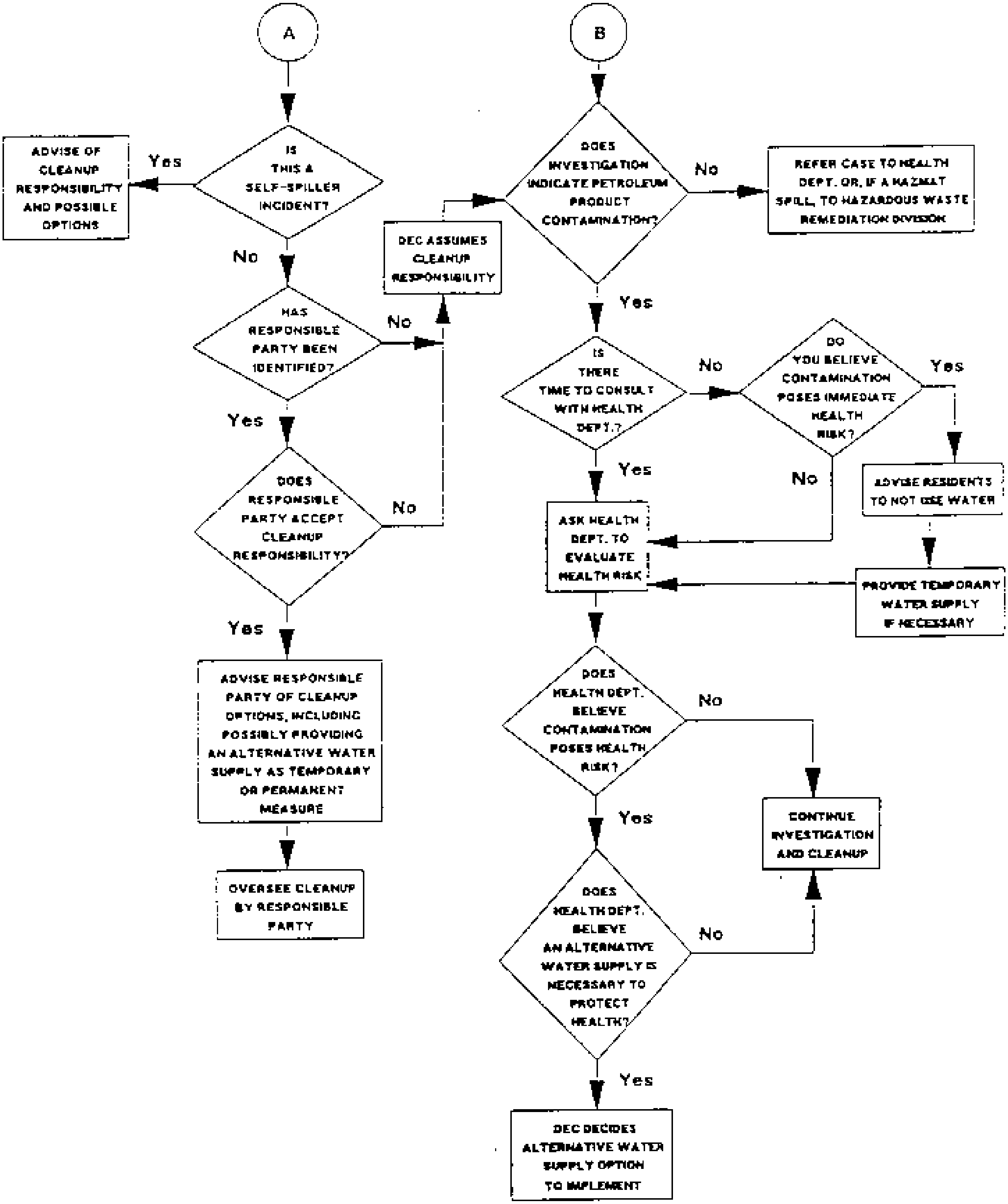
  - Negotiations between the Central Office, Fund Administrator, and the municipality and its water authority. Municipalities will often negotiate with RPs over which households qualify as affected households. This can be difficult in cases where the extent of contamination is not known, and movement of affected ground water or aquifer is uncertain. Households unaffected today could be affected in the future depending on hydrogeological characteristics.
  - creating new water districts
  - preparation of engineering designs
  - sign-off by the affected households.

Guidance Summary-At-A-Glance (cont.)

. SPILL RESPONDER ACTIONS REGARDING NEED FOR ALTERNATIVE WATER SUPPLY



Guidance Summary-At-A-Glance (cont.)



1.6.8 Corrective Action - Alternative Water Supplies

When a spill reaches ground water or surface water, there is a chance that a public and/or private drinking water supply will be contaminated. Investigating whether a water supply has been contaminated and the degree of exposure to contaminants hazardous to the public health is one of your primary concerns in an investigation of any spill. Once you obtain information that shows a water supply has been contaminated by a spill, however, it becomes the responsibility of the local and/or state health department to decide whether the contamination is serious enough to warrant provision of an alternative water supply in order to protect public health. **This is not a decision spill responders have the authority to make except on an emergency basis**, as described below. You do assist health officials by providing information about the extent and degree of water supply contamination based upon your investigation.

If the health department decides that an alternative water supply is warranted, your next steps will depend upon which of the following scenarios apply to the spill you are investigating. These scenarios include:

(1) A petroleum product spill where the responsible party (RP) is unknown or has refused to accept responsibility to clean up the spill. In this instance, the state will direct the cleanup and you will have the primary responsibility for providing the alternative water supply.

(2) A petroleum product spill where the RP is known and accepts responsibility to clean up the spill. In this instance, you will oversee the RP-directed cleanup and will be involved to a very limited degree in the RP's actions to provide an alternative water supply.

(3) A hazardous substance (non-petroleum) product spill. Except in emergency situations, you do not have the authority to spend Oil Spill Fund or LUST Trust Fund monies to respond to such spills, which includes spending funds to provide an alternative water supply.

(4) A self-spiller incident. An example of this type of incident is when a release from a homeowner's underground tank contaminates his or her water supply well. Unless other wells are affected by this spill, it is the homeowner's responsibility to take remedial actions, including providing an alternative water supply. **In no case will state funds be used to provide an alternative water supply or temporary water supply for use by the self-spiller.**

This section describes policies and procedures applicable to a state-directed cleanup involving provision of an alternative water supply. Where appropriate, however, we highlight how these policies and/or procedures change when an RP directs cleanup of the spill.

Before proceeding, we need to touch upon what steps you may take in a situation where an imminent health threat exists, in your judgment, and there is insufficient time for the health department to respond. Remember, it is preferable to have a health department official make the decision that an alternative water supply is required to protect human health. In those few instances where immediate action is needed before the health department can be consulted, you may:

NOTES

(1) Advise the residents to discontinue using their contaminated water supply and switch to an alternative supply (e.g., bottled water), or

(2) Install a temporary water treatment system that renders the contaminated supply fit for consumptive and/or other uses, and then alert health department officials to the problem.

You may use Oil Spill Fund or LUST Trust Fund monies to provide the alternative supply or to install the treatment system if the spill involves a petroleum product or if the nature of the spilled material is not known. Once you determine that a hazardous substance product is involved, however, you must discontinue using state or federal fund monies and refer the case to the Hazardous Waste Remediation Division.

1. BSPR Policy on Providing Alternative Water Supplies

The objective in providing an alternative water supply is the same as with any other remedial measure: to adequately protect human health. The key difference, again, is that the decision to provide an alternative water supply is not a decision spill responders make. Public health officials are officially responsible for making alternate water supply decisions. Instead, it is your job to implement that decision by choosing among either temporary or permanent alternative water supply options.

Some of the general guidelines to follow in these situations are the following:

The moment you have data or other reason to believe that a private or public water supply has been contaminated by a petroleum spill, notify the appropriate health department officials of this fact and request their assistance. Forward all copies of any drinking water quality tests you have authorized to the appropriate health department.

Coordinate your response with the health department.

Defer to health officials in their assessment of health hazards associated with a contaminated water supply.

Be sure to follow the provisions of the Regional Contingency Plan as it applies to spill incidents where water supplies are contaminated.

Any questions directed to you concerning a contaminated water supply should be referred to the health department.

Once the health department makes its decision that an alternative supply is needed, you are solely responsible for choosing the type of alternative water supply to be provided. The health department may express a preference; however, only BSPR staff may choose the type of alternative supply to be implemented using state and/or federal monies.

You may choose to provide either a temporary or permanent alternative water supply that is technically feasible and cost-effective. Your final decision will be subject to approval from the BSPR Central Office and the Fund Administrator.

A temporary alternative water supply is usually provided when the water supply contamination problem is expected to be short-lived given the remedial measures being taken to clean up the spill, but there need to be interim measures taken to protect the public health. In this instance, providing the temporary supply is part of the emergency response to the spill and its impact, although the temporary alternative supply may remain in use for some time. When a temporary supply is provided, you are to work with health officials to monitor its effectiveness until it is removed (and then you must arrange to monitor the quality of the original water supply for a period of up to one year).

Providing a permanent alternative water supply is one of several options for long-term corrective action of a spill. It can be the best option if, based upon your evaluation of the spill, you determine that:

It is technically infeasible to clean up the spill so that drinking water contaminants are reduced to acceptable standards;

It may take too long to clean up the spill to acceptable standards;

It is a more permanent method of reducing the human health risk; and/or

It is less cost-effective to clean up the spill through other means.

In evaluating these factors, your technical infeasibility assessment is based upon the spill- and site-specific conditions, and upon your (and others') previous experiences with spill cleanups and provision of alternative water supplies. Your cost-effectiveness assessment should include an evaluation of the permanency of the results achieved, and of all costs (capital, operation, and maintenance over the lifetime of the technology) incurred to implement the remedial solution.[29]

The remainder of this section provides guidance and guidelines to evaluate and choose among different alternative water supply options. Also covered are the procedures to follow in implementing your selected option.

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[29] *In actuality, you are constantly evaluating the technical feasibility and cost-effectiveness of remedial alternatives throughout the spill response process and not just when alternative water supply options are considered.*

2. Potable Water Quality Criteria

As a little background, you should understand the criteria and standards a health department will use to judge the quality of a water supply for human consumption.[30] The health department will compare these criteria and standards to the contaminant concentrations you measure in the private or public water supply to assess the human health risk. In most cases, these criteria and standards are health-based; that is, they have been judged to represent the highest acceptable levels for drinking water that will ensure the protection of human health.

The available standards and criteria are Department of Health (DOH) standards, contained in the New York State Codes, Rules, and Regulations (NYCRR). For raw water standards:

10 NYCRR, Part 170, Source of Water Supply (see Appendix G), and

For drinking water standards:

10 NYCRR, Part 5, Drinking Water Supplies (see Appendix H).

The NYCRR may list more than one standard that applies to the same chemical constituent. In these cases, the rule is to apply the more stringent of the two standards. If a standard for a certain chemical constituent does not exist, you should consult Technical Operating Guidance (TOG) 1.1.1 (see Appendix E on Ambient Water Quality Standards). This TOG lists the water quality standards and guidance values for toxic and nonconventional pollutants categorized according to the New York State Water Classification System. Those classes of water sources deemed safe for drinking water purposes include the following: A, A-S, AA, AA-S, and GA.[31]

3. Providing a Temporary Alternative Water Supply

Once a health department official determines that a health hazard exists, you may decide that temporary provision of an alternative water supply is sufficient. This could be your choice, for example, where the contamination problem is expected to be short-lived or as an interim measure until a decision is made on the progress of the remedial measures being taken. In the interim, therefore, between the time the cleanup is begun and when it produces its intended effect, a

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[30] *For information on NYSDOH policies and procedures for detecting organic chemicals in drinking water see Attachment 1.6-3 at the end of this subsection.*

[31] *If there is no standard for a certain chemical constituent, it is possible to calculate a numerical value that you can use to represent the human health and potable water standard using the guidance and formulas provided in 10 NYCRR, Part 700, Tests or Analytical Determinations (see Appendix I).*

temporary supply (e.g., bottled water or an activated carbon unit) could be provided to eliminate any exposure to contaminants in the drinking water.

If an activated carbon unit is provided, you will need to work with health officials to monitor its effectiveness over time until it is removed. For as long as the temporary treatment system is in place, you must monitor the quality of treated water monthly to detect when the carbon filters need replacing. After the carbon filter is removed, you must continue to monitor the drinking water supply monthly for the first six months and then every other month until one year has elapsed from the time the system was removed. This rigorous monitoring schedule must be maintained to ensure that contaminant concentrations do not again exceed healthful levels.

Historically, this aspect of providing temporary alternative water supplies has been the most problematic for spill response personnel. There have been several occasions in which an activated carbon unit had been removed from service based upon a one-time assessment that contaminant concentrations had been reduced to acceptable levels -- only to be reactivated again, and yet again, when contaminant levels were found to have increased. Consequently, continuing to monitor contaminant levels after the removal of a temporary alternative supply is extremely important. This type of situation might have been avoided (and could be avoided in the future!) if there had been a more thorough evaluation of the effectiveness of the chosen spill clean-up technology. It is possible that the funds spent on a temporary alternative water supply (which can be considerable) might have been better spent on providing a more permanent alternative water supply.

4. Providing a Permanent Alternative Water Supply

There will be situations in which you decide that the more technically feasible and cost-effective option for effectively responding to a spill is to provide a permanent alternative water supply to the affected parties. Such situations are to be distinguished from those in which a health department urges the adoption of the permanent water supply option regardless of whether other measures might be as effective in remedying the contamination. Health departments generally prefer the permanent alternative water supply option because it is permanent and because of the lower associated health risk. BSPR shares this preference to a degree, but we must also consider that other remedial measures can be equally effective and implemented at less cost. Therefore, whether a contaminated water supply does indeed pose a health threat is a decision for the health department to make, you decide how best to remedy the situation, should a health threat exist, and whether a permanent alternative water supply is the better option when state or federal funds will be spent.

The factors that you may find pertinent in making this decision include your knowledge of the specific contaminants involved; your knowledge of the hydrogeologic setting of the spill site; and your past spill clean-up experience. Your evaluation of factors such as these will be very much a spill- and site-specific assessment, and largely a matter of professional judgment (other BSPR staff should be consulted). BSPR allows state funds to be spent to provide a permanent alternative water supply as a long-term corrective action when:

- A determination is made pursuant to TOG 2.1.1 (Ground-water Contamination Remediation Strategy) to proceed with remediation or to discontinue remediation (see Appendix F).
- This solution is cost-effective when compared with other remedial alternatives.

For example, a whole-house treatment system is usually considered an interim measure to provide potable water until the cleanup has been completed or permanent alternative water supplies (e.g., extending a municipal system) have been put in place. However, in situations where there are no other cost-effective or technically feasible solutions, long-term arrangements for installation and maintenance of a whole-house water treatment system is acceptable. Use of activated carbon filtration units is acceptable as cost-effective long-term corrective action when:

- There are a limited number of affected households;
- Hook up to alternate water supply is neither possible or economically infeasible due to lack of an existing or expandable municipal water system; and
- There is insufficient knowledge on the source of the pollutant or hydrogeologic setting to successfully drill a replacement well.

Other sections of this manual that you may consult to help you decide what type of alternative water supply will be most appropriate include Part 3, Section 1, Synopsis of Spill Management and Clean-Up Techniques; Part 1, Section 4, Site Investigation; and Part 1, Section 6.1, Exposure and Risk Assessment.

a. Permanent Alternative Water Supply Options

Once you decide to provide a permanent alternative water supply, you must choose to implement one of three basic permanent options. These options include:

- Installing an activated carbon water filter, which will remain in place on a permanent basis, in each affected household;
- Drilling a new well to replace the affected private or public supply well(s); or
- Connecting the affected households to an existing public water supply system.

Your choice of the option is not made strictly on your own, however, and other parties may have to be brought in to actually implement the option selected. For example, you must consult with the state health department and any county or local health department to implement any of these options. For instances in which an existing water supply system might be used, you will have to work with a municipality, local water district, or local water company.

b. Choosing Among Available Options

Choosing among available permanent alternative water supply options involves:

- Using your knowledge of the spill and spill site and past experience with similar situations;
- Making a comparison of the relative cost-effectiveness, technical feasibility, and permanency of results achieved across these options; and
- Negotiating with local authorities about their cooperation in extending an existing water supply system to cover the parties affected by the contaminated supply.

Making Use of Current Information and Past Experience

Your technical feasibility assessment of these three options should be based upon your knowledge of the spill's effects and the spill site -- based both on the information you obtained during your site investigation, as well as your past experiences in similar situations. For example, it may or may not be technically feasible to replace a well, as the spill may have contaminated the only productive aquifer of previously good quality. In most instances, it is possible to design an activated carbon filtration unit for an individual household; however, proper continued maintenance of the unit may be problematic. The issue in exercising this option is usually the high cost of the long-term maintenance program. Cost will usually be the principal issue for hook-up to and/or extension of an existing water supply system as well, although there may be some technical problems to address (e.g., increasing the diameter of the water supply line or upgrading the quantity and/or quality of the supply source).

Judging Cost-Effectiveness

We recommend a "simple" comparison of the total capital and operation and maintenance (O&M) costs incurred in implementing alternative options throughout the lifetime of the technology rather than a "present value" analysis of each option. The emphasis on "lifetime costs" is important because an option that is relatively inexpensive to install may end up being very expensive to maintain and monitor over its operating lifetime. In most cases, the cost estimates you generate must be forwarded to the BSPR Central Office for a "reasonableness review." However, your RSE may authorize the expenditure of funds -- without first obtaining approval from the BSPR Central Office -- for any option that costs less than or equal to $11,000. To implement an option whose estimated cost is greater than $11,000, you must have the prior approval of the Director of the BSPR.

Your assessment as to how effective the option will be will be based on the degree of confidence you have that the solution will continue to function as intended. As previously mentioned, options such as carbon filter installation or well replacement can prove problematic in that their effectiveness is dependent upon proper maintenance or your reasonable certainty that the contamination will not spread to the new well. In some respects, therefore, your assessment of the permanency of the option reflects a judgment of the risk inherent in implementing that option. Your assessment of the effectiveness of the options should be made with the help of regional staff, hydrogeologists, and other experts from the BSPR Central Office, and you may even wish to seek advice from standby contractors.

Negotiations With Local Authorities

Negotiations with local authorities may influence the alternative water supply option you choose to install. Choosing to connect affected households to an existing water supply system cannot be implemented without negotiating with officials operating that system. You may be required, therefore, to act as an intermediary between the affected households, the state, and a municipality or local water district in these negotiations. When doing so, keep in mind that the state funds only those portions of a water supply extension project that correct the water contamination problems of the households affected by the spill. If a municipality desires to accomplish other objectives in the project, such as upgrading the size of the water supply lines or improving the quantity and/or quality of its water supply source (assuming it was not affected by the spill), these are not aspects of a project to which spill response funds can be committed.

One issue that can be difficult to resolve in these negotiations is establishing the total number of "affected" households. Usually, an "affected" household is established on the basis of water quality testing data as evaluated by the health department. A household's water supply that is not presently affected by contaminants from the spill, however, can be affected later as contaminants migrate through ground water or along subsurface utilities. As a result, residents and/or their public representatives may argue for expanding the list of "affected" households established solely on the basis of testing data (for a specific time period) for reasons such as these. If this particular issue does arise in your negotiations with a municipality, refer the case to the BSPR Central Office for resolution.

NOTES

Your final, best-choice option will often be one that meets a combination of the technical feasibility, cost, and effectiveness or permanency criteria. You may, at your discretion, weight these criteria differently on a spill-specific basis provided that adequate protection of human health is achieved. You are encouraged to select the most reasonable and defensible option, not necessarily the least-cost option.

5. Procedures for Implementing a Permanent Alternative Water Supply

If there is a contaminated water supply, consider all the alternatives to providing a clean water system: water filter system, new well, and hook-up to municipal system. For long-term problems, a new well or hook-up to a municipal system should be considered after a cost comparison is made. Procedures for these three alternatives are described below. Approval from the BSPR Central Office is required before a permanent alternative water supply can be provided. Notify the Fund Administrator for his/her concurrence on projects that have costs greater than $10,000, are controversial in nature, and/or involve purchasing property with fund monies. For those projects that require purchasing property, it is preferable that the affected party purchase the property with the state's approval, and they will be reimbursed for the costs (e.g., survey, lawyer's fee, purchasing price). Procedures for installing activated carbon water filters:

1. Prior to installation, confirm petroleum pollution contamination through analytical tests performed by a DEC contract laboratory using state-approved analytical procedures. In areas of unknown water quality (high iron concentration, sulfur, etc.) sampling should be done before a filter system is ordered or installed to make sure the system will work properly. The following items should be tested for, if applicable: NH3 organic nitrogen, nitrite, nitrate, CL-, coliform, s.p.d. (STD plate count), sulfate, metals priority pollutants (13), hardness, fluoride 624 for MTBE.

2. Prepare a Solicitation package (for detailed procedures see Appendix J, on Soliciting Quotes, Installing, Monitoring, and Maintaining a Whole House Water Treatment System):

   - Review and revise (if required) the specifications in soliciting quotations for a water treatment system (see Appendix J);

   - Include the required NYSDEC standard clauses (see Exhibit 1.6-9 in Part 1, Section 2, Contractor Selection and Call Out);

   - Provide analysis reports for water samples; and

   - Set a deadline for contractors to return their price quotes.

NOTES

3. Prepare and send letters to all locally known water treatment vendors, those listed in the yellow pages and/or those maintained on a regional address list. Note in the letter that their response is required if they are to remain on the address list or be placed on the list for future solicitations (see Appendix J1).

4. Examine quotes received, select and make an award to the lowest qualified bidder, or provide justifications for rejecting the lowest bidder and selecting the next lowest bidder.

5. Follow administrative procedures and documentation as well as installation specifications approved by NYSDOH as shown in Appendix J.

6. Make arrangements for a DEC contract laboratory to periodically sample and test the drinking water (both before and after the filters are changed). See schematic diagram of whole-house water treatment system in Appendix J for locations of pre-filter and post-filter sampling taps. Sample taps every month for the first six months and then every other month thereafter. Laboratories should use methods 503.1 or 601 along with other appropriate sampling.

7. Send copies of all analytical tests to local/state health departments. Individuals should be provided copies of tests performed on their water supply. See sample letters in Exhibits 1.6-69 and 1.6-70.

8. Individuals should be referred to health department(s) for proper interpretation of the test results.

9. If filters are used as a temporary alternative water supply option, they may be removed when:

    a. Pollution dissipates and contaminant concentrations remain below state drinking water standards for one year;

    b. A clean alternative water supply is provided; and/or

    c. Test and other data indicate that the pollution is not related to a petroleum product.

10. In cases where, in procedure #9 above, neither a, b, or c occurs, then the state may opt to purchase the filters and/or settle with the property owner(s). If you choose to drill a replacement well you must have information on the source and extent of contamination, and be knowledgeable about the aquifer characteristics. Based on these data, you must predict the

Exhibit 1.6-69

Sample Letter to Health Authorities Concerning Analytical Test Results

[Date]

[Addressee]
[Address]

Dear Sir or Madam:

On [insert date], the [insert name of laboratory] analyzed water quality samples collected from the [name] residence on [street address] in [city/town] by [region] Bureau of Spill Prevention and Response personnel. These samples were collected from the [describe sampling locations] as part of a continuing state-directed spill response [insert spill #].

The analytical results for these samples are attached. The analytical method used was [describe method]. The detection limit for this method is [insert limit]. A copy of these test results is being provided under separate cover to [insert name of resident].

If you have any questions concerning these analytical results, please feel free to give me a call at [insert phone number].

Sincerely yours,

Exhibit 1.6-70

Sample Letter to Residents of Affected Household Concerning Analytical Test Results

[Date]

[Addressee]
[Address]

Dear [Mr. Ms. Mrs.] [Name]:

On [insert date], the [insert name of laboratory] analyzed water samples collected from your residence by [region] Bureau of Spill Prevention and Response personnel on [insert date]. These samples were collected from the [describe sampling locations] as part of a continuing state-directed spill response [insert spill #].

The analytical results for these samples are attached. A copy of these results has been provided to the [insert name of health department] under separate cover. If you should have any questions concerning these results, contact the [insert name of health department] directly at [insert phone number]. If I can be of any assistance, you may call me at [insert phone number].

Sincerely yours,

future direction and rate of any spread in the contaminant plume to determine whether the replacement well will remain free of contamination.

6. Procedures for Drilling a Replacement Well (for more detailed instructions see Appendix K, Guidelines for Replacement of a Single Water Supply)

1. No public or private drinking water wells are to be drilled without prior approval from the Director of the BSPR. Copies of all pertinent information you used to evaluate whether or not to install a replacement well shall be forwarded to the Director for his or her review. The information should include copies of all lab test results, a brief narrative of events, geological reports, maps, and any other pertinent information. If drilling the replacement well is deemed appropriate by the Director, follow the procedures described below for obtaining releases and soliciting bids.

2. Use an existing standby contractor approved to drill supply wells, or prepare a Solicitation Package (see Attachment A of Appendix K),[32] which should include:

    # Replacement well and pump specifications for site conditions;[33]

    # NYSDEC required standard Clauses (see Part 1, Section 2, Contractor Selection and Call-Out);

    # Available subsurface information such as boring logs and soil samples from observation wells; and

    # Details for return of price quotes.

3. Prepare and send letters to all local well drillers, those listed in the yellow pages and/or those maintained on a regional address list. Note in the letter that a response is required to remain on or be placed on the address list for future well replacement solicitation.

4. Obtain releases and subrogation receipts (see Attachment B, Guidelines for Replacement of a Single Water Supply, Appendix K).

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[32] *For more information on contractor solicitation procedures, see Part 1, Section 2, Contractor Selection and Call Out.*

[33] *These specifications may be changed to reflect actual site conditions provided prior approval had been obtained from Chief of the Spill Response Section.*

NOTES

5. Examine quotes, select and make award to lowest qualified bidder, or provide justification for rejecting the lowest bidder and selecting the next lowest bidder.[34]

7. Procedures for Extending or Hooking-Up to An Existing Water Supply System

1. Meet with the municipality or water authority that operates the water supply system.

2. Inform the municipality/water authority that the state intends to hook up to or extend an existing water supply system to remediate the impact of a spill for several affected households. Negotiations with the municipality will determine which households are "affected."

3. If possible, have municipality/water authority be DEC's agent in the planning and design of the project either using their own staff or contractors. Ensure that they keep records.

4. Inform the municipality/water authority that they are responsible for all the "leg work," such as setting up a new water district, soliciting bids, obtaining easements, securing a new water supply permit, and the like. Ensure that all their expenditures are fully documented and forwarded to the BSPR Central Office.

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[34] *These steps are followed only when it is necessary to solicit bids from non-standby contractors. Otherwise, work may start as soon as you obtain approval to use standby contractor.*

Attachment 1.6-3

Organic Chemicals in Drinking Water

Policy

Organic chemicals in drinking water should be reduced to the lowest level possible, ideally to nondetectable levels, to limit exposure of the public. The action step levels listed on the attached Action Step Table are to be used in evaluating the drinking water quality and determining appropriate response at public water systems for organic chemicals without an established Part 5 maximum contaminant level (MCL).

Action Steps

Action step levels have been established by the Department to provide guidance in responding to organic chemical concerns at public water systems. When water quality sampling identifies an organic chemical at or above the level listed on the Action Step Table, the noted action must be undertaken. The indicated values are action steps and should not be referred to or used as standards (maximum contaminant levels) for drinking water or environmental quality.

The Action Step Table listing will be updated periodically. Therefore, prior to recommending a specific action to a public water system, the Bureau of Public Water Supply Protection (BPWSP) should be contacted to determine if there are any changes to the action step values and for assistance in interpreting how these action steps relate to the specific public water system situation.

References

A. 10 NYCRR, Part 5: Drinking Water Supplies.

B. Environmental Health Manual Item PWS 159, Responding to Organic Chemical Concerns at Public Water Systems.

Attachment 1.6-3

Organic Chemicals in Drinking Water
(continued)

ACTION STEP TABLE

ORGANIC CHEMICAL	ACTION STEP 1	ACTION STEP 2
Unspecified:		
Individual	50 ug/l	10 ug/l
Total	100 ug/l	50 ug/l
Xylenes (Total)	50 ug/l	10 ug/l
Aldicarb	7 ug/l	3 ug/l
Atrazine	25 ug/l	5 ug/l
Carbofuran	15 ug/l	3 ug/l
Benzene	5 ug/l	1 ug/l
Vinyl Chloride	5 ug/l	1 ug/l
PCB (Total)	1 ug/l	*

*Any positive result.

NOTE:

1. ACTION STEP 1 level being met or exceeded requires discontinued use of the source or other appropriate steps to assure the safety of the public's health and initiation of EHM Procedure PWS 159, Responding to Organic Chemical Concerns at Public Water Systems.
2. ACTION STEP 2 level being met or exceeded requires notification of the Bureau of Public Water Supply Protection and initiation of EHM Procedure PWS 159, Responding to Organic Chemical Concerns at Public Water Systems.

Objective

To assure effective response to organic chemical concerns at public water systems through problem identification and verification, coordination of response, and implementation of remedial and follow-up actions.

Policy

When the presence of an organic chemical at or above an established Maximum Contaminant Level (MCL) or Action Step Level [Environmental Health Manual (EHM) Technical Reference: PWS 69] in a public water system is confirmed, appropriate steps must be taken to assure the safety of the public's health. However, use of a primary source of supply will not be discontinued without Bureau of Public Water Supply Protection (BPWSP) authorization.

Upon notification to the BPWSP that the levels specified in EHM Technical Reference PWS 69 or a Part 5 MCL have been exceeded, the response outlined below should be initiated.

Each response should: identify and verify the problem, develop a course of action and describe how problem resolution will be tracked. The recommended course of action for the public water system will, as a minimum, include a water quality monitoring program, an engineering and/or hydrogeological study and an acceptable plan for problem resolution.

Procedure

Bureau of Public Water Supply Protection (BPWSP)	1. Designates point person within BPWSP and completes Problem Alert Form (FOMG-1)
	2. Develops a public water system profile with the appropriate field units, bureaus, and/or agencies. The profile should contain the data specified in the Supplementary Information Section.

Attachment 1.6-3

Organic Chemicals in Drinking Water (continued)

	3. Notifies and consults with staff of the Bureau of Toxic Substance Assessment (BTSA) regarding the health implications of the particular chemical(s) suspected to be present. This data is to be added to the public system profile.
	4. Arranges with the BTSA when setting priorities for the analysis of samples submitted to the Wadsworth Center for Laboratories and Research (WCL&R).
Bureau of Toxic Substance Assessment	5. Develops fact sheets on the health effects of the suspected chemical(s) and distributes to consumers and local physicians and nurses as necessary.
Regional Office	6. Designates a point person within Region and coordinates site inspection with the Local Health Unit (LHU) for the purpose of: a. verifying conditions and status and b. collection of necessary samples.
Wadsworth Center for Laboratories and Research (WCL&R)	7. Conducts appropriate analyses and reports results to LHU, Region, BPWSP and BTSA as requested.
BPWSP	8. Prepares in conjunction with the Region and LHU a recommended course of action and forwards it to the Director, BPWSP, for approval.

Attachment 1.6-3

Organic Chemicals in Drinking Water
(continued)

	9. Consults with the BTSA and Field Operations Management Group as appropriate. Keeps Region/LHU informed of course of action to be taken and roles and responsibilities of all parties.
LHU	10. Notifies the public water system of actions to be taken and maintains surveillance over the system's response.
	11. Notifies Region of any significant changes in status.
Regional Office	12. Assists LHU as requested and submits periodic status reports to the BPWSP.
	13. In conjunction with the LHU prepares a final report when the problem is corrected and all remedial measures are completed.
BPWSP	14. Provides, as necessary, liaison with other agencies.

Organic Chemicals in Drinking Water
(continued)

References

A. 10 NYCRR, Part 5: Drinking Water Supplies.

B. EHM Technical Reference Item PWS 69 - Organic Chemical Action Steps for Drinking Water.

Supplementary Information

A public water system profile developed under this manual item shall include, as a minimum the following:

A. Source and Treatment Characteristics:
   1. Surface or Groundwater Conditions, including quantity and quality characteristics
   2. Capacity/Safe Yield of Primary and Auxiliary Source
   3. Emergency Interconnections
   4. Available Treatment
   5. Flow Conditions
   6. Dilution Factors

B. Service Area Characteristics:
   1. Population Served
   2. Average/Maximum Consumption
   3. Distribution Storage
   4. Residential, Commercial, Industrial Usage

C. Location Map:
   1. Sources
   2. Treatment and Storage Facilities
   3. Distribution System
   4. Interconnections
   5. Potential Sources of Chemical found

D. Water Quality Summary
   1. Raw
   2. Treated

Attachment 1.6-3

Organic Chemicals in Drinking Water
(continued)

E. Key Utility and Community Personnel

   1. Name/Position
   2. Address
   3. Telephone Numbers

F. Special Conditions

G. Potential Water Conservation Measures

H. Health Implications of the Contaminant

I. Central Office, Regional and Local contact persons with phone numbers.

REFERENCES

1. National Research Council. 1983. Risk Assessment in the Federal Government: Managing the Process. Committee on the Institutional Means for Assessment of Risks to Public Health. National Academy Press.

2. See Note 1.

3. U.S. Environmental Protection Agency. Office of Underground Storage Tanks. March 2, 1987. "The Appropriateness of Benzene as an Indicator Chemical for Leaking UST Sites." Prepared by Camp Dresser, & McKee Inc., Boston, MA.

4. Camp, Dresser & McKee, Inc. April 1987. "The Cost-Effectiveness of Alternative Corrective Action Technologies," prepared for the U.S. Environmental Protection Agency, Office of Underground Storage Tanks.

5. Chemvront, D.A., Giggy, C.L., Loven, C.G., and Swett, G.H. "Groundwater Treatment with Zero Air Emissions."