TECHNICAL

RESOURCE MATERIAL

SYNOPSIS OF SPILL MANAGEMENT AND CLEAN-UP TECHNOLOGIES

NOTES

Synopsis of Spill Management and Clean-up Technologies

GUIDANCE SUMMARY AT-A-GLANCE

The following table lists those technologies covered in this section and the page cross-reference. Note that these technologies have been grouped into three categories:

-- Assessment and Treatment of Soils;
-- Assessment and Recovery of Free Product and Ground Water; and
-- Treatment of Ground Water.

Each subsection begins with a summary table describing the application, necessary equipment, limitations, costs, and pertinent additional reference materials. Each technology is discussed in terms of its capabilities; design, operation, and maintenance; costs; and advantages and disadvantages.

NOTES

Synopsis of Spill Assessment and Clean-up Technologies

GUIDANCE SUMMARY AT-A-GLANCE
(continued)

Other sections of this manual with additional information on the kind and use of spill management and remediation technologies include:

-- Part 1, Section 3, Emergency Response;
-- Part 1, Section 4, Site Investigation Procedures; and
-- Part 1, Section 6, Corrective Action.
-- Part 2, Section 3, Proper Management of Spill Residuals and Debris.

Treatment of Soil

Soil Contamination Treatment Process	Design and Installation	Advantages and/or Disadvantages
Excavation and Disposal (without treatment)	- Proper equipment selection (back-hoes, loaders, dozers, cranes, pumping and tank truck equipment) - Operational areas established including area zones for hot, transition and clean zones - Utilization of air monitoring equipment, as necessary - Additional operational areas for staging, treating, storage, decontamination, as necessary	Advantages - High "applicability" at UST sites and most "non-UST" sites - Reduces contaminant mobility - Approaches 100% removal of contaminants in soil excavated Disadvantages - Contaminants are brought to surface increasing exposure risks - Large quantities may make method impractical or too costly - Not readily applicable in heavily urbanized areas - Transfers contaminants and problems off site - Disposal at landfill is only alternative
Enhanced Volatilization Types: Enclosed mechanical aeration Low temperature thermal stripping Venting	- Determination of appropriate volatilization process/system: - Address site specific operational constraints - Common design criteria include: # Soil type # Contaminant type # Vent spacing # Vent depth # Blower requirements # Vapor Emission Control	Advantages - VOC removal of approx. 99.99% Disadvantages - May require vapor phase treatment and dust control - Not usable with non-volatile contaminants

SYNOPSIS OF SPILL MANAGEMENT AND CLEANUP TECHNOLOGIES: GUIDANCE SUMMARY-AT-A-GLANCE
Treatment of Soil
(continued)

Soil Contamination Treatment Process	Design and Installation	Advantages and/or Disadvantages
Soil Washing/Flushing	- Determine washing agent (flushing agent/solvent) most appropriate for contaminant(s): # Water # Chelating/complexing # Surfactants # Acids/Bases # Reducing agent - Flushing agent effect(s) on soil properties - Define contamination boundaries/ distribution - Site suitability for well/drains/flooding determination - Control of flushing agent application rate - Equipment considerations (drains, elutriate collection/distribution) - Reapplication of recovered elutriate - System must be controlled hydraulically to not allow flushing agent to escape to ground water	<u>Advantages</u> - Applicable at UST sites - Can accelerate contaminant removal rate - Removal of contaminants up to 99.99% possible <u>Disadvantages</u> - Not as effective for low-permeability soils - Applicable for some heavy metals - May require separation techniques such as distribution, evaporation, and centrifigation

Soil Contamination Treatment Process	Design and Installation	Advantages and/or Disadvantages
Biodegradation Types: 1. In Situ 2. Excavated	- Determination of existing microbial population, biodegradability of organic contaminant, and other environmental parameters (pH, temperature, nutrient level) - Maintenance of dissolved oxygen sustaining microbial population - Determination of site hydrology (important to prevent migration outside of closed system) - Treatment system should provide adequate contaminant and treatment agent contact - Recovery of contaminant and treatment agent as necessary - Performance monitoring, as necessary - Understanding of soil chemistry and hydrology	<u>Advantages</u> - Possibly most promising in situ treatment technique; short treatment times possible - Soil bacteria metabolize hydrocarbons and other environmental contaminants - Indigenous microbial population can be enhanced with genetically engineered (acclimated) microorganisms <u>Disadvantages</u> - Biologic systems are sensitive and can be upset - Difficult to supply nutrients and oxygen throughout treatment zone - High cost
Incineration (Thermal Destruction)	- Determine appropriate incineration process: # Mobile/stationary # Rotary-kiln # Fluidized bed # Multiple hearth - Determine hazardous incineration end-products - Air pollution control equipment determination and monitoring, as necessary - Determine appropriate combustion temperature and residence times (determined by contaminant combustion characteristics)	<u>Advantages</u> - Mobile units show promise for use at UST sites - Reduces contaminant volume and mobility - Appropriate for volatile and nonvolatile contaminant destruction <u>Disadvantages</u> - Permitting requirements can delay use - Less cost-effective for smaller volumes of contaminated soil

Ground-Water Contamination Treatment Process	Design and Installation	Advantages and/or Disadvantages
Activated Carbon Adsorption	- Pretreatment via biodegradation, filtration, and/or air stripping, as necessary - Mobile carbon systems easy to operate and compact - Carbon system sizing includes: # Hydraulic retention time (hrs) # Flow (gallons/min) # Hydraulic capacity of carbon (gallon/waste/pound carbon) # Collected volume of treated ground water at breakthrough (gallons) # Carbon density (pounds carbon/cubic foot) - Improve efficiency with additional carbon columns - Determine thermal destructive properties of contaminants for regeneration or for means of disposal - Minimal operations and maintenance with adequate automatic controls	<u>Advantages</u> - Widely used for treatment of contaminated ground water - Good to excellent removal of some metals and inorganics - Well-suited for removal of mixed organics of low solubility and varying concentration <u>Disadvantages</u> - Contaminant's polarity determines removal effectiveness. the removal of highly polar contaminants is least effective - Pretreatment may be necessary with oil and grease influent concentrations of $\leq$ 10 ppm - Very high cost

Ground Water/Free Product Recovery Systems	Design and Installation	Advantages and/or Disadvantages
Air Stripping	- Similar in construction to water cooling tower (e.g., modular) - Determine appropriate design based on: # Tower diameter # Packing heights # Air/water ratios # Tower packing materials - Computer modeling available to determine system/site design - Readily connected to vapor recovery equipment	Advantages - Countercurrent packed tower most appropriate configuration for the treatment of contaminated ground water - Mobile units are easily obtained and frequently used at UST sites - Removal of volatile organics from ground water - Varying levels of removal achieved by varying air to water ratios - Can be rapidly deployed to site Disadvantages - Stripped organics emissions may require hook-up to vapor-recovery equipment - Odors can cause problems - Requires means to handle water effluent - Clogging by bacteria - Not applicable for fuel oils (volatiles only)

Ground Water/Free Product Recovery Systems	Design and Installation	Advantages and/or Disadvantages
Chemical Treatment Types # Neutralization # Precipitation # Oxidation/reduction # Ion exchange	- Chemical metering equipment, where appropriate - Adequate mixing employed, as necessary - Enclosed processing to prevent fume/gas escape, as necessary - Process monitoring equipment, as necessary - Storage units, as necessary	<u>Advantages</u> - Withdrawal of contaminated ground water treated chemically via various treatment methods or combination of methodologies - pH adjustment with addition of acids/bases - Chemical treatment methodologies used as pretreatment as necessary to other treatment processes - Contaminants in solution transformed to solid state - Contaminant oxidation state transformed (e.g., eliminate toxicity or easier handling of contaminant) <u>Disadvantages</u> - Possibility of incomplete chemical reactions - Probably not applicable to most UST sites
# Interceptor Ditches # Groundwater Reinjection # Groundwater Pumping # Well Points # Deep Wells # Ejector Wells	Each system is site specific and is dependent on the following: # Depth of contaminants # Rate of aquifer recovery # Area geology # Type of treatment system (i.e., subsurface treatment or above ground treatment) - Determine number of wells and/or trenches required	<u>Advantages</u> - Each system is used singularly or in combination - Used to contain, divert or remove contaminants <u>Disadvantages</u> - Performance is based on system design - Reliability of pumping system is affected by mechanical/electrical failure

Costs of Recovery and Treatment

Soil Contamination Treatment Process	Summary of Costs
Excavation and Disposal	- Equipment plus labor costs can range from $1200 per day to $2000 per day - Disposal (excluding transportation): can range from $90 to $240 per ton
Enhanced Volatilization Types: # Low temperature thermal stripping # Venting	- Low temperature thermal stripping ranges in cost from $56 to $120 per cubic yard for processing 10,000 tons or more - Venting (passive and active): ranges in cost from $10 to $20 per cubic yard
Soil Washing/Flushing	- Usually combined with other treatment processes - $150-200 per cubic yard
Biodegradation In Situ	- Based on volume of soil/water to be treated - Costs are site-specific and usually high
Incineration (Thermal Destruction)	
Incineration facility	- From $350 per drum up to $1500 per ton/rolloff rental costs
On-site mobile unit	- About $250-$350 per ton; minimum of 500 tons

Costs of Recovery and Treatment (continued)

Contaminated Water Treatment Processes	Summary of Costs
Activated Carbon Adsorption	- A mobile GAC System (10 gallons/minute costs about $25,000 to $40,000 for delivery and start up; $18,000 to $24,000/yr for regeneration costs - Actual costs are site-specific
Air Stripping	- Costs on a volume-treated basis are usually $0.05 to $0.25 per 1000 gallons - Typical capital cost is $27,000 to $55,000 - Typical Operation and Maintenance cost is $1,000 - $6,000 per year

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3.1 Synopsis of Spill Assessment and Clean-up Technologies

This section is intended as a companion to several other sections in the manual, particularly Section 1.6, Corrective Action. We reserved this section for a more detailed discussion of spill assessment and clean-up technologies and their costs. The cost information provided is limited, however, and you are encouraged to refer to cost information in your spill response contracts.

We divided this section into two subsections. The first subsection summarizes those technologies and techniques useful in the assessment or investigation of subsurface contamination. These technologies and techniques include:

- Soil Gas/Vapor Monitoring;
- Geophysical Techniques
- Well Drilling Methods; and
- Monitoring/Observation Wells.

The second subsection covers a variety of recovery and clean-up technologies and techniques for soil and/or ground water contaminated by petroleum products. These technologies include the following:

Soil	Ground Water
# Excavation and Disposal;	# Well Points;
# Venting;	# Ejector Wells;
# Enhanced Volatilization;	# Ground-Water Pumping;
# In-Situ Soil Washing/ Flushing;	# Ground-Water Reinjection;
# Chemical Extraction;	# French Drains/Interceptor Trenches;
# Bioremediation;	# Carbon Adsorption;
# Incineration; and	# Air Stripping; and
# Asphalt Incorporation.	# Bioremediation.

1. Spill Contamination Assessment and Investigation

The following subsections describe methods and techniques that are usable in the assessment and investigation of subsurface petroleum contamination.

a. Soil Gas/Vapor Monitoring

The monitoring of soil gases may be used to identify the presence or absence of petroleum products. Samples may be collected for qualitative analysis in the field or sent to the laboratory for quantitative analysis. Direct-reading instruments provide for real-time analysis in the field and can detect contaminants in concentrations down to one part per million

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(ppm). Real-time data can be used on-the-scene to guide clean-up decisions (e.g., how much contaminated soil to remove).

The soil gas sample is collected using a push probe to create a 1/4- to 1/2-inch hole in the soil. Typically, the probe is driven (by hand or mechanically) some four feet or so into the soil, however, a drill rig may be used to reach deeper soil depths for sampling probable contamination at depth. The sampling probe is then removed and a perforated tube or piping is inserted into the hole. The perforated tubing/piping allows petroleum vapors to be drawn from the surrounding soil by means of a peristaltic pump and into a sampling chamber, vial, or bag. Air samples can then be withdrawn and analyzed (either in the field or in the laboratory).

A discussion of the different kinds of direct-reading instruments can be found in Part 2, Section 1, Personal Health and Safety Protection. All monitoring equipment should be intrinsically safe for operation in a potentially explosive environment.

The following guidelines should be followed to facilitate accurate recording and interpretation of these direct-reading instruments in the field:

- Calibrate instruments according to the manufacturer's instructions before and after every use.

- Develop chemical response curves, if these are not provided by the instrument manufacturer.

- Instrument's readings have limited value where contaminants are unknown. When recording readings of unknown contaminants, report them as "needle deflection" or "positive instrument response" rather than specific concentrations (i.e, ppm).[4] Conduct additional monitoring at any location where a positive response occurs.

- A reading of zero should be reported as "no instrument response" rather than "clean" as non-detectable quantities of the contaminant may be present.

- The survey should be repeated with several detection systems to maximize the number of chemicals detected.

[4]*"Needle deflection" or "positive instrument response" indicates that one or more contaminant, which are measurable by the direct-reading instrument, are present.*

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These instruments are generally rented as part of a contractor's service or purchased by the Central Office for use by spill response staff.

The use of direct-reading instruments allows for portability and the real-time analysis of samples in the field. The soil monitoring points are easily installed as either permanent or temporary monitoring stations. The use of these instruments is, however, limited to:

- **#** The device's ability to detect only certain compounds or class of compounds;
- **#** An overall detection limit of 1 ppm;
- **#** May detect non-hazardous compounds that results in a false reading of the contaminant levels; and
- **#** Measurement are mostly qualitative rather than quantitative for vapor emissions.

The interpretation of data obtained at a site during monitoring should be conservative.

------ SOIL GAS MONITORING SUMMARY ------

APPLICATION: Identify quickly the presence of volatile gases/vapors in soils. Can be used to quickly screen sites for the extent of volatile contamination.

EQUIPMENT: Variety of temporary or permanent sampling installations can be used. Samples can be analyzed in the field with a flame ionization detector (FID) or photoionization detector (PID, or HNu meter). Samples can be analyzed in the field with a portable gas chromatograph (GC) or in the laboratory with a GC or gas chromatograph/mass spectrometer (GC/MS). Compound-specific Draeger tubes can also be used in the field to sample soil vapor, but are more often used for ambient air monitoring.

LIMITATIONS: The detection equipment should be calibrated and proven intrinsically safe for explosive environment prior to its use. Readings should be carefully interpreted to avoid false detection or not detecting trace amounts. Technique must be used carefully in high clay soils as clay impedes migration of vapors. Should not be used if ground water is within five

NOTES

feet of ground surface. Best used to focus follow-up confirmatory sampling.

COST: Cost to purchase field air monitoring instruments range from \$4,000 to \$10,000. Laboratory equipment costs are much higher. Typical rental fees for field equipment range from \$50 to \$120 per day. Soil gas sampling by a contractor can cost from \$125 to \$250 per sample depending upon number of samples and method of analysis, but inclusive of sample collection costs. Costs for a typical soil gas survey may be in the range of \$2000 to \$4000 per day.

REFERENCES: [1,2,5,8,10]

b. Geophysical Techniques

Geophysical survey techniques can be used to complement the more traditional and intrusive site investigation techniques of drilling soil borings and monitoring wells. They can be used, for example, to quickly screen a site to provide information on subsurface soil and rock conditions, such as depth to bedrock or the presence of preferential flow paths. Obtaining the same information through the use of borings and monitoring wells often involves far greater expense and disruption of on-site activities, and is accomplished mainly by educated guesswork. Geophysical survey techniques offer a means to minimize such "hit or miss" guesswork and help focus drilling activities (i.e, reduce the number of drilling sites) and confirmatory sampling efforts.

Geophysical survey methods can be applied at UST release sites to:

- Locate buried pipelines in clearing an area for drilling or as preferential flow paths for contaminant migration;

- Locate abandoned tanks that may be a source of contamination;

- Map natural geohydrologic features such as buried stream channels, clay layers, and bedrock; and

- Map conductive contaminant plumes and track plume migration.

These methods can be cost-effective, site reconnaissance techniques to provide spatial coverage of a site with less risk than associated with a conventional drilling program. Geophysical measurements are, however, remote-sensing (as opposed to direct sampling) methods because they respond to changes in physical or chemical parameters in the subsurface from a distance. They can provide both indirect and direct measurement of subsurface properties.

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Unlike discrete sampling with borings and wells, which yields only limited spatial and volumetric information, geophysical methods "measure" or "sample" a much larger volume of the subsurface environment. This aspect of geophysical measurement has both advantages and disadvantages. By measuring a larger volume of the subsurface, these techniques provide an average picture of subsurface conditions. However, if a geohydrologic feature or anomalous condition is small, it may not be detected in this larger volume. There is a trade-off, then, between geophysical and direct sampling methods. The former can provide more representative results while the latter provides for better resolution. Used together, the two methods can effectively complement one another. Geophysical methods can be used to locate the anomalous and non-anomalous zones of interest that then can be subject of direct sampling efforts.

Six geophysical techniques have been applied in subsurface contamination investigations, including UST assessments. These techniques are:

- Ground-penetrating radar (GPR);
- Terrain conductivity or electromagnetic (EM) induction;
- Resistivity;
- Seismic refraction;
- Metal detection; and
- Magnetometry.

Metal detection and magnetometry are useful in locating buried metal such as pipelines, tanks, and drums. GPR can define the boundaries of subsurface geohydrologic features such as buried trenches, stream channels, and the like. Terrain conductivity and resistivity methods can help define contaminant migration in both the unsaturated and saturated zones. Resistivity and seismic techniques are used in determining geological stratigraphy.

Exhibits 3.1-1 and 3.1-2 summarize the typical primary and secondary applications and other characteristics of these six techniques in contamination assessments. These are all surface-type geophysical methods; excluded from this discussion are the downhole methods, such as gamma ray borehole logging, and the airborne or satellite remote-sensing methods.

It should be noted that the performance of any geophysical technique depends on its specific application and site conditions. No single method works at all sites or for all investigation problems. They should always be used in conjunction with some

Exhibit 3.1-1

Applications of Geophysical Methods to Contamination Assessments

Application	Radar	Terrain Conductivity	Resistivity	Seismic Refraction	Metal Detection	Magnetometry
Map Geohydrologic Features	P	P	P	P	N/A	N/A
Map Conductive Contaminant Plumes	S	P	P	N/A	N/A	N/A
Locate and Define Trenches with Metal	P	P	S	S	S	S
Locate and Define Trenches without Metal	P	P	S	S	N/A	N/A
Locate and Define Buried Metal	S	S	N/A	N/A	P	P

P = primary method S = secondary method N/A = not applicable

Source: Adapted from U.S. EPA. Geophysical Techniques for Sensing Buried Wastes and Waste Migration. Prepared by Technos, Inc. and Lockheed Engineering and Management Services Co., Inc. Prepared for Office of Research and Development, Environmental Monitoring Systems Laboratory, Advanced Monitoring Systems Division, Las Vegas, Nevada.

Exhibit 3.1-2

Characteristics of Six Geophysical Survey Methods

Method	Responds to Change In	Mode of Measurement	Depth of Penetration	Resolution
Ground Penetrating Radar (GPR)	Complex Dielectric Constant of soil, rock, pore fluids, and man-made objects	Continuous Profile .4 Km/hr. detail - 8 Km/hr. reconnaissance (ground contact not necessary)	One to ten meters typical-highly site specific. Limited by fluids and soils with high electrical conductivity and by fine grain materials	Greatest of all six geophysical methods
Electromagnetics (EM)	Bulk electric conductivity of soil, rock and pore fluids (pore fluids tend to dominate)	Continuous profiles to 0.5 to 15 meters depth. Station measurements to 15 to 60 meters depth. Some sounding capability (ground contact not necessary)	Depth controlled by system coil spacing 0.5 to 60 meters typical	Excellent lateral resolution. Vertical resolution of two layers. Thin layers may not be detected.
Resistivity Sounding (RES)	Bulk electrical resistivity of soil, rock and pore fluids (pore fluids tend to dominate)	Station measurements for profiling or sounding (must have ground contact)	Depth controlled by electrode spacing. Limited by space available for array. Instrument power and sensitivity become important at greater depth.	Good vertical resolution of three to four layers. Thin layers may not be detected.
Seismic Refraction	Seismic velocity of soil or rock which is related to density and elastic properties	Station measurements (must have ground contact)	Depth limited by array length and energy source	Good vertical resolution of three to four layers. Seismic velocity must increase with depth - thin layers may not be detected

Exhibit 3.1-2

Characteristics of Six Geophysical Survey Methods (continued)

Method	Responds to Change In	Mode of Measurement	Depth of Penetration	Resolution
Metal Detector (MD)	Electrical conductivity of ferrous and non-ferrous metals	Continuous (ground contact not necessary)	Single target three meters Larger targets up to six meters	Very good ability to locate targets
Magnetometer (MAG)	Magnetic susceptibility of ferrous metals	Continuous total field or gradient measurements. Many instruments are limited to station measurements. (Ground contact not necessary)	Single target up to six meters Larger targets up to 20 meters	Good ability to locate targets

level of direct sampling and their successful application is dependent upon integrating the geophysical data with other sources of information. To differing degrees, each technique also requires a skilled, experienced operator not only in the use of the equipment, but also in the engineering and earth sciences.

The following summaries of each geophysical method were taken from "Geophysical Techniques for Sensing Buried Wastes and Waste Migration" issued by the U.S. EPA.

Ground-penetrating radar

Ground-penetrating radar (GPR) uses high frequency radio waves to acquire subsurface information. From a small antenna, which is moved slowly across the surface of the ground, energy is radiated downward into the subsurface, then reflected back to the receiving antenna, where variations in the return signal are continuously recorded. This produces a continuous cross-sectional "picture" or profile of shallow subsurface conditions. These responses are caused by radar wave reflections from interfaces of materials having different electrical properties. Such reflections are often associated with natural geohydrologic conditions such as bedding, cementation, moisture and clay content, voids, fractures, and intrusions, as well as man-made objects.

GPR responds to changes in soil and rock conditions. An interface between two soil or rock layers having sufficiently different electrical properties will show up in the radar profile. Buried pipes and other discrete objects will also be detected. The depth of penetration is highly site-specific, being dependent upon the properties of the site's soil and rock. The method is limited in depth by attenuation, primarily due to the higher electrical conductivity of subsurface materials. Generally, better overall penetration is achieved in dry, sandy, or rock areas; poorer results are obtained in moist, clayey, or conductive soils. However, many times data can be obtained from a considerable depth in saturated materials, if the specific conductance of the pore fluid is sufficiently low. GPR penetration from one to ten meters is common.

The continuous nature of the GPR method offers a number of advantages over some of the other geophysical methods. The continuous vertical profile produced by GPR permits much more data to be gathered along a traverse, thereby providing a substantial increase in detail. The high speed of data acquisition permits many lines to be run a across a site, and in some cases, total site coverage is economically feasible. High resolution work can be accomplished by towing the antenna by hand at slower speeds. Resolution ranges from centimeters to several meters depending upon the antenna (i.e., frequency) used. A change in frequency is accomplished by selecting the appropriate antenna; antennas of higher frequency and shorter wavelength (500 to 900 MHz) provide resolution of

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a few centimeters, but are unable to penetrate the ground very far, due to increased losses at these higher frequencies. Lower-frequency antennas (80 to 125 MHz) are capable of working to greater depths and of operating in poor soil conditions, but lack the resolution to define features smaller than about one meter in size.

Exhibit 3.1-3 shows a simplified diagram of a GPR system. The system consists of a control unit, antenna, graphic recorder, and an optional magnetic tape recorder. Various antennas may be used with the system to optimize the survey results for individual site conditions and specific requirements.

The impulse radar transmits electromagnetic pulses of short duration into the ground from a broad-band antenna. The antenna is usually in close proximity to the surface of the ground. Pulses radiated from the antenna are reflected from various interfaces within the subsurface and are picked up by the receiver section of the antenna. They are then returned to the control unit for processing and display. Radar reflections will be returned from any natural or man-made object which has a contrast in its dielectric properties. Reflections from deeper targets will appear lower on the graphic display.

The time the electromagnetic pulse takes to travel from the antenna to the buried object and back to the antenna is proportional to the depth of the buried interface or object. This time is called two-way travel time and is dependent on the dielectric properties of the media through which the pulse travels. These dielectric properties are in turn a complex function of the composition and moisture content of the subsurface soil and rock materials. In almost all cases, the moisture content has the greatest influence, because water has a very high relative dielectric value compared to common soils and rock. The greater the amount of water saturation, the lower the radar velocity. Accordingly, the lower the velocity, the lower the object will appear in the radar record. Depth is calculated from this velocity using:

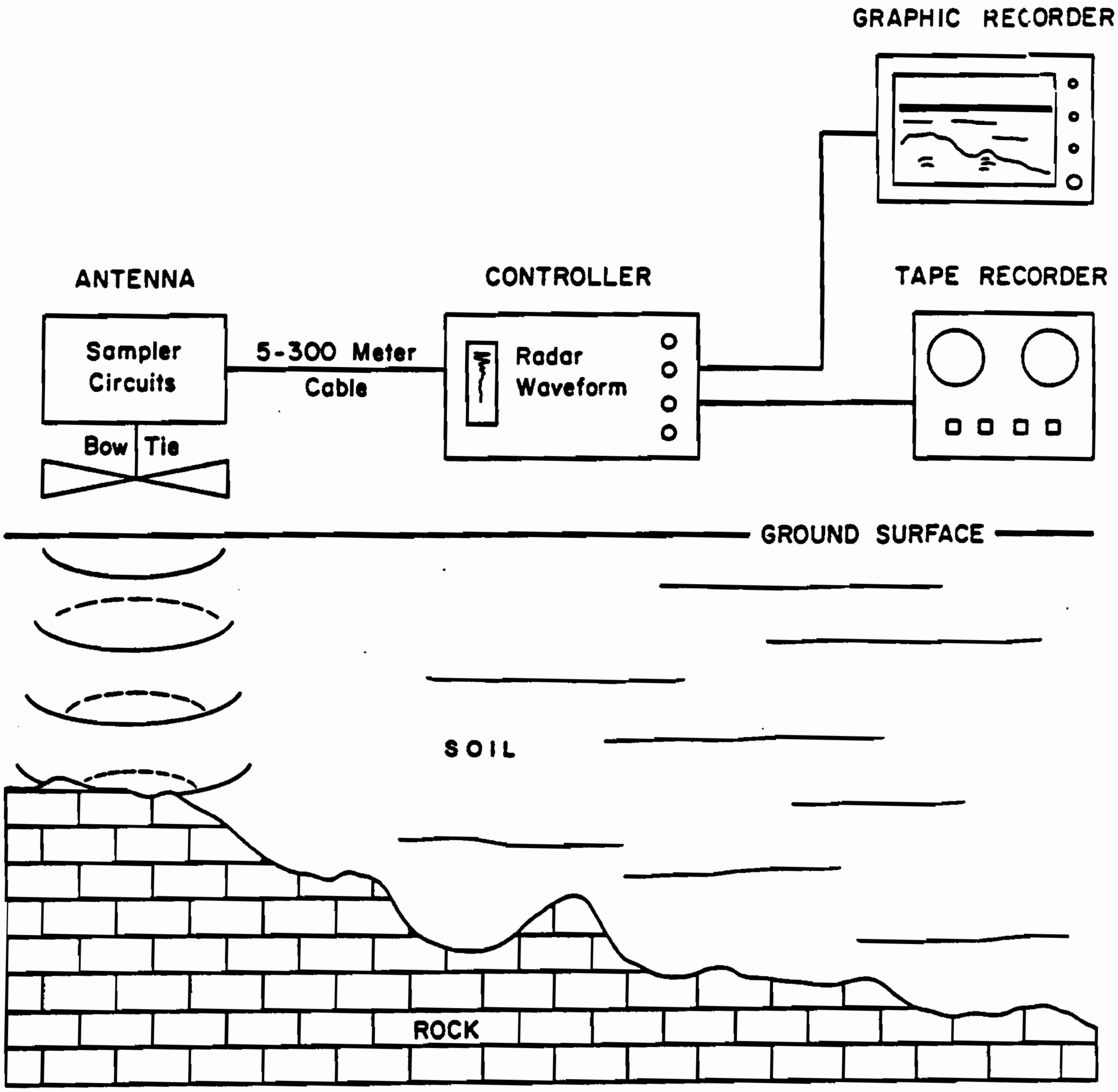
$$D = \frac{CT}{2E_r} = \frac{VmT}{2}$$

where Vm = velocity in material
C = a constant, the velocity of light (3×10^8) m/sec
Er = relative dielectric constant
T = two-way travel time in nanoseconds
(1 nanosecond (ns) = 10 seconds)

Depth of penetration is a function of the GPR signal attenuation within the subsurface media. This attenuation consists of electrical losses, scattering losses, and spreading losses. Since

Exhibit 3.1-3

Diagram of Ground Penetrating Radar System



spreading losses are inherent in GPR systems, they are constant and will not be considered further. Electrical and scattering losses, however, are highly dependent on site conditions.

The primary factors controlling electrical attenuation of GPR are the electrical conductivity of the soil/rock system and the radar frequency. An increase in either subsurface conductivity or the radar frequency will result in greater attenuation of the radar signal. The frequency of the radar may be varied by changing antennas. Unfortunately, the conductivity of the subsurface cannot be varied. High conductivities due to dissolved salts from natural sources or contamination will cause strong attenuation of the radar signal.

An increase in the water content of dry soil or rock can also increase its electrical conductivity greatly. Similarly, an increase in clay content will usually increase conductivity. However, water or clay content alone will not always seriously degrade GPR performance. Experience has shown that penetrations of more than ten meters can be obtained in water-saturated sands where conductivity is low.

Generally, the requirement for attaining adequate penetration depth will be the major factor in determining the appropriate antenna. Once adequate radar penetration is achieved, the resolution requirements may then be considered. Generally, results obtained with 250-500 MHz antennas are excellent for delineation of soil horizons, soil/rock surfaces, soil piping, buried trenches, and other shallow and smaller targets. Attenuation caused by subsurface conditions may require the use of lower-frequency antennas. In these cases, the 80 MHz-125 MHz frequency antennas can be used at the expense of some resolution.

Radar reflections from a single interface generally result in a set of multiple black bands on the graphic display. This type of response is inherent in the impulse method. Generally the location of an interface is picked to be at one of the while lines between the black bands. Occasionally, these multiple bands can obscure information if two interfaces are close together. If necessary, special processing techniques, originally developed for seismic exploration, can be employed to help alleviate this problem.

Sources of unwanted noise that can degrade GPR data can be grouped as follows:

#System noise;

#Overhead reflections due to power lines, trees, and the like (pertinent to unshielded antennas only);

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#Noise due to surface factors such as ditches, metal, and the like;

#Noise due to natural subsurface features or buried trash; and

#External and electromagnetic noise from radio transmitters.

Of these factors, system noise is the most common problem. Steady-state noise may be introduced by improper cable placement. Locating antennas too close to a metal object will also cause noise problems. Such noise can be minimized, but not always eliminated, by system adjustments.

Lower-frequency antennas are not shielded on their top surfaces and, therefore, receive radar reflections from overhead objects such as tree branches, power lines, and buildings. Such a reflection can be identified by means of the characteristic signal associated with its very low two-way travel time in air. Once identified, such signals can be ignored in the analysis of the data.

Surface noise may be generated by pieces of metal lying on the ground, which can cause a reverberation or ringing of the radar signal throughout the record. While smaller objects such as nails do not ordinarily cause problems, an object as small a wire coat hanger can create a substantial problem. An effort should be made to remove such debris from the immediate area of the radar antenna path.

Small topographic variations may cause some variations in the data. Crossing a small ditch, for example, can introduce a band of noise in the data. Radar records acquired in areas having appreciable clay concentrations at the surface will often have a smeared or distorted appearance, which may mask useful information in the data. In addition, some natural geologic settings will result in apparent noisy data caused by scattering from a large number of natural boulders. If radio transmitters are in use nearby, their radiated signal will occasionally cause significant noise to appear on the graphic record.

------ GROUND-PENETRATING RADAR SUMMARY ------

Capabilities

#The radar method provides continuous data along a traverse line, producing a picture like display in real time.

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#Traverse speeds should range from 0.5 to 2 km/hr for a detailed survey up to 8 km/hr for lower resolution reconnaissance surveys.

#The graphic record can often be interpreted in the field.

#The method provides very high resolution from a few centimeters to one meter, depending upon the frequency (i.e., antenna) used.

#System optimization to local site conditions can be accomplished by changing antennas (i.e., frequency). Higher frequencies provide for the best resolution. Lower frequencies provide for deeper penetration.

#Approximate depths and relative depths are easily established using simple assumptions and interpretation techniques.

#The method may be used in fresh water and through ice to obtain profiles of depths and sediments.

#A wide variety of processing techniques may be applied to radar data to aid interpretation and presentation.

Limitations

#Depth of penetration is very site-specific and limited by the electrical conductivity of pore fluids and clay minerals.

#Depth of penetration is commonly less than 10 meters. In extreme soil conditions, effective penetration may be less than one meter.

#Both the instrumentation and technique are sophisticated and, therefore, require experienced personnel for operation.

#Interpretation of raw data may be very difficult under some conditions.

#Semi-quantitative and quantitative assessments require considerable care to avoid numerous interpretation pitfalls.

#Depth calibration requires careful on-site work and, if site conditions change, the depth calibration will be affected. Further, the depth scale is often nonlinear.

#The data can be affected by a variety of sources of noise.

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Terrain Conductivity or Electromagnetic Induction

The terrain conductivity or electromagnetic (EM) induction method provides a means of measuring the electrical conductivity of subsurface soil, rock, and ground water. Electrical conductivity is a function of the type of soil and rock, its porosity, its permeability, and the fluids that fill the pore space. In most cases, the conductivity (specific conductance) of the pore fluids will dominate the measurement. Accordingly, the EM method is applicable to an assessment of natural geohydrologic conditions and to mapping of many types of contaminant plumes. Additionally, trench boundaries, buried wastes and drums, as well as metallic utility lines can be located with EM techniques.

Natural variations in subsurface conductivity may be caused by changes in soil moisture content, ground-water specific conductance, the depth of soil cover over rock, and the thickness of soil and rock layers. Changes in basic soil or rock types, and structural features such as fractures or voids may also produce changes in conductivity. Localized deposits of natural organics, clay, sand, gravel, or salt-rich zones will also affect subsurface conductivity.

Many contaminants will provide an increase in free ion concentration when introduced int other soil or ground-water systems. This increase over background conductivity enables detection and mapping of contaminated soil and ground water. **Large amounts of organic fluid such as diesel fuel, however, displace the normal soil moisture, causing a** decrease **in conductivity, which may also be mapped.** The mapping of a plume will usually define the local flow direction of contaminants. Contaminant migration rates can be established by comparing measurements taken at different times.

The absolute values of conductivity for geologic materials (and contaminants) are not necessarily diagnostic in themselves, but the variations in conductivity, laterally and with depth, are significant. It is these variations that enable the investigator to find anomalous conditions rapidly.

Since the EM method does not require ground contact, measurements may be made quite rapidly. Lateral variations in conductivity can be detected and mapped by a field technique called profiling. Profiling measurements may be made to depths ranging from 0.75 to 60 meters. Instrumentation and field procedures have been developed recently that make it possible to obtain continuous EM profiling data to a depth of 15 meters. This continuous measurement allows increased rates of data acquisition and improved resolution for mapping small geohydrologic features. The excellent lateral resolution obtained from EM profiling data has been used

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to advantage in efforts to reveal the migration of contaminants into the surrounding soil or to delineate fracture patterns. Profiling is the most cost-effective use of the EM method.

Vertical variations in conductivity can also be detected by the EM method. A station measurement technique called sounding is employed for this purpose. Data can be acquired from depths ranging from 0.75 to 60 meters. This range of depth is achieved by combining results from a variety of EM instruments, each requiring different field application techniques.

The basic principle of operation of the electromagnetic method is shown in Exhibit 3.1-4. The transmitter coil radiates an electromagnetic field that induces eddy current loops in the earth below the instrument. Each of these eddy current loops, in turn, generates a secondary electromagnetic field that is proportional to the magnitude of the current flowing within that loop. A part of the secondary magnetic field from each loop is intercepted by the receiver coil and produces an output voltage, which (within limits) is related linearly to subsurface conductivity. This reading is a bulk measurement of conductivity; the cumulative response to subsurface conditions ranging all the way from the surface to the effective depth of the instrument.

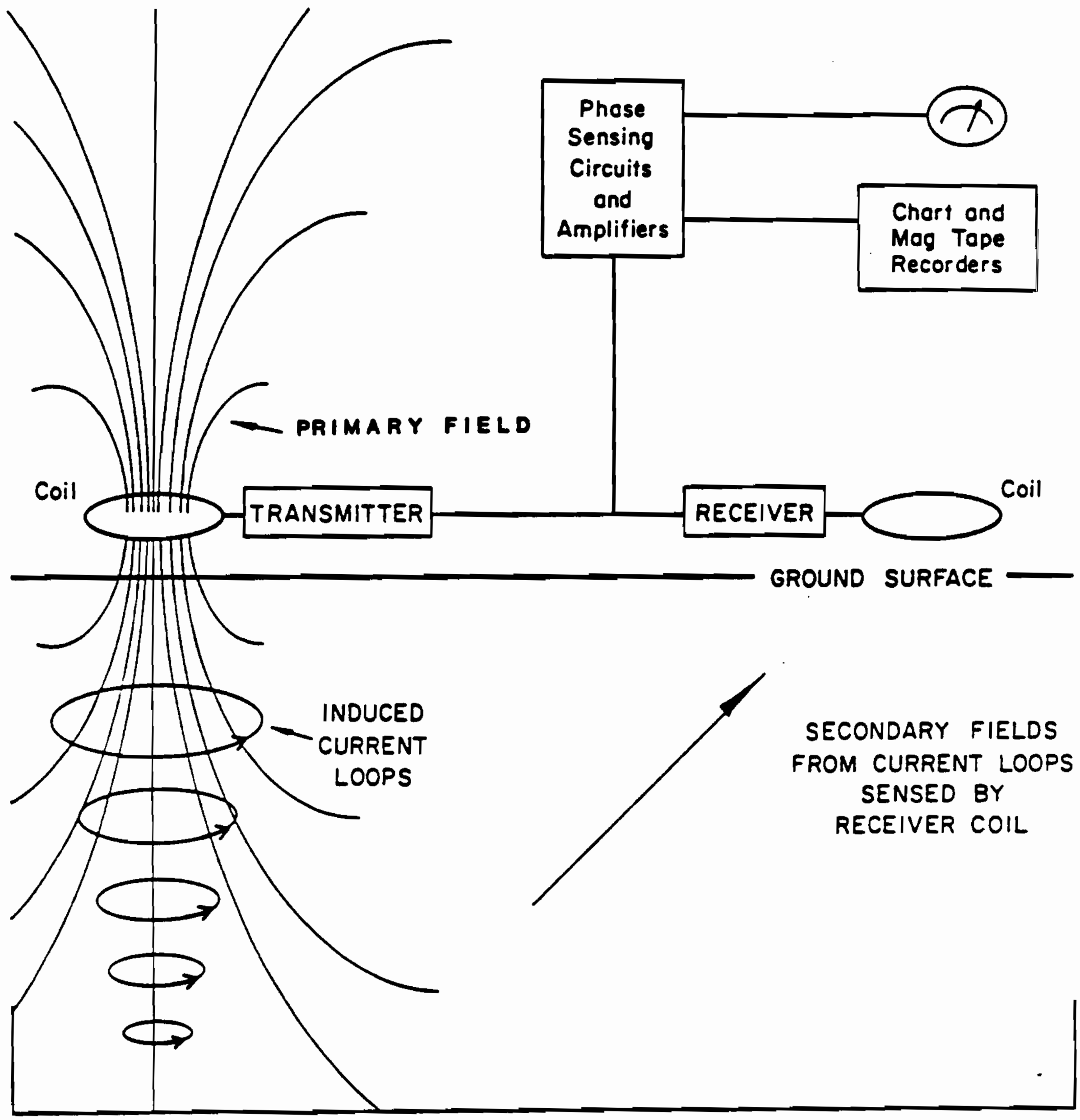
The sampling depth of EM equipment is related to the instrument's coil spacing. Instruments with coil spacings of 1, 4, 10, 20 and 40 meters are available commercially. The nominal sampling depth of an EM system is taken to be approximately 1.5 times the coil spacing. Accordingly, the nominal depth of response for the coil spacings given above is 1.5, 6, 15, 30 and 60 meters.

The conductivity value resulting from an EM instrument is a composite, and represents the combined effects of the thickness of soil or rock layers, their depths, and the specific conductivities of the materials. The instrument reading represents the combination of these effects, extending from the surface to the arbitrary depth range of the instrument. The resulting values are influenced more strongly by shallow materials than by deeper layers, and this must be taken into consideration when interpreting the data. Conductivity conditions from the surface of the instrument's nominal depth range contribute about 75 percent of the instrument's response. However, contributions from highly conductive materials lying at greater depth may have a significant effect on the reading. EM instruments are calibrated to read subsurface conductivity in millimhos per meter (mm/m).

Most soil and rock minerals, when dry, have very low conductivities. On rare occasions, conductive minerals like

Exhibit 3.1-4

Diagram Showing EM Principle of Operations



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magnetite, graphite, and pyrite occur in sufficient concentrations to greatly increase natural subsurface conductivity. Most often, conductivity is overwhelmingly influenced by water content and the following soil/rock parameters:

- The porosity and permeability of the material;
- The extent to which the pore space is saturated;
- The concentration of dissolved electrolytes and colloids in the pore fluids; and
- The temperature and phase state (i.e., liquid or ice) of the pore water.

A unique conductivity value, therefore, cannot be assigned to a particular geologic material, because the interrelationships of soil composition, structure, and pore fluids are highly variable in nature.

Contaminants migrating into the soil and the ground-water system contribute large amounts of electrolytes and colloids to both the unsaturated and saturated zones. In either case, the ground conductivity may be greatly affected, sometimes increasing by one to three orders of magnitude above background values. However, if the natural variations in subsurface conductivity are very low, contaminant plumes of only 10 to 20 percent above background may be mapped.

In the case of spills involving heavy non-polar, organic fluids such as diesel oil, the normal soil moisture may be displaced or a sizeable pool of oil may develop at the water table. In these cases, subsurface conductivities may decrease causing a negative EM anomaly, if substantial quantities of non-conductive contaminants are present.

EM systems are susceptible to signal interference from a variety of sources, originating both above the ground and below. Electromagnetic noise may be caused by nearby power lines, powerful radio transmitters, and atmospheric conditions. At some sites, shallow EM surveys can be carried out in the immediate vicinity of power lines; at others, conditions may be so bad that measurements are impossible. Generally, deeper measurements using larger coil spacings will be more susceptible to noise than shallower measurements. In addition to other forms of electromagnetic noise, instrument responses from subsurface or surface metal may make it difficult to obtain a valid measurement. For instance, piles of drums, nearby vehicles, fences, or railroad tracks can act as targets and produce an unwanted response. Within a range of 1.5 to 2 times the coil spacing, these large items may influence the data. Small items of metallic trash usually create no problem. Buried pipes and cables

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will cause very large EM anomalies. However, because of their characteristic response, they can be recognized.

------ ELECTROMAGNETIC INDUCTION SUMMARY ------

Capabilities

#The EM profile method permits rapid data acquisition, resulting in high-density and high-resolution surveys.

#Profiling data may be acquired from various discrete depths ranging from 0.75 meters to 60 meters.

#Continuously-recording instruments (to 15 meter depth) can increase survey speed, density, and resolution permitting total site coverage, if required.

#EM reads directly in conductivity units (millmhos/meter) permitting use of the raw data in the field and correlation to specific conductance of ground-water samples.

#EM can map local and general changes in the natural geohydrologic setting.

#Direction of plume flow can be determined from an EM conductivity map.

#EM measurements taken at different times can provide the means to compute movement rates of contaminants.

#EM can detect and map preferential flow pathways such as buried stream channels or trenches.

#EM can detect and map the location of buried metallic objects and utility lines.

Limitations

#EM has less sounding (vertical) resolution than the resistivity method (see following subsection) because of its limited number of depth intervals.

#The acquisition of data from depths of 0.75 to 60 meters requires the use of three different EM systems.

#Continuous data can be obtained from depths up to about 15 meters.

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- #EM measurements become nonlinear in zones of very high conductivity.

- #The EM method is susceptible to noise from a number of source, including natural atmospheric noise; power lines; radio transmitters; buried metallic trash; pipes; cables; and nearby metal fences, vehicles, and buildings.

Resistivity

The resistivity method is used to measure the electrical resistivity of the geohydrologic section, which includes the soil, rock and ground water. Accordingly, this method may be used to assess lateral changes and vertical cross sections of the natural geohydrologic settings. In addition, it can be used to evaluate contaminant plumes.

Application of this method requires that an electrical current be injected into the ground by a pair of surface electrodes. The resulting potential field (voltage) is measured at the surface between a second pair of electrodes. The subsurface resistivity can be calculated by knowing the electrode separation and geometry of the electrode positions, applied current, and measured voltage. Resistivity, therefore, is the reciprocal of conductivity, the parameter directly measured by the EM technique.

In general, most soil and rock minerals are electrical insulators (i.e,. they are highly resistive); hence the flow of current is conducted primarily through the moisture-filled pore spaces within the soil and rock. Therefore, the resistivity of soils and rocks is predominantly controlled by the porosity and permeability of the system, the amount of pore water, and the concentration of dissolved solids in the pore water.

The resistivity technique may be used for "profiling" or "sounding." Profiling provides a means of mapping lateral changes in subsurface electrical properties. This field technique is well suited to the delineation of contaminant plumes and the detection and location of changes in natural geohydrologic conditions. Sounding provides a means of determining the vertical changes in subsurface electrical properties. Interpretation of sounding data provides the depth and thickness of subsurface layers having different resistivities. Commonly up to four layers may be resolved with this technique.

In general, soils and rocks become less resistive as:

- #Moisture or water content increases;

- #Porosity and permeability of the formation increases;

- #Dissolved solid and colloid (electrolyte) content increases; or

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#Temperature increases (a minor factor, except in areas of permafrost).

Very dry sand, gravel, or rock as encountered in arid or semi-arid areas will have very high resistivity. As the empty pore spaces fill with water, resistivity will drop. Conversely, the resistivity of earth materials that occur below the water table, but lack pore space (such as massive granite and limestone) will be relatively high and will be primarily controlled by current production along cracks and fissures in the formation. Clayey soils and shale layers generally have lower resistivity values, due to their inherent moisture and clay mineral content. In all cases, an increase in the electrolyte, total dissolved solids, or specific conductance of the system will cause a marked increase in current conduction and a corresponding drop in resistivity. **This fact makes resistivity an excellent technique for the detection and mapping of conductive contaminant plumes.**

It is important to note that no geologic unit or contaminant plume has a unique or characteristic resistivity value. Its measured resistivity is dependent on the natural soil and rock present, the relative amount of moisture, and its specific conductance. However, the natural resistivity value of a particular formation or unit may remain within a small range for a given area.

Exhibit 3.1-5 is a schematic diagram showing the basic principles of operation. The resistivity method is inherently limited to station measurements, since electrodes must be in physical and electrical contact with the ground. This requirement makes the resistivity method slower than a non-contract method such as EM.

Many different types of electrode spacing arrays may be used to make resistivity measurements; the more commonly used include Wenner, Schlumberger, and dipole-dipole (see Exhibit 3.1-6). Due to its simple electrical geometry, the Wenner array is most often used, however, its use is not necessarily recommended for all site conditions. The choice of array will depend upon project objectives and site conditions.

Using the Wenner array, potential electrodes are centered on a line between the current electrodes; an equal spacing between electrodes is maintained. These "A" spacings commonly range from 0.3 meters to more than 100 meters. The depth of measurement is related to the "A" spacing and may vary depending upon the geohydrology.

Exhibit 3.1-5

Diagram Showing Basic Concept of Resistivity Measurement

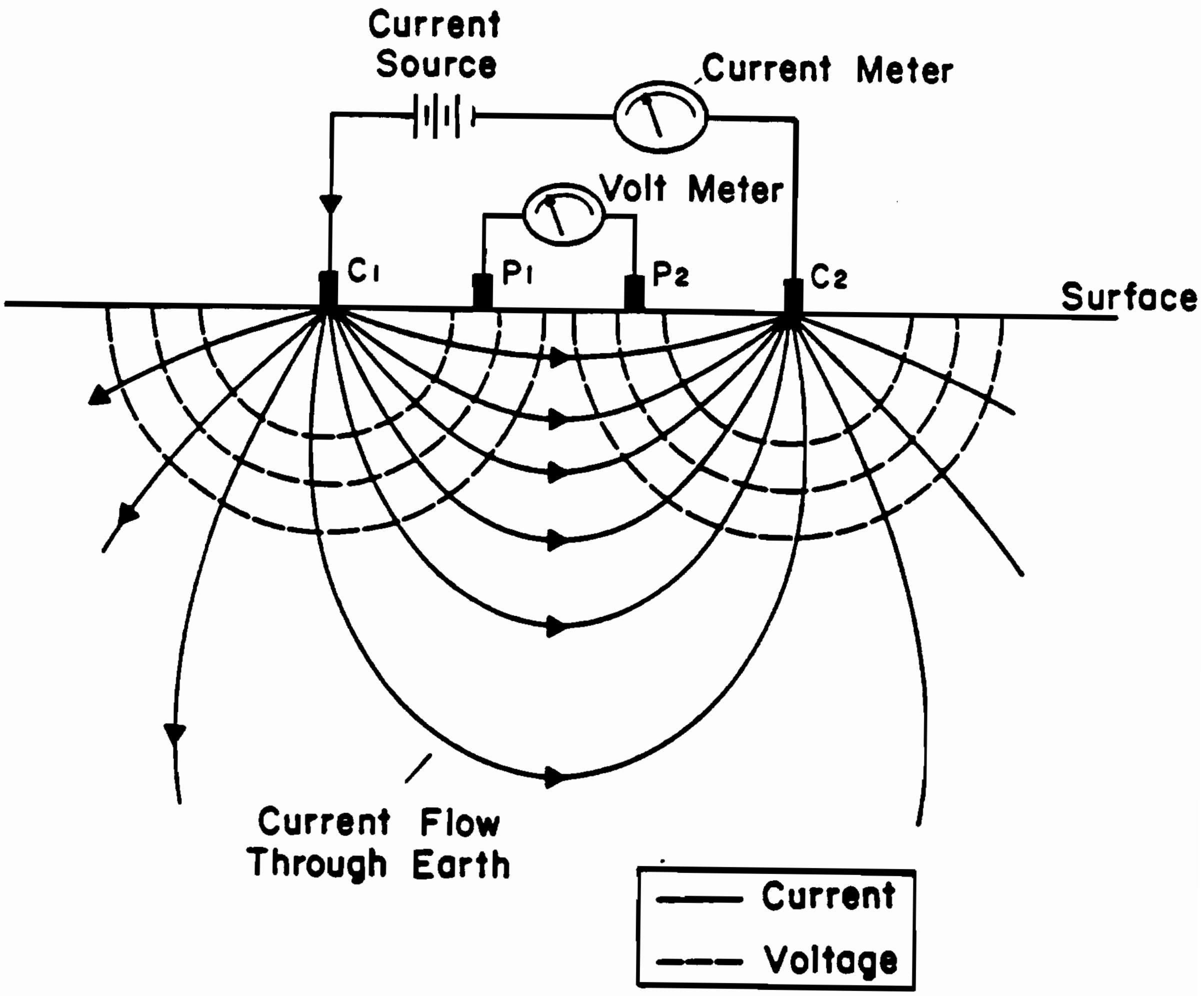
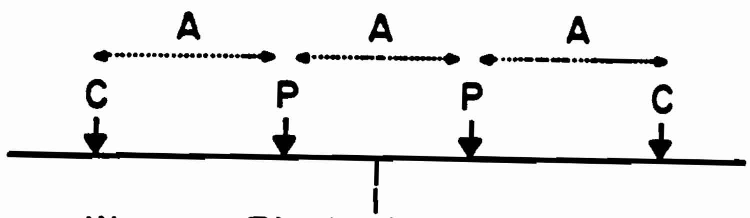
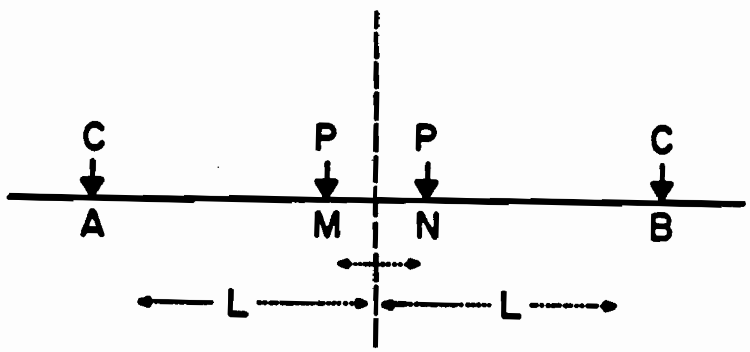


Exhibit 3.1-6

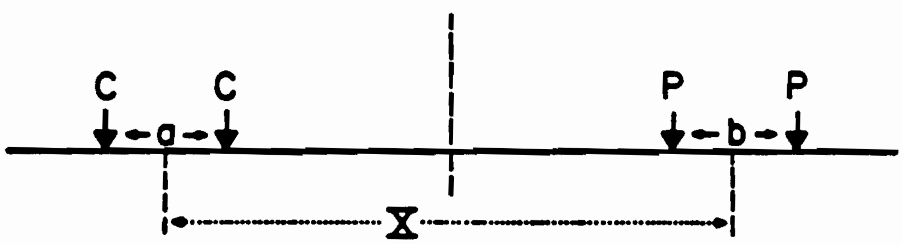
Common Electrode Arrangements in the Resistivity Measurement



Wenner Electrode Arrangement



Schlumberger Electrode Arrangement



Axial Bipole - Bipole Electrode Arrangement

Notes:
C = a current electrode
P = a potential electrode

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Current is injected into the ground by the two outer electrodes that are connected by cables to a DC or low-frequency AC current source. The distribution of current within the earth is influenced by the relative resistivity of subsurface features. The current flow within the subsurface produces an electric field with lines of equal potential, perpendicular to the lines of current. The potential field is measured by a voltmeter at the two inner electrodes.

Profiling uses a fixed electrode spacing with electrode "A" spacing set at one to two times the depth of interest. The fixed-spacing electrode array is moved to a number of different locations to obtain data over the entire area of interest. Since depth of influence remains constant from one station to the next, profiling measures lateral changes in resistivity. Such changes permit the detection and mapping of anomalous spatial features over the area surveyed. The method may be modified to include measurements at more than one depth, thereby providing additional information on lateral variations with depth.

The sounding technique relies on making a series of resistivity measurements, each with successively larger electrode spacings. As the "A" spacing is increased, the depth of sampling at the sounding station also increases. The maximum "A" spacing should be at least three to four times the depth of interest in order to permit adequate characterization of deeper layers. Therefore, the overall array length including current electrodes will be nine to 12 times the depth of interest.

Some surface conditions may limit or preclude use of the resistivity method. Dry surface material having extremely high resistivity will make injection of the current difficult and require special field procedures. In areas with paved surfaces such as asphalt and concrete roads or parking lots, electrode contact may not be possible.

Survey objectives will determine whether profiling or sounding data is required. For example, profiling should be used for mapping contaminant plumes. Because profiling is a faster field technique, a larger number of stations may be occupied with the higher density providing better lateral resolution. The selection of the proper "A" spacing for the profiling survey may be determined from several initial soundings in the area of the suspected plume.

Equipment-related noise may occur due to improper coupling of the wires or reels of long cable arrays. Poor electrical contact between the ground and electrodes will also produce noisy data. Exceeding the depth capability (power and receiver sensitivity) of the resistivity instrumentation will also yield poor data at very large electrode spacings.

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Cultural noise caused by stray currents, potential fields, and electromagnetic energy can interfere with the resistivity measurement. This interference can be caused by nearby power lines and man-induced ground currents. The influence of nearby fences, railroad tracks, and buried metallic pipes and cables can "short" or strongly distort current flow.

Natural sources of electrical noise include earth currents and spontaneous potential (SP). Most modern instruments are designed to cope with such noise problems.

Poor electrode contact with the earth, and local variations in shallow subsurface conditions near the electrodes can produce significant scatter in the data. Decreasing the spacing between stations, using appropriate field arrays and using averaging techniques can minimize the influence of these variations.

------RESISTIVITY SUMMARY ------

Capabilities

- Resistivity profiling techniques can be used to detect and map contaminant plumes and changes in geohydrology.

- Resistivity sounding methods can estimate the depth, thickness, and resistivity of subsurface layers, or the depth to the water table.

- Both profiling and sounding data can be evaluated qualitatively or semi-qualitatively in the field.

- Resistivity values can be used to identify the probable geologic composition of a layer or to estimate the specific conductance of a contaminant plume.

- The depth to the bottom of trenches or other subsurface features can sometimes be estimated.

Limitations

- The sounding technique requires that site conditions be relatively homogeneous laterally.

- The method is susceptible to noise caused by nearby fences, pipes, and geologic scatter, which may interfere with the usefulness of the data.

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- # Quantitative interpretation requires the use of master curves and/or computer programs and experience in their use.

Seismic Refraction

Seismic refraction techniques are used to determine the thickness and depth of geologic layers and the travel time or velocity of seismic waves within the layers. Seismic refraction methods are often used to map depths to and the thickness of specific horizons such as bedrock, clay layers, and the water table. It can also be used for the detection and location of anomalous features, such as pits and trenches.

Seismic waves transmitted into the subsurface travel at different velocities in various types of soil and rock and are refracted (or bent) at the interfaces between layers. This refraction affects their path of travel. An array of geophones on the surface measures the travel time of the seismic waves from the source to the geophones at a number of spacings. The time required for the wave to complete this path is measured, permitting a determination to be made of the number of layers, the thicknesses of the layers and their depths, as well as the seismic velocity of each layer. The wave velocity in each layer is directly related to its material properties such as density and hardness.

A seismic source, geophones, and a seismograph are required to make the measurements. The seismic source may be a simple sledge hammer with which to strike the ground. Explosives and any other seismic sources may be utilized for deeper or special applications. Geophones implanted in the surface of the ground translate the received vibrations of seismic energy into an electrical signal. This signal is displayed on the seismograph permitting measurement of the arrival time of the seismic wave. Since the seismic method measures small ground vibrations, it is inherently susceptible to vibration noise from a variety of natural and cultural sources.

Although a number of elastic waves are inherently associated with this method, conventional seismic refraction methods are concerned only with the compressional wave (primary or P-wave). The compressional wave is also the first to arrive which makes its identification relatively easy.

These waves move through subsurface layers. The density of a layer and its elastic properties determine the speed or velocity at which the seismic wave will travel through the layer. The porosity, mineral composition, and water content of the layer affect both its density and elasticity. Seismic velocities for different types of soil and rock overlap, therefore, knowing the velocities of these layers alone does not permit a unique determination of their composition. However, if this knowledge is combined with geologic information, it can be used intelligently to identify geologic strata.
In general, velocity values are greater for:

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- # dense rocks than light rocks;
- # older rocks than younger rocks;
- # igneous rocks than sedimentary rocks;
- # solid rocks than rocks with cracks or fractures;
- # unweathered rocks than weathered rocks;
- # consolidated sediments than unconsolidated sediments;
- # water-saturated unconsolidated sediments than dry unconsolidated sediments; and
- # wet soils than dry soils.

A seismic source produces seismic waves that travel in all directions into the ground. One of these waves, the direct wave, travels parallel to the surface of the ground. A seismic sensor (geophone) detects the direct wave as it moves along the surface layer. The time of travel along this path is related to the distance between the sensor and the source and the material composing the layer.

If a denser layer with a higher velocity, such as bedrock, exists below the surface soils, some of the seismic waves will be bent or refracted as they enter the bedrock. This phenomenon is similar to the refraction of light rays when light passes from air into water. One of these refracted waves, crossing the interface at a critical angle, will move parallel to the top of the bedrock at the higher velocity of the bedrock. The seismic wave travelling along this interface will continually release energy back into the upper layer by refraction. These waves may then be detected in the surface at various distances from the source.

Beyond a certain distance (called the critical distance), the refracted wave will arrive at a geophone before the direct wave. This happens even though the refraction path is longer, because a sufficient portion of the wave's path occurs in the higher velocity bedrock. Measurement of these first arrival times and their distances from the source permits calculation of layer velocities, thicknesses, and bedrock depth. Application of the seismic method is generally limited to resolving three to four subsurface layers.

The preceding concepts are based upon the fundamental assumptions that:

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- Seismic velocities of geologic layers must increase with depth. This requirement is generally met at most sites.

- Layers must be of sufficient thickness to permit detection.

- Seismic velocities of layers must be sufficiently different to permit resolution of individual layers.

There is no way to establish from the seismic data alone whether a hidden layer is present; therefore, correlation to a boring log or geologic knowledge of the site must be used to provide a cross check. If such data are not available, the investigator must take this into consideration in evaluating the data.

Variations in the thickness of the shallow soil zone, inhomogeneities within a layer, or irregularities between layers will often produce geologic scatter or anomalies in the data. This data scatter is useful information revealing some of the natural variability of the site. For example, a zone containing a number of large boulders in a glacial till deposit will yield inconsistent arrival times, due to variable seismic velocities between the boulders and the clay matrix. An extremely irregular bedrock surface as is often encountered in karst limestone terrain, likewise, will produce scatter in the seismic data.

Seismic signals are strongly affected by ground vibration noise; less so by geologic scatter. In addition, the subjective pick of first arrival time can contribute a few milliseconds of error.

Unwanted vibrations that affect the seismic signal at the geophone may be caused by:

- Winds sufficient to move nearby trees strongly;

- Sounds of airplanes;

- Surface sources, such as moving vehicles on nearby highways and railroads;

- Field crews walking near geophones; or

- Nearby blasting or operation of heavy construction equipment.

Geologic scatter may be caused by lateral variation in layer composition or an irregular interface between layers. Examples include:

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- # Variations in the thickness of the "soil zone;"
- # Boulders in glacial clay or till;
- # Zones of increased cementation in sandstone and limestone;
- # Lenses of sand in clay layers;
- # Variations in saturated water content caused by perched water tables;
- # Irregular bedrock surfaces; and
- # Limestone containing numerous cavities.

------ SEISMIC REFRACTION SUMMARY ------

Capabilities

- # Seismic refraction measurements can provide depth and thickness of subsurface geologic layers including depth to rock and water table.
- # Seismic velocity of the layers can be related to their physical properties including composition, density, and elastically.
- # Disturbed soil zones can often be detected and mapped, permitting the location and delineation of these zones. Depth to these areas may be estimated without drilling.

Limitations

- # Seismic data is gathered as a station measurement and involves relatively slow field procedures compared to continuous methods.
- # Interpretation requires that site condition be relatively uniform to obtain highly accurate results.
- # The seismic method is very susceptible to vibration noise.

Metal Detection

NOTES

Metal detectors (MD) are designed to locate buried metallic objects. A metal detector responds to the electrical conductivity of metal targets, which is relatively high compared to normal levels of soil conductivity. These targets must, of course, be within the range of the instrument to be detected. The metal detector is a continuously-sensing instrument that can provide total site coverage and is well suited for locating buried metal. In UST investigations, MDs are invaluable for detecting buried pipelines, abandoned tanks, and the boundaries of known tanks prior to the start of drilling operations.

Metal detectors can detect any kind of metallic material, including both ferrous metals such as iron and steel, and non-ferrous metals, such as aluminum and copper. Metal detectors have a relatively short detection range. Small metal objects such as spray cans or quart-sized containers can be detected at a distance of approximately one meter. Because the response of a metal detector increases with the target's surface area, larger objects, like tanks, may be detected at depths of three to six meters.

There are many different types of metal detectors available commercially. We will consider one general class of equipment: pipeline/cable locators.

Numerous pipeline/cable locator metal detectors are commercially available. Besides being effective for locating buried utility cables and pipes, they can be used to detect larger buried targets such as underground tanks, with the added feature that they will not respond to small, unwanted surface targets.

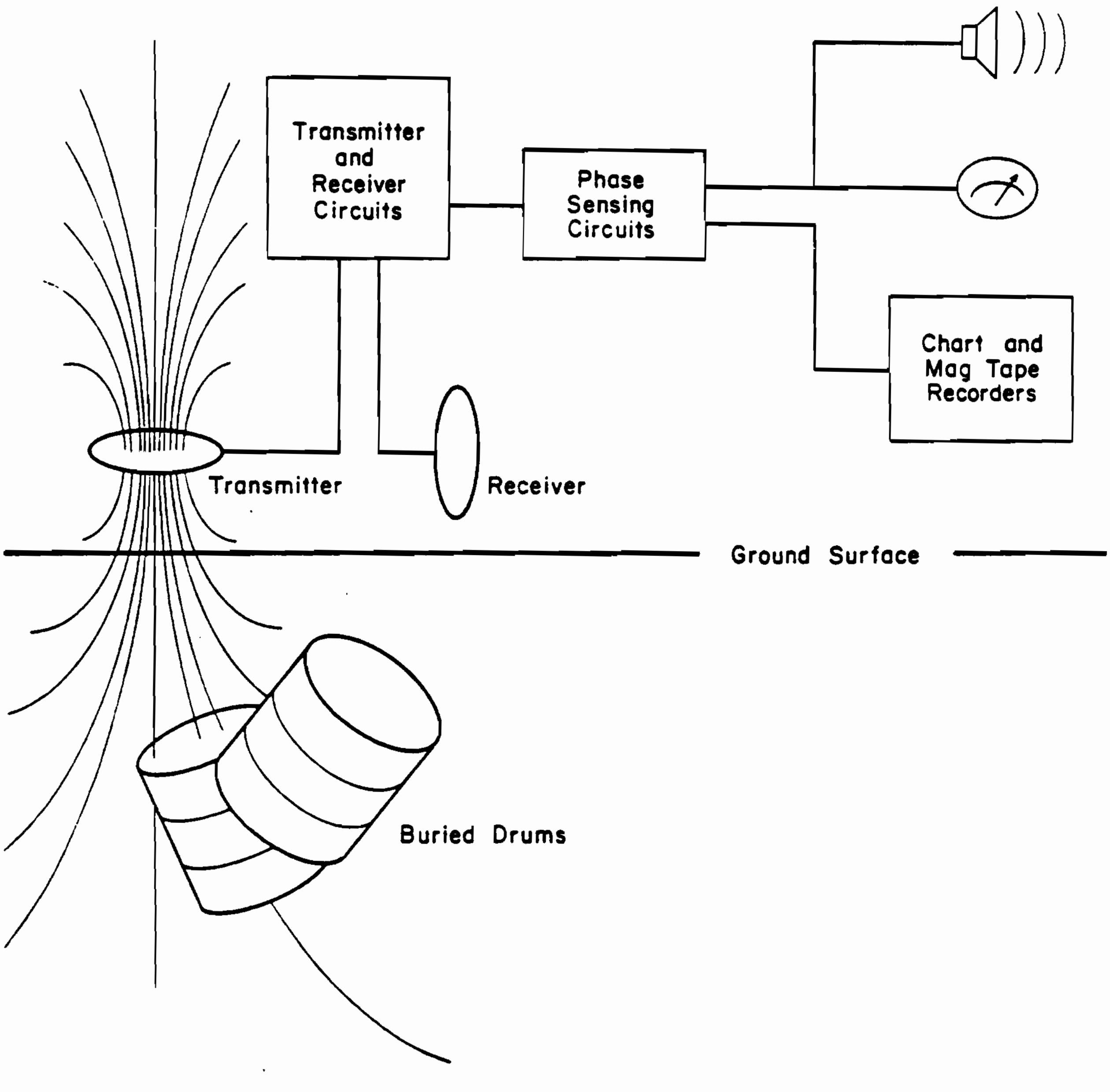
Exhibit 3.1-7 shows the principle of operation and the functional parts of a typical pipe/cable detector. The transmitter of a metal detector creates an alternating magnetic field around the transmitter coil. A balance condition must be achieved to cancel the effect of this primary field at the receiver coil. The balance or null is accomplished by orienting the planes of the two coils perpendicular to one another. The primary field will induce eddy currents in a metal target within range of the instrument. These eddy currents, in turn, produce a secondary field which interacts with the primary field to upset the existing balance condition.[5] The result will be an output on a meter and/or an audio signal.

Several factors influence metal detector response: the properties of the target, the properties of the soil, and the characteristics of the metal detector itself. The target's size and its depth of burial are the two most important factors. The larger the surface area of the target, the greater the eddy currents that may be induced, and the greater the depth at

[5]*Other types of metal detectors combine the transmitter and receiver coils into one sensor package, and they may respond to the eddy currents generated in the target in different ways. These eddy currents may be sensed directly by the receiver or they may cause direct loading effects on the transmitter.*

Exhibit 3.1-7

Simplified Block Diagram of a Pipe/Cable Type Metal Detector System



Note: Primary field from transmitter is distorted by buried metallic objects causing upset of null at receiver coil.

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which the target may be detected (i.e., response is proportional to the cube of the area).

The MD's response to a target decreases at a rate equal to reciprocal of its depth to the sixth power ($1/depth^6$). Therefore, if the distance to the target is doubled, the MD response will decrease by a factor of 64. Consequently, the MD is a relatively nearfield device; it is generally restricted to detecting small targets at relatively shallow depths or larger targets at limited depths. Generally, most metal detectors are incapable of responding to any targets, no matter how large, at depths much greater than six meters.

Although the shape, orientation and composition of a target will influence the MD response, these factors will have much less influence than will the size and depth of the target. Target deterioration, however, may have significant impact. If a target is corroded, its surface area will be significantly reduced and this, in turn, will degrade the response of a metal detector.

High concentrations of natural iron-bearing minerals in the soil will limit the performance of many metal detectors. Similarly, high concentrations of salt water, acids, and other highly conductive fluids will also reduce the effectiveness of a metal detector. Iron minerals, conductive fluids, and metallic debris will affect the MD in much the same way as a target. A false response will be produced that may confuse the searcher or render the search impossible. In the case of metallic debris, the successful application of a MD will depend on the relative size of the debris and its density. Some compensation for natural soil conditions, metallic debris, and nearby metallic structures can be made by using certain specialized equipment and modified field procedures.

The effectiveness of a metal detector is dependent upon the relative magnitude of the target signal, the noise produced by the surrounding soil, and other variables. The procedure used to null a metal detector serves to cancel most of the soil interference; however, some level of noise from soil conditions may be present during a survey. As the target response decreases and/or the noise level increases, the target response will eventually be lost in the noise. While it is true that the larger coils will yield better signals from larger and deeper targets, they are also more susceptible to soil effects and other electrical interference. However, the larger coils can be raised up to about one meter off the ground to minimize both the soil effects and the effects of metal trash near the surface.

When the coil is carried too close to the ground, small shallow targets may easily saturate the system to a full-scale response. When this occurs, other targets, no matter how large, cannot cause a further increase in response and will, therefore, remain undetected.

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It is important to understand that a metal detector radiates a field in all directions. However, its most sensitive zones are "focused" directly above and below the plane of the sensor coils. This characteristic can be quite useful in the field. The focused response characteristic of the MD will allow the operator to work relatively near some metallic items, so long as they are far enough to the side of the sensor coil.

The operator must exercise care to avoid interference from nearby fences and vehicles, as well as from buildings and buried pipes. For example, by running a survey line parallel or oblique to one or more unknown pipelines, the operator can cause invalid data to be produced. Certain welded fence materials and the mesh used for concrete reinforcement will provide a very good MD response, despite the fact that they are not solid metallic surfaces.

Precaution must also be taken to remove metal from the operator, or to minimize its effects. Steel-toed boots, respirators, and air bottles can all cause considerable problems with noise.

------ METAL DETECTOR SUMMARY ------

Capabilities

- # Metal detectors respond to both ferrous and non-ferrous metals.
- # They will detect single, small, metallic objects at depths up to one to three meters.
- # They will detect larger metallic objects at depths of three to six meters.
- # Metal detectors provide a continuous response along a traverse line.
- # A wide range of commercial equipment is available most of which is relatively easy to use.
- # Metal detectors provide very good definition of boundaries of metallic pipes and tanks.
- # Limited semi-quantitative information may be obtained from the use of commercial detectors.
- # Specialized equipment is available for recording data, coping with unique site conditions, or obtaining semi-quantitative information.

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Limitations

- # Metal detectors are inherently limited in depth capability.

- # They are susceptible to a wide range of noise sources, including that introduced by natural soil, metallic debris, and nearby metal fences and structures.

- # They are limited in providing quantitative data concerning the number and depth of metallic targets.

- # Specialized metal detector instruments are uncommon and require experienced operators.

- # Complex site conditions will demand increased operator skill levels, special equipment, and more sophisticated data processing systems.

Magnetometer

Magnetic measurements are commonly used to map regional geologic structure and to explore for minerals. They are also used to locate pipes and survey stakes or to map archeological sites.

A magnetometer measures the intensity of the earth's magnetic field. The presence of ferrous metals creates variations in the local strength of that field, permitting their detection. A magnetometer's response is proportional to the mass of the ferrous target. Typically, a single smaller target can be detected at distances up to six meters, while larger targets can be detected at distances up to 20 meters or more.

Some magnetometers require the operator to stop and take discrete measurements; other instruments permit the acquisition of continuous data as the magnetometer is moved across the site. The continuous coverage is much more suitable for high resolution requirements and the mapping of extensive areas.

The effectiveness of a magnetometer can be reduced or totally inhibited by noise or interference from time-variable changes in the earth's field and spatial variations caused by magnetic minerals in the soil, or iron and steel debris, ferrous pipes, fences, buildings, and vehicles. Many of these problems can be avoided by careful selection of instruments and field techniques.

The earth's magnetic field behaves much as if there were a large bar magnet embedded in the earth. Although the earth's field intensity varies considerably throughout the United States, its average value is

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approximately 50,000 gammas. The angle of the magnetic field with respect to the earth's surface also varies. In the U.S., this angle of inclination ranges approximately 60 to 75 degrees from the horizontal.

The intensity of the earth's magnetic field changes daily with sunspots and ionospheric conditions, which can cause large and sometimes rapid variations. With time, these variations produce unwanted signals (noise) and can substantially affect magnetic measurements.

If the magnetic properties of the soil and rock were perfectly uniform, thee would be no local magnetic anomalies; however, a concentration of natural iron minerals, or a buried iron object, will cause a local magnetic anomaly which can be detected at the surface.

There is a wide variety of magnetometers available commercially; two basic types commonly used are the fluxgate and the proton magnetometer. In a fluxgate magnetometer, the sensor is an iron core that undergoes changes in magnetic saturation level in response to variations in the earth's magnetic field; differences in saturation are proportional to variations in field strength. The electronic signals produced by these variations are amplified, then fed to an amplifier, whose output drives a meter or a recorder.

The signal output of a single element fluxgate magnetometer is extremely sensitive to orientation. To overcome this problem, two fluxgate elements can be rigidly mounted together to form a gradiometer. This gradiometer measures the gradient of a directional component of the earth's magnetic field. The gradiometer configuration of the fluxgate magnetometer, one which measures the vertical component of the field, is the instrument that is discussed in this section.

In a proton magnetometer, an excitation voltage is applied to a coil around a bottle containing a fluid such as kerosene. The field produced reorients the protons in the fluid; when the excitation voltage is removed, the spinning protons reorient to line up with the earth's magnetic field. By nuclear precession they generate a signal, the frequency of which is proportional to the strength of the field. The signal is amplified and the precession frequency measured by the use of counter circuits. The frequency is electronically translated into gammas and the output is fed to a digital display, a digital memory, or a strip chart recorder. Proton magnetometers measure the earth's total field intensity and they are not sensitive to orientation. However, the proton magnetometer will cease to function when it is used in areas with very high magnetic gradients (above 5,000 gammas/meter), which may be found in junk yards or near steel bridges, buildings, vehicles, and the like.

Several factors influence the response of a magnetometer. The mass of a buried target is one factor; it will affect the magnetometer's response in direct proportion to the amount of ferrous metal present. The depth of the

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target is an even more significant factor, as response varies by one over the distance cubed ($1/d^3$) for total field measurements; this means that the response will decrease by a factor of eight if the distance between the target and the magnetometer is doubled. If a gradiometer is used, the response falls off even faster, at the rate of one over the distance to the fourth power ($1/d^4$). If sensors of identical sensitivity are used, the total field system provides the greater working range.

Another factor which will influence the response of a magnetometer is the permanent magnetism of the target. Ferrous objects will have two superimposed magnetic values; one due to induced magnetism and one due to permanent magnetism. The permanent magnetism of an object is like that of a bar magnet. Its value may be many times that of the induced magnetism, which may add to or reduce the resulting anomaly. As a result, the value of a magnetic anomaly may vary over a wide range, making the quantitative analysis of magnetic data difficult. In addition, the target's shape and orientation together with its state of deterioration also affect the magnetometer's response.

Noise may be caused by time variations such as the natural changes in the earth's field and by spatial variations. Spatial noise, may be associated with changes in local soil conditions or produced by passing over ferrous debris.

The effects of time changes in the earth's field can be eliminated from total field measurements by using a second magnetometer as a base station. The time changes sensed by the fixed base stations are removed from the values obtained by the search magnetometer. The result of this process is a series of measurements showing only the spatial changes in the magnetic field. A gradiometer accomplishes this process automatically.

By lifting the sensor up off the ground and carrying it at some distance above the surface, the noise due to natural soil and rock variations and small particles of metal debris can be minimized. At the same time, the increased target-to-sensor distance will not appreciably reduce the instrument's response if the target is large. In this case, the advantage of reducing noise must be weighed against the accompanying disadvantage of decreasing the instrument's sensitivity.

Cultural features can cause large unwanted anomalies in magnetic data. For example, a buried pipe may be the cause of a large magnetic anomaly, but it can often be identified as such and be separated from other targets. However, if a small tank is buried next to a large iron pipe, the tank probably will not be identified as a separate target and could remain undetected.

Noise interference from personal effects and clothing may also be a problem. The solution is to eliminate all ferrous material from the operator's person. Steel-toed boots and some respirators are sources of noise, but they may be required safety measures at certain locations. Noise from this equipment must be minimized by keeping the sensor as far from the operator as possible.

----- MAGNETOMETER SUMMARY ------

Capabilities

- # Magnetometers respond to ferrous metals (iron or steel) only.
- # Individual, small, metal targets can be detected at depths up to six meters. Larger targets can be detected at depths up to 20 meters.
- # Magnetometers can provide a greater depth range than metal detectors.
- # Interpretations of their data may be used to provide estimates of the number and depth of buried metal objects.
- # They van provide a continuous response along a traverse line.

Limitations

- # In general, magnetometers are susceptible to noise from many different sources, including stell fences, vehicles, buildings, iron debris, natural soil minerals, and underground utilities.
- # Low-cost units are limited in depth range, but their limitations make them less susceptible to noise interference.
- # Total field instruments are also sensitive to fluctuations in the earth's magnetic field, which can seriously affect data.
- # Data is of limited use in determining the number and depth of targets.
- # Complex site conditions require the use of highly skilled operators, special equipment, and sophisticated data processing systems.

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c. Well Drilling Techniques

There are a number of techniques which can be used for the drilling of monitoring and/or collection wells. It is important to understand that the method used may have an affect on the quality of the ground-water samples and the productivity of the well. The methods used in drilling wells include the following.

Hollow- and solid-stem augering

Hollow-and solid-stem augering is an appropriate drilling method for the installation of monitoring wells as no drilling fluids are used and disturbance to the geologic materials penetrated is minimal. Auger rigs are not used when consolidated rock must be penetrated. The maximum well depth that can be achieved with auger rigs is limited to no more than 150 feet.

The advantage of a hollow-stem auger is that it provides continuous access for the collection of soil samples without removing the auger. Depending on the size of the auger and borehole, the well casing may be inserted before the auger is removed.

A solid-stem auger is used in fine-grained, unconsolidated materials (i.e., sand, silt, clay) that will not collapse when the auger is removed. The solid-stem drilling method is similar to hollow-stem augering except that the solid stem auger must be removed from the hole to allow the insertion of the well casing and screen. Geologic cores cannot be collected when using a solid-stem auger. Therefore, geologic sampling must rely on collection of the drill cuttings that are brought to the surface during drilling. This does not allow for soil sampling at a discrete depth.

Cable-tool Drilling

Cable-tool drilling is one of the oldest methods used in the water well industry. Even though the rate of penetration is rather slow using this method, it does offer many advantages for monitoring well construction. With the cable-tool, excellent formation samples can be collected and the presence of thin permeable zones can be detected. As drilling progresses, a casing is normally driven into the borehole and can function as a temporary casing within which the monitoring well can be constructed.

Air-rotary Drilling

In air-rotary drilling, air is forced down the drill stem and back up the borehole to remove the cuttings. This technique has been found to be particularly well suited for drilling in fractured rock formations.

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Air-rotary drilling should not be attempted in highly contaminated environments, however. The ground water and cuttings blown out of the borehole are difficult to control and can pose a hazard to the drill crew and observers. Air-rotary drilling should also not be used when volatile contaminants are of interest as these contaminants will be stripped out of the water. Water samples withdrawn from the hole will, therefore, not be representative of in-situ conditions. Various foam additives are also used to aid removal of the drill cuttings; this represents a significant organic contamination problem for the installation of monitoring wells.

Air-Rotary with Percussion Hammer

Air-rotary with percussion hammer increases the effectiveness of air-rotary drilling for karst or highly creviced formations. Addition of the percussion hammer allows the casing to be driven into the geologic formation, cutting the loss of air circulation in highly creviced rock formations, and maintaining an open hole in soft formations. Monitoring wells may also be installed inside the driven casing prior to its removal. The problems associated with well contamination and crew safety referenced in the discussion of air-rotary drilling must still be considered, however.

Reverse-Rotary Drilling

Reverse-rotary drilling has limited application for monitoring well completion. The reverse-rotary method requires the use of large quantities of water. The water is circulated down the borehole and up the drill stem to remove cuttings. This water can be lost into the surrounding formations (i.e, porous sand) in the process with the result that conditions are created that are not representative of in-situ ground-water quality.

Hydraulic ("Mud") Rotary

Hydraulic rotary, or "mud" rotary, is probably the most popular method used in the water well industry. However, hydraulic rotary presents some disadvantages for monitoring well completion. With this technique, a drilling mud (usually bentonite) is circulated down the drill stem and up the borehole to remove cuttings. The mud that is left behind on the sides of the borehole must later be removed from the area of the well screen in order for the well to be developed properly. With small diameter wells, complete removal of the drilling mud is not always achieved. The results is that organic components in the drilling mud are introduced into surrounding aquifer.

The drilling method chosen should be based on an evaluation of those factors discussed in the Design and Installation subsection that follows. A summary of the drilling principles, advantages, and disadvantages can be found in Exhibit 3.1-8.

Exhibit 3.1-8

Advantages and Disadvantages of Selected Drilling Methods for Monitoring Well Construction

Method	Drilling Principle	Advantages	Disadvantages
Drive Point	1.25 to 2 inch ID casing with pointed screen mechanically depth.	Inexpensive. Easy to install, by hand if necessary. Water samples can be collected as driving proceeds. Depending on overburden, a good seal between casing and formation can be achieved.	Difficult to sample from smaller diameter drive points if water level is below suction lift. Bailing possible. No formation samples can be collected. Limited to fairly soft materials. Hard to penetrate compact, gravelly materials. Hard to develop. Screen may become clogged if thick clays are penetrated. PVC and Teflon casing and screen are not strong enough to be driven. Must use metal construction materials which may influence some water quality determinations.

Exhibit 3.1-8

Advantages and Disadvantages of Selected Drilling Methods for Monitoring Well Construction (continued)

Method	Drilling Principle	Advantages	Disadvantages
Auger, Hollow- and Solid-stem	Successive 6-foot flights of spiral-shaped drill stem are rotated into the ground to create a hole. Cuttings are brought to the surface by the turning action of the auger.	Inexpensive. Fairly simple operation. Small rigs can get to difficult-to-reach areas. Quick set-up time. Can quickly construct shallow wells in firm, noncavey materials. No drilling fluid required. Use of hollow-stem augers greatly facilitates collection of split-spoon samples. Small-diameter wells can be built inside hollow-stem flights when geological materials are cavey.	Depth of penetration limited, especially in cavey materials. Maximum depths 150 feet. Cannot be used in rock or well-cemented formations. Difficult to drill in cobbles/boulders. Log of well is difficult to interpret without collection of split spoons due to the lag time for cuttings to reach ground surface. Vertical leakage of water through borehole during drilling is likely to occur. Solid-stem limited to fine-grained, unconsolidated materials that will not collapse when unsupported. With hollow-stem flights heaving materials can present a problem. May need to add water down to auger to control heaving or wash materials from auger before completing well.

Exhibit 3.1-8

Advantages and Disadvantages of Selected Drilling Methods for Monitoring Well Construction (continued)

Method	Drilling Principle	Advantages	Disadvantages
Jetting	Washing action of water forced out of the bottom of the drill rod clears hole to allow penetration. Cuttings brought to surface by water flowing up the outside of the drill rod.	Inexpensive. Driller often not needed for shallow holes. In firm, noncavey deposits where hole will stand open, well construction fairly simple.	Somewhat slow, especially with increasing depth. Extremely difficult to use in very coarse materials, i.e., cobbles/ boulders. A water supply is needed that is under enough pressure to penetrate the geologic materials present. Difficult to interpret sequence of geologic materials present. Maximum depth 150 feet, depending on geology and water pressure capabilities.
Cable-tool (percussion)	Hole created by dropping a heavy "string" of drill tools into well bore, crushing materials at bottom. Cuttings are removed occasionally by bailer. Generally, casing is driven just ahead of the bottom of the hole; a hole greater than 6 inches in diameter is usually made.	Can be used in rock formations as well as unconsolidated formations. Fairly accurate logs can be prepared from cuttings if collected often enough. Driving a casing ahead of hole minimizes cross-contamination by vertical leakage of formation waters. Core samples can be obtained easily.	Requires an experienced driller. Heavy steel drive pipe used to keep hole open and drilling "tools" can limit accessibility. Cannot run some geophysical logs due to presence of drive pipe. Relatively slow drilling method.

Exhibit 3.1-8
Advantages and Disadvantages of Selected Drilling Methods for Monitoring Well Construction
(continued)

Method	Drilling Principle	Advantages	Disadvantages
Hydraulic Rotary	Rotating bit breaks formation; cuttings are brought to the surface by a circulating fluid (mud). Mud is forced down the interior of the drill stem, out the bit, and up the annulus between the drill stem, and the wall. Cuttings are removed by settling in a "mud pit" at the ground surface and the mud is circulated back down the drill stem.	Drilling is fairly quick in all types of geologic materials. Borehole will stay open from formation of a mud wall on sides of borehole by the circulating drilling mud. Eases geophysical logging and well construction. Geologic cores can be collected. Virtually unlimited depths possible.	Expensive, requires experienced driller and fair amount of peripheral equipment. Completed well may be difficult to develop, especially small diameter wells, because of mud wall on borehole. Geologic logging by visual inspection of cutting is fair due to presence of drill mud. Thin beds of sand, gravel, or clay may be missed. Presence of drilling mud can contaminate water samples, especially the organic, bio-degradable muds. Circulation of drilling fluid through a contaminated zone can create a hazard at the ground surface with the mud pit and cross-contaminate clean zones during circulation.
Reverse Rotary	Similar to Hydraulic Rotary method except the drilling fluid is circulated down the borehole outside the drill stem and is pumped up the inside, just the reverse of the normal rotary method. Water is used as the drilling fluid, rather than mud, and the hole is kept open by hydrostatic pressure of the water standing in the well.	Creates a very "clean" hole, not dirtied with drilling mud. Can be used in all geologic formations. Very deep penetrations possible. Split-spoon sampling possible.	A large water supply is needed to maintain hydro-static pressure in deep holes and when highly conductive formations are encountered. Expensive - experienced driller and much peripheral equipment required. Hole diameters are usually large, commonly 18 inches or greater. Cross-contamination from circulating water likely. Geologic samples borough to surface are generally poor, circulating water will "wash" finer materials from sample.

Exhibit 3.1-8

Advantages and Disadvantages of Selected Drilling Methods for Monitoring Well Construction (continued)

Method	Drilling Principle	Advantages	Disadvantages
Air Rotary	Very similar to Hydraulic Rotary, the main difference being that air is used as the primary drilling fluid as opposed to mud or water.	Can be used in all geologic formations; most successful in high fractured environments. Useful at any depth. Fairly quick. Drilling mud or water not required.	Relatively expensive. Cross-contamination from vertical communication possible. Air will be mixed with water in the hole and that which is blown from the hole can potentially create unwanted reactions with contaminants; may affect "representative" samples. Cuttings and water blown from the hole can pose a hazard to crew and surrounding environment if toxic compounds encountered. Organic foam additives to aid cuttings removal may contaminate samples.
Air-Percussion Rotary or Downhole-Hammer	Air Rotary with a hammer connected to the bit to fracture rock.	Very fast penetrations. Useful in all geologic formations. Only small amounts of water needed for dust and bit temperature control. Cross-contamination potential can be reduced by driving casing.	Relatively expensive. As with most hydraulic rotary methods, the rig is fairly heavy, limiting accessibility. Vertical mixing of water and air creates cross-contamination potential. Hazard posed to surface environment if toxic compounds encountered. Organic foam additives for cuttings removal may contaminate samples.

Source: USEPA. Groundwater, 625/6-87/016.

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There are several factors that should be considered when selecting the appropriate drilling technique. These include the: (a) type of formation; (b) depth of drilling; (c) depth of desired screen setting below top of zone of saturation; (d) types of contaminants expected; (e) location of drilling sites (i.e. accessibility); (f) design of monitoring well desired; and (g) availability of drilling equipment.

Most ground-water monitoring wells will be completed in glaciated or unconsolidated materials and will be relatively shallow, i.e., less than 50 to 75 feet in total depth. In these settings, hollow-stem augering usually will be the method of choice. Solid-stem auger, cable-tool, and air-percussion also offer advantages depending on the area geology and contaminant of interest.

Completing the well installation after the borehole is drilled is accomplished using the double-casing method. In this method, the outside casing, corresponding to the size of the outer diameter of the borehole, is installed as the hole is drilled or after it is finished. A second casing containing the well screen is then centered within the outer casing. The selected filter pack material is then placed between the inner and outer casings. After a few feet of filter pack material has been introduced, the outer casing is pulled back an equal distance and the procedures are repeated until the filter pack extends to the desired level above the well screen.

The outer casing may be removed or left in place above the level of the well screen. In either case, the top of the annular space above the filter pack must be sealed with bentonite clay to isolate the filter pack from the grout. If the outer casing is not removed, the inner casing above the well screen may be removed as long as the outer and remaining inner well casing overlap a few feet. The top of the inner casing should be sealed using a lead slip packer. The annular space left between the outer casing and the aquifer should also be sealed with grout. Grout can be poured into the annular space or may be pumped through a small diameter PVC pipe. The latter technique is known as the tremie method of grout placement and is used typically when the depth to fill with grout exceeds 15 feet. Withdrawal pumps are then installed in the inner casing and the well is developed.

Well installation and development costs are site-specific. Some of the factors that determine these costs are site hydrogeology, the characteristics of the contaminants, the extent of contamination, the periods and duration of pumping necessary to develop the well, the local wage rates, and the availability of supplies and equipment. As summarized in Exhibits 3.1-9 and 3.1-10, these costs can be grouped into three categories: (1)

Exhibit 3.1-9

Typical Range of Costs for Wellscreens and Wellpoints

Type	Division	Costs (1998 $)
Drive Wellpoint	stainless steel 1-1/4 to 2-in ID	$30.00 to $42.00/ft
	low carbon steel 1-1/4 to 2-in ID	$16.05 to $37.45/ft
	PVC plastic 1-1/4 to 2-in ID	$5.35 to $6.42/ft
Wellscreens	stainless steel 1-1/4 to 36-in ID	$30.00 to $652.17/ft
	low carbon steel 1-1/4 to 36-in ID	$16.00 to $181.90/ft
	PVC plastic 1-1/4 to 12-in ID	$10.70 to $64.20/ft
Jetting Screens (fittings)	cast iron or mild steel 2 to 12-in ID	$32.10 to $288.90
Baildown Shoe (fittings)	mild steel 4 to 12-in ID	$192.60 to $856.00

Source: USEPA. Leachate Plume and Management. Office of Research and Development, 540/2-85/004, November 1985.)

Exhibit 3.1-10

Average Drilling Costs (1988) for Unconsolidated Materials

NOTE: **Use production rate and cost data contained in spill response contracts for estimating costs. These costs are provided for comparison purposes only.**

Drilling Technique	Drilling Costs ($/hr)	Average Production Rates (ft/hr)	Drilling Cost ($/ft)
Conventional Hydraulic Rotary	$120/hr	40ft/hr	$3.00/ft
Reverse Hydraulic Rotary	$240/hr	40 ft/hr	$6.00/ft
Air with Pneumatic Hammer	$200/hr	40-50 ft/hr	$4.00-$5.00/ft
Auger	$118/hr	20-40 ft/hr	$2.85-$5.90/ft
Bucket Auger	$120 to $160/hr	50 ft/hr	$2.40-$3.20/ft
Cable-Tool	$80-$90/hr	4 ft/hr	$20.00-22.50/ft
Hole Puncher (jetting)[1]			$37.45/ft
Selfjetting[1]			$19.26/ft

[a] Includes rental of all necessary equipment; e.g., wellpoints, pumps and headers.

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mobilization costs; (2) installation and removal costs; and (3) operation and maintenance costs.

Mobilization costs include all costs incurred in obtaining the needed equipment and having it available at the site. Some of the items included in mobilization costs are: (a) purchase of the well components; (b) deployment of the installation and well development equipment; (c) purchase of the pumping equipment; (d) purchase of the generators, switches, and cables; (e) installation of the necessary utilities; (f) handling of the drilling wastes and development water; (g) decontamination of the drill rig and tools; and (h) compliance with all health and safety requirements.

------ WELL DRILLING SUMMARY ------

APPLICATION:Several methods are used in well installations. The choice of the most appropriate method is a function of the well type, depth, and characteristics of the earth materials in which the well must be completed.

EQUIPMENT: Different drilling techniques include hollow- and solid-stem augers, cable-tool, air-rotary, air-rotary with percussion hammer, and reverse-rotary drilling.

LIMITATION: Each drilling method has limitations with regard to the well's intended use, well depth, and parent rock material.

COST: Drilling costs range from $2.50 to more than $37 per linear foot depending upon the method used.

REFERENCES:[4,6]

d. Monitoring/Observation Wells

A monitoring well is built specifically for the purposes of obtaining a sample for laboratory analysis of ground-water quality. A monitoring well can be completed as a temporary or permanent installation with permanent installations preferred if sampling activities are to continue for more than a few days. Whatever the well type, however, it is imperative that the well be constructed properly to ensure that the collected samples are as representative as possible of the ground water surrounding the well's location.

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Components to be considered in monitoring well design include:

- # Location and number of wells;
- # Casing material;
- # Well screen size, depth of placement, and material;
- # Well diameter;
- # Gravel pack placement;
- # Sealant materials;
- # Well development; and
- # Well security.

The location and number of monitoring wells must ensure that the area of contaminated ground water to be sampled is intercepted by the well installation. A minimum of three wells are needed to provide sufficient data on ground-water flow direction. If there is a significant vertical component to ground-water flow, it may be necessary to install a cluster of wells at a single location with each well in the cluster screened at a different depth. Cluster wells may also provide data on the vertical extent of contamination in an aquifer.

In most monitoring situations, the objective is to determine the extent of ground-water contamination. Most contaminants will descend vertically through the unsaturated zone and then, upon reaching the saturated zone, move laterally along the ground-water gradient. In order to properly assess ground water quality, samples should be collected from at least one upgradient and two downgradient wells. The upgradient well should be located in an area believed unaffected by the contamination. Samples from this upgradient well will establish background ground-water quality.

The type of material used to construct a monitoring well can have an effect on the quality of the collected water sample. The well casing material must retain its structural integrity for the duration of the monitoring program under actual subsurface conditions. The well casing material should neither adsorb nor leach chemical constituents. The use of PVC, Teflon, stainless, or low carbon steel for monitoring wells is a site-specific decision and dependent on the type of ground-water contaminants expected to be encountered. PVC well casing should be adequate for most petroleum products. There are advantages and disadvantages for each of the casing materials (see Exhibit 3.1-11). Teflon[R] is the most chemically inert of the materials, however, is the most expensive and difficult to use. PVC-Type 1 has a very good chemical resistance except in

Exhibit 3.1-11

Recommendations for Rigid Materials in Sampling Applications (in decreasing order of preference)

Material	Recommendations
Teflon(R)	Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions. Virtually an ideal material for corrosive situations where inorganic contaminants are of interest.
Stainless Steel 316 (flush threaded)	Recommended for most monitoring situations with detailed organic analytical needs, particularly for aggressive, organic leachate impacted hydrogeologic conditions.
Stainless Steel 304 (flush threaded)	May be prone to slow pitting corrosion in contact with acidic high total dissolved solids aqueous solutions. Corrosion products limited mainly to Fe and possibly Cr and Ni.
PVC (flush threaded) other noncemented connections, only NSF* approved materials for well casing or potable water applications	Recommended for limited monitoring situations where inorganic contaminants are of interest and it is known that aggressive organic leachate mixtures will not be contacted. Cemented installations have caused documented interferences. The potential for interaction and interferences from PVC is not recommended for detailed organic analytical schemes.
	Recommended for monitoring inorganic contaminants in corrosive, acidic inorganic situations. May release Sn or Sb compounds from the original heat stabilizers in the formulation after long exposures.
Low-Carbon Steel	May be superior to PVC for exposures to aggressive aqueous organic mixtures. These materials must be very carefully cleaned to remove oily manufacturing residues. Corrosion is likely in high dissolved solids acidic environments, particularly when sulfides are present. Products of corrosion are mainly Fe and Mn, except for galvanized steel which may release Zn and Cd. Weathered steel surfaces present very active adsorption sites for trace organic and inorganic chemical species.

(R) Trademark of DuPont, Inc.

* National Sanitation Foundation approved materials carry the NSF logo indicative of the product's certification of meeting industry standards for performance and formulation purity.

Source: USEPA. Practical Guide for Groundwater Sampling, 600/2-85/104.)

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high concentrations of low molecular weight ketones, aldehydes, and chlorinated solvents. Stainless steel is the most chemically resistant of the ferrous materials, although it may be susceptible to high concentrations of chloride ions. The use of other ferrous materials may result in leaching of manganese, zinc, cadmium, and iron into the ground water.

Commercially manufactured well screens are preferred for monitoring well construction. The use of non-commercial screens may allow the soil to clog the screen pores. In formations where fine sand, silt, and clay predominate, sawed or torch-cut slots will not be small or uniform enough to prevent soil from entering the well. The practice of sawing slots in PVC pipe should be avoided in monitoring situations where organic chemicals are of concern. This practice exposes fresh surfaces of PVC increasing the possibility of releasing compound ingredients or reaction products.

The screen length and the depth at which it is placed in the monitoring well depends on such factors as the seasonal fluctuation in water table elevation, the behavior of the contaminant as it moves through the unsaturated and saturated zones, and the objectives of the monitoring program.

Typically, a well screen length is selected that will accommodate the seasonal changes in water table elevation and still allow water (and product) to flow freely into the well. As a general rule, the well screen should be sized to extend five feet above the seasonal high water table elevation and ten feet below the elevation where ground water is first encountered to accommodate drawdown of the water table.

In other settings, the objective may be to monitor only the first water-bearing zone encountered, for example, monitoring a perched aquifer near a potential contaminant source in a relatively impermeable glacial till. In this case, the "aquifer" may be only six inches to a few feet thick, and the screen should be no more than one to two feet in length. This will help minimize any siltation problems due to the surrounding fine-grained materials and avoid the possible entry of water from other saturated zones.

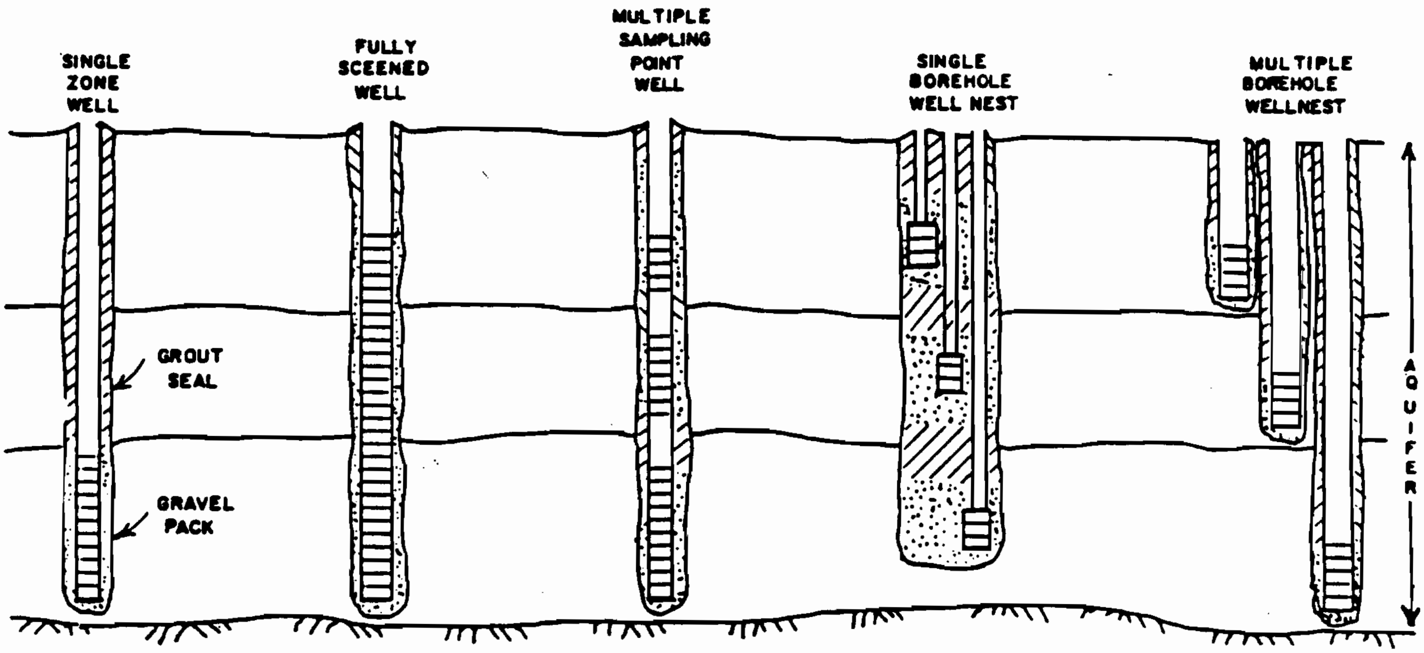
If the aquifer is too thick to monitor with one long section of screen and sampling at specific depth intervals is necessary, vertical nesting of wells is common (Exhibit 3.1-12). Multiple wells are completed in a single borehole with each well screened at a different depth.

Exhibit 3.1-12 depicts various types of monitoring well screens and designs. The advantages and disadvantages of each well type are discussed in Exhibit 3.1-13.

Until recently, the choice of monitoring well size was driven by installation cost and the minimum size of the sampling and

Exhibit 3.1-12

Well Configurations Used for Ground-Water Monitoring



Source: USEPA. *Leachate Plume Management.* Office of Research and Development, 540/2-85/004, November 1985.

Exhibit 3.1-13

Advantages and Disadvantages of Various Types of Monitoring Well Configurations

Well Configuration	Advantages	Disadvantages
Simple Zone Well	Relatively simple to install. Can be installed by a variety of methods. Can provide discrete samples from a precise interval, thus aiding data interpretation. Easy to prevent interaquifer contamination if designed and installed properly.	Vertical distribution of contaminants or hydraulic gradients cannot be determined. Many wells are needed to delineate plume, increasing costs and the time required to install and sample the contaminants.
Fully Screened Well	Relatively simple to install. Can be installed by a variety of methods. Can provide composite samples of large intervals, thus reducing the number of samples. Produces relatively higher yields and thus, are more amenable to pump testing.	Highly contaminated waters may be diluted by less contaminated waters during sampling, biasing results. Vertical distributions of contaminant and hydraulic gradients cannot be determined. Vertical migration of contaminants may occur over screened interval spreading contaminants to clean zones. Impossible to prevent interaquifer mixing if screened over more than one aquifer.
Multiple Sampling Point Well	Can provide information on the vertical distribution of contaminants and hydraulic gradients. Installation is rapid and simple, although construction takes longer than for wells with a single screen. Can be used to obtain composite samples. Fewer wells are needed in a monitoring system, thus reducing costs.	Preventing interaquifer contamination is difficult if not impossible. Sampling is complicated, time consuming, and requires specialized equipment. Cost per well is fairly high.
Single-Borehole Well Nest	Provides information on the vertical distribution of contaminants and hydraulic gradients. Preventing Interaquifer contamination is generally not difficult. Sampling is not difficult but may required specialized equipment, depending on well diameters.	Number of suitable installation methods is restricted. Improper construction can reduce effectiveness and cause vertical movement of contaminants.

Exhibit 3.1-13

Advantages and Disadvantages of Various Types of Monitoring Well Configurations (continued)

Well Configuration	Advantages	Disadvantages
Multiple Borehole	Provides information on the vertical distribution of contaminants and hydraulic gradients. Installation simple by a variety of methods. Preventing aquifer cross contamination is not difficult. Sampling is simple and usually does not require specialized equipment.	Installation is fairly time consuming, but not difficult. Cost per nest is very high.

Source: USEPA. Leachate Plume Management. Office of Research and Development, 540/2-85/004, November 1985.

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pumping equipment that could be inserted and installed. Four-inch wells used to be the standard minimum size. Recently, however, smaller-diameter (two inches or less) pumps have become commercially available with the capability of pumping water from depths as great as 100 feet. Two-inch diameter wells, less costly to install, are rapidly becoming the standard in monitoring well technology. NYSDEC prefers the installation of two-inch wells for monitoring unless a well may be used for product recovery by means of a skimmer device. In the latter case, a four-inch well is preferred.

The larger diameter monitoring wells are still preferred, however, whenever these wells may later be used as part of the free product recovery or ground-water pumping system. Larger diameter wells also merit consideration when sampling at depths of hundreds of feet or more and in other situations where the additional strength of large diameter casing is needed. Cluster well installations will also require a larger diameter borehole (i.e., 12 inches) to accommodate the multiple well casings, however, the individual wells in the cluster can be smaller.

The gravel pack performs the following functions:

- Fills the annular space preventing the uncontrolled collapse of the formation against the well screen;

- Retains a sufficient percentage of fine-grain sediment thus preventing sediment from being drawn into the well to affect water quality or to clog the well screen;

- Passes a small amount of fines and mud cake to help create a flow link between the monitoring well and the surrounding aquifer formation.

It is important to seal various areas of the completed monitoring well to prevent the intrusion of surface runoff or the passage of contaminants down into previously uncontaminated aquifers.

Surface runoff can infiltrate the monitoring well by seeping down an improperly sealed well casing from the ground surface. The result, at a minimum, can be a dilution of contaminant concentrations in the ground water. Surface runoff may also contain contaminants of its own (e.g., road salts). To prevent surface water infiltration, monitoring wells are usually sealed with a neat cement grout, dry bentonite (powdered, granulated, and pelletized), or a bentonite slurry.

The other important well seal is just above the gravel pack and screened interval in the well. This seal functions to prevent any ground water and/or contaminants present above the saturated zone being monitored from migrating down and into that saturated zone. Again, a bentonite seal is typically used.

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A bentonite seal has traditionally been considered to provide a better seal than cement. Recent investigations have shown, however, that some organic compounds can migrate through bentonite. The choice of a bentonite or cement seal, therefore, must be made carefully.

Well development is the process followed to remove drilling materials and fine sediment from the aquifer formation around the area of the well screen. Otherwise, these materials might clog the well screen and reduce the ability of water to flow into the well.

The development of a well is accomplished by using one of the following methods:

Bailing. Development of small diameter well can be accomplished using a bailer that is raised and lowered into the well by hand. This method is slow and the development of deep wells would be fatiguing.

Surge block. Two pieces of wood separated by a rubber gasket and connected to a long rod can be used as a plunger to move large volumes of water into and out of the well screen. Care must be taken to not damage the well casing and surge blocks can become lodged in the well preventing the use of that well.

Water Pumping. Pumps are used to remove nearly all the water from the well. The well is then allowed to recover whereupon the water is pumped out again. The procedure is repeated until the variation across three consecutive measurements of pH, temperature, and specific conductance is within 10 percent.

Air Pumping. Air can be pumped into the well to essentially blow water in and out of the well screen and, potentially, out of the well. It is generally not recommended because of the potential health hazards from contact with contaminated water expelled from the well. Air surging methods should also not be used if there is a danger of creating explosive conditions. Care must be taken to filter the air so as not to contaminate the ground water with compressor oils.

Clean Water. Open borehole wells can be developed using clean water. Clean water is circulated down the well casing, through the well screen, and back up the borehole. This procedure effectively breaks down any sediment accumulated around the well screen.

The security and safety of most monitoring wells must be protected to against damage or intentional or unintentional contamination of the well.

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Well protectors, large diameter steel casing placed around the monitoring well and extending several feet below ground surface, are used to protect the well casing from damage (see Exhibit 3.1-14). The protectors are usually seated in the cement surface seal to a depth below the frost line. Locking caps are frequently used so that unauthorized personnel may not gain access to the well.

Costs associated with the installation of monitoring wells are dependent on drilling method. Refer to Exhibits 3.1-8 and 3.1-9 for cost estimates.

------ MONITORING/OBSERVATION WELL SUMMARY -----

APPLICATION: Provide access to ground water for sample collection and analysis.

EQUIPMENT: Monitoring well casing and screen material, gravel pack, and sealing material.

LIMITATIONS: Limitations are determined by the well's construction and intended use.

COST: Cost for the installation of a 20-feet deep monitoring well using a hollow-stem auger will depend on the geologic materials drilled through and the features of the well (e.g., locking caps).

2. Spill Clean-up Technologies for Soil

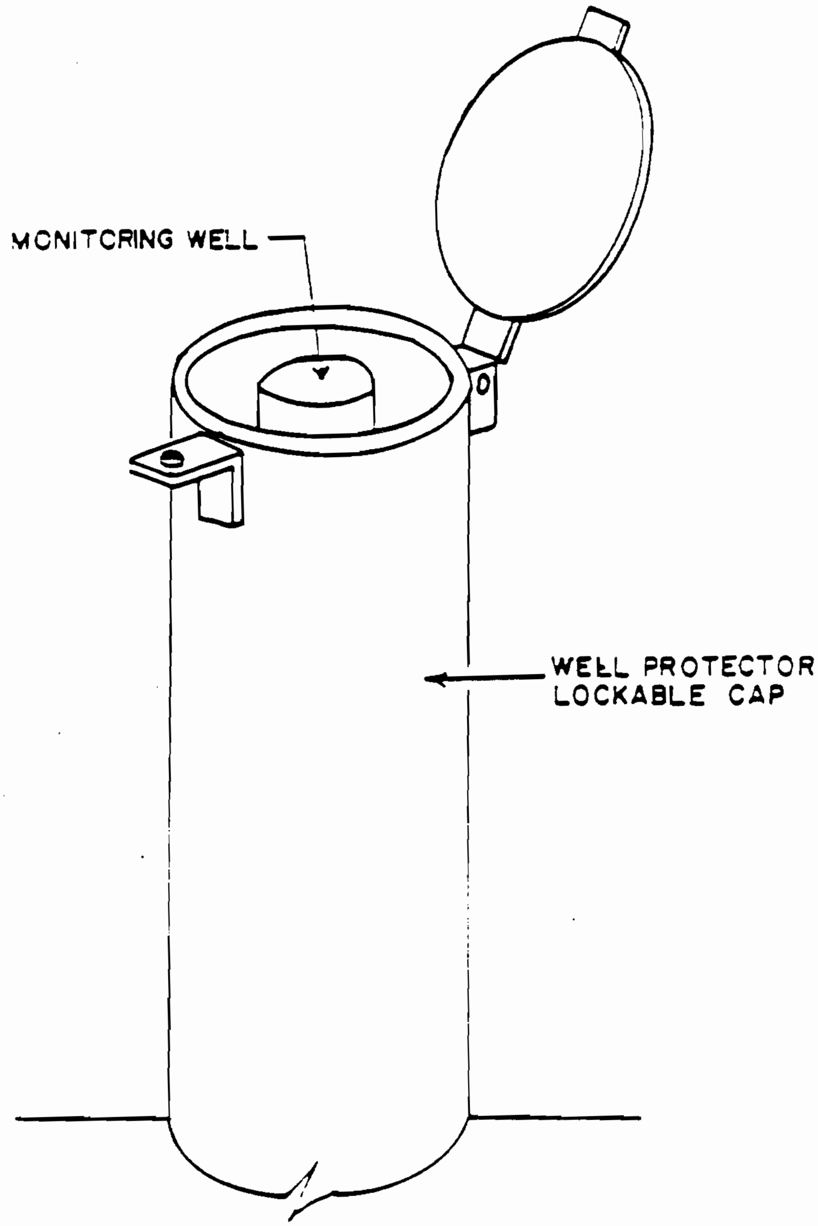
The following technologies can be used for the cleanup of soils contaminated by petroleum products.

a. Soil Excavation and Disposal

The immediate removal of the petroleum contaminants prevents continued migration of petroleum products through the subsurface environment to possibly contaminate ground water and/or surface water, or from entering subsurface structures as free product. Conventional construction equipment (e.g., backhoes) can be used.

Exhibit 3.1-14

Typical Well Protector Installation



Source: USEPA. *Groundwater*, 625/6-87/016.

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Effectiveness of excavation as a remedial technique depends upon the depth of contamination, stability of the earth materials, accessibility of the contaminated soil, and work space constraints. Deeper excavations require shoring to prevent cave-ins. While backhoes are capable of excavating contaminated soil with little or no disturbance to the surrounding area, they do require some operating room and site area for the accommodating the soil pile. Backhoes can only excavate down to a maximum of 45 feet (see Exhibit 3.1-15). Front end loaders and bulldozers are used when larger volumes of soil must be excavated, but require much more operating room.

Petroleum-contaminated soil should not be excavated unless the soil can be disposed of properly and cost-effectively. Disposal capacity for contaminated soils varies across the state. See Part 2, Section 3, Proper Management of Spill Residuals and Debris for explanation of NYSDEC regulations governing the land disposal of petroleum-contaminated soils.

There are no design, operation, and maintenance considerations, in the usual sense of these terms, in using the excavation and disposal technology. There must be sufficient operating space for the equipment and the contaminated soil must be accessible. Dewatering of the excavation may be necessary in areas with a shallow ground-water table.

Typical total costs for labor and equipment to excavate contaminated soil are provided in the individual spill response contracts. The cost for disposal of the excavated material depends on whether it is classifiable as a hazardous waste or not. The disposal of nonhazardous petroleum-contaminated soils ranges in cost from $60 to $110 per ton (excluding transportation costs). Material classified as a hazardous waste must be taken to a permitted, secure, waste disposal facility, if it is to be landfilled. Costs for disposal of hazardous contaminated soil at secure landfills can range from $120 to $240 per ton or even higher (excluding transportation costs).

Removal of contaminated soil from the subsurface environment eliminates a potential long-term source of free product and vapor. Otherwise, mobile liquid and/or gaseous product may continue to move through the subsurface to contaminate ground water and/or surface water (prolonging cleanup of these resources), or create potentially explosive conditions in subsurface structures. The removal of contaminated surface soils eliminates a direct contact hazard and any contribution of contaminated runoff to surface waters. Excavation can be completed using readily available equipment and, in most cases, fairly quickly. For spills that contaminate only a small volume of soil material, it may be the only remedial action necessary.

The nature of excavation activities increases the potential for exposure of workers and the surrounding public to contaminants unless precautions are taken (like excavating on calm days and placing the soil pile on plastic sheeting, in a contained area, and covering it). Volatile contaminants are released into the atmosphere

Exhibit 3.1-15

Maximum Reach and Depth for Various Sized Hoes
(Maximum Digging Angle of 45°)

Hoe Size (yd^3)	Maximum Reach of Boom (ft)	Maximum Depth of Excavation (ft)
1	35	22
1-1/2	42	25
2	49	30

Source: Remedial Action at Waste Disposal Sites (Revised) EPA 625/6-85/006.

during the excavation process. It is also not a permanent treatment option. Contaminants are not destroyed, rather they are transferred to another location for land disposal. It is possible to treat the contaminated soil onsite to lower contaminant concentrations such that on-site disposal is allowed (e.g., replace the soil in the excavation). This option requires adequate space to operate the treatment method (rotation of the soil pile to enhance volatilization or low-temperature volatilization) and may not be feasible in congested areas due to concerns over exposure to volatile contaminants.

Disposal of contaminated soil offsite requires facilities that can and will accept these materials, and may be expensive, especially if these facilities are not located in the vicinity of the spill site. Even if the contaminated soil is nonhazardous, some local sanitary landfills will not accept petroleum-contaminated soil for disposal. As the transportation distance increases and/or if the soil is classified as hazardous waste, the cost for off-site land disposal increase dramatically.

------ SOIL EXCAVATION AND DISPOSAL SUMMARY ------

APPLICATION:May be a quick and effective means of removing contaminants from the spill site.

EQUIPMENT: Backhoes, loaders, and dozers are commonly used for larger excavations. May only require using a shovel.

LIMITATIONS:Potentially high transportation and disposal cost, especially for hazardous wastes. Requires sufficient working space. Area or depth of excavation may be constrained. General trend away from excavation toward on-site remediation.

COST: Cost for excavation equipment range from $650 to $1970 per day. The cost for the disposal of non-hazardous material range from $60 to $110 per ton. Hazardous materials disposal rate ranges from $120 to $240 per ton not including transportation.

REFERENCES:[6]

b. Soil Venting

Soil venting refers to techniques used to enhance subsurface ventilation and volatilization of volatile organic contaminants in the soil and from off the water table. Effectiveness of this technology is highly site-specific. Soil porosity, soil water content, clay content, ambient temperatures, and other factors all influence effectiveness. Water content influences volatilization rate by changing rate at which compounds move through unsaturated zone. An increase in soil water content

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generally decreases volatilization rate. Decreasing soil porosity and increased clay content impedes vapor flow. Increased mineral and organic content of soil increases ability of soils to adsorb contaminants and volatilization rate is reduced. Volatilization rate increases with temperature; this is why some system designs incorporate injection of heated air. Increasing wind speed and evaporation of water at soil surface will also aid volatilization.[6]

There are two basic venting system designs: passive vapor control and active vapor control (i.e., mechanically drawing air through the soil matrix). Both systems can be used to stop and/or divert the migration of volatile contaminants in the soil gas to protect subsurface structures. Exhibits 3.1-16 and 3.1-17 are schematics of an active vapor system design and passive vapor system design (two variants), respectively. Active vapor systems can be based on just drawing soil gas out of the soil or simultaneously injecting unheated or heated air into the soil.

There are two variants of a passive vapor control system. A high-permeability (relative to the surrounding soil) system uses a backfilled trench located between the migrating contamination and the area to be protected. The trenches are excavated down to the contaminated zone or to the water table and backfilled with a highly-permeable medium such as 1/4-inch (at least) diameter crushed stone or gravel. PVC piping can also be placed in the backfill to ensure that vapors can pass out of the soil even when the soil surface has been sealed by frost or some other impermeable cover.

A low-permeability passive vapor control system consists of a trench with the downgradient wall lined with a synthetic membrane barrier to retard vapor flow beyond the trench. The trench is then backfilled with crushed stone or gravel to create a preferential flow path for the soil vapor to be vented to the atmosphere. PVC piping may also be installed in the backfill.

Active vapor control systems may consist of:

- Air injection wells if heated (pre-injection air heater required) or unheated air is to be injected to help increase the volatilization rate;

- Vapor extraction/recovery wells installed as slotted or screened PVC pipe;

- Lateral vapor collection header/manifold PVC pipe ductwork connecting the vapor-recovery wells;

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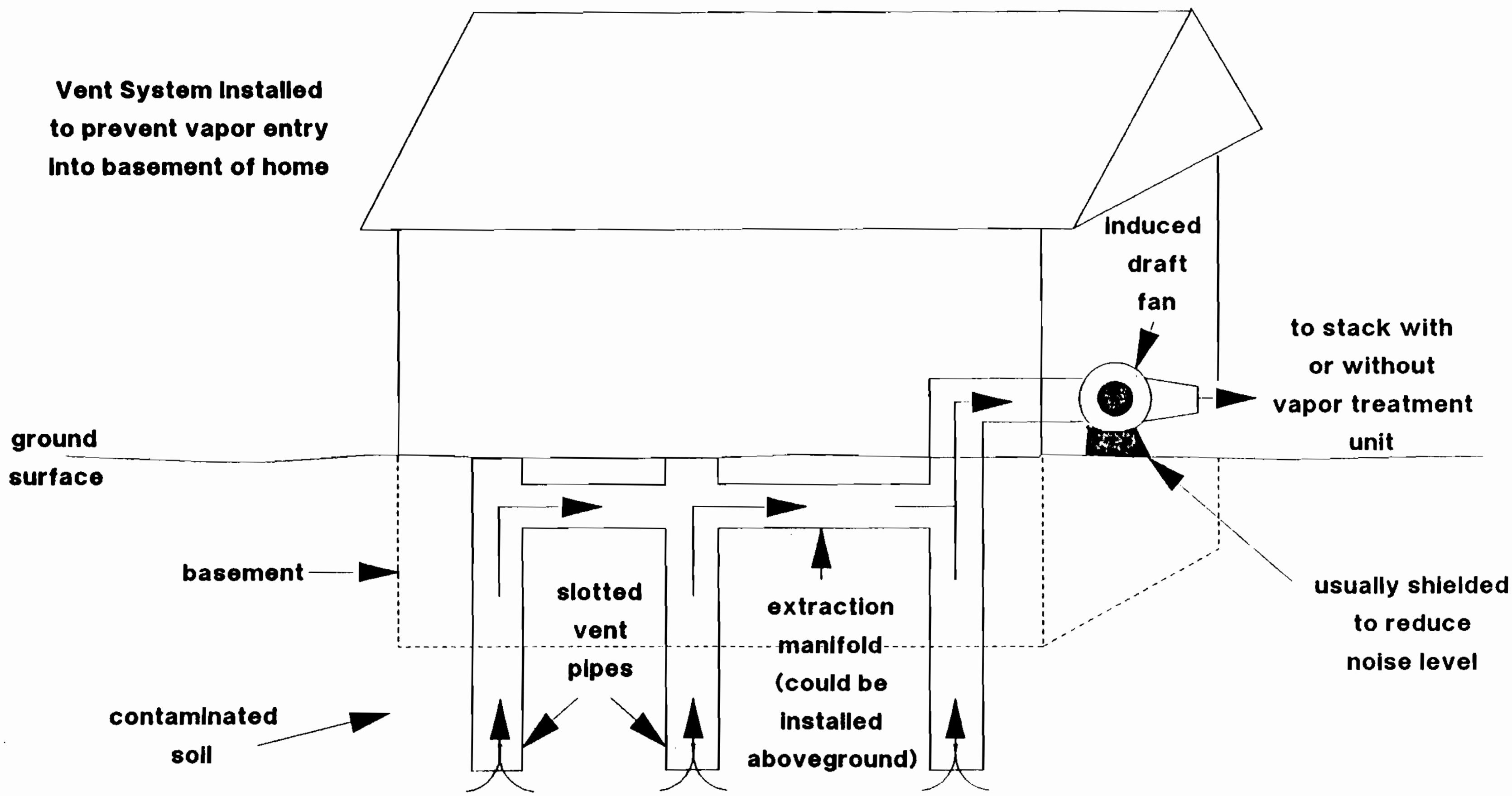
[6] *Often the soil acts as a vast heat sink and subsurface temperature rises are not appreciable. In cold climates, however, air heaters are valuable for system freeze protection.*

Exhibit 3.1-16

Active Vapor Control System

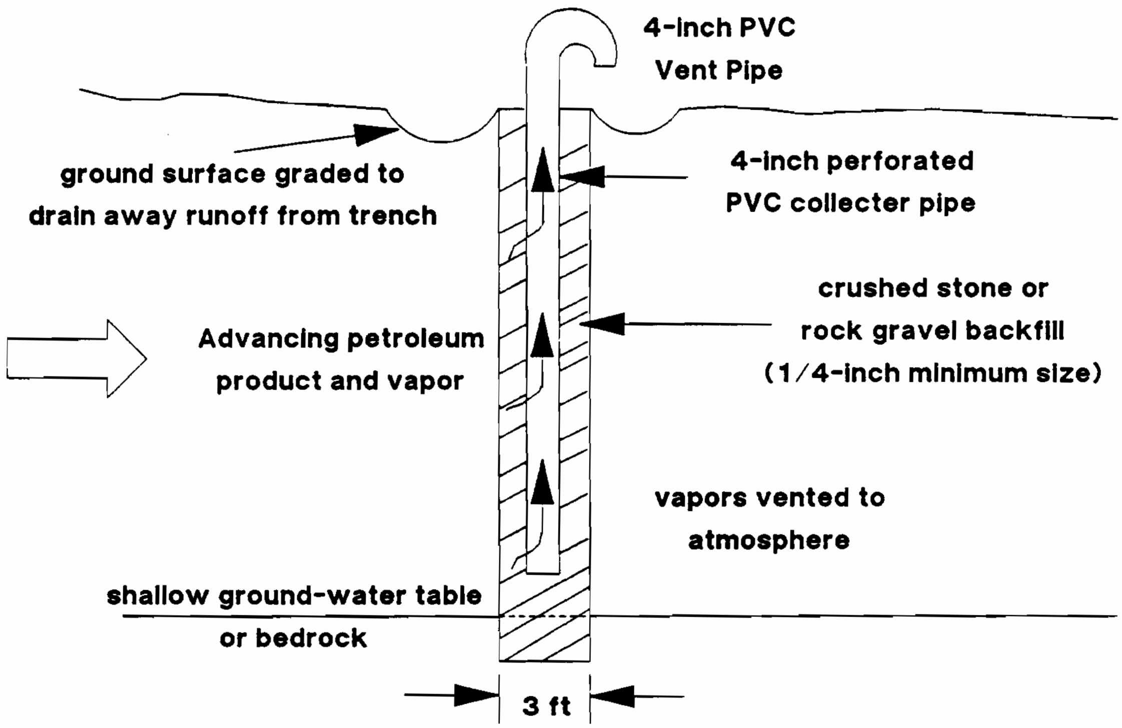


Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.

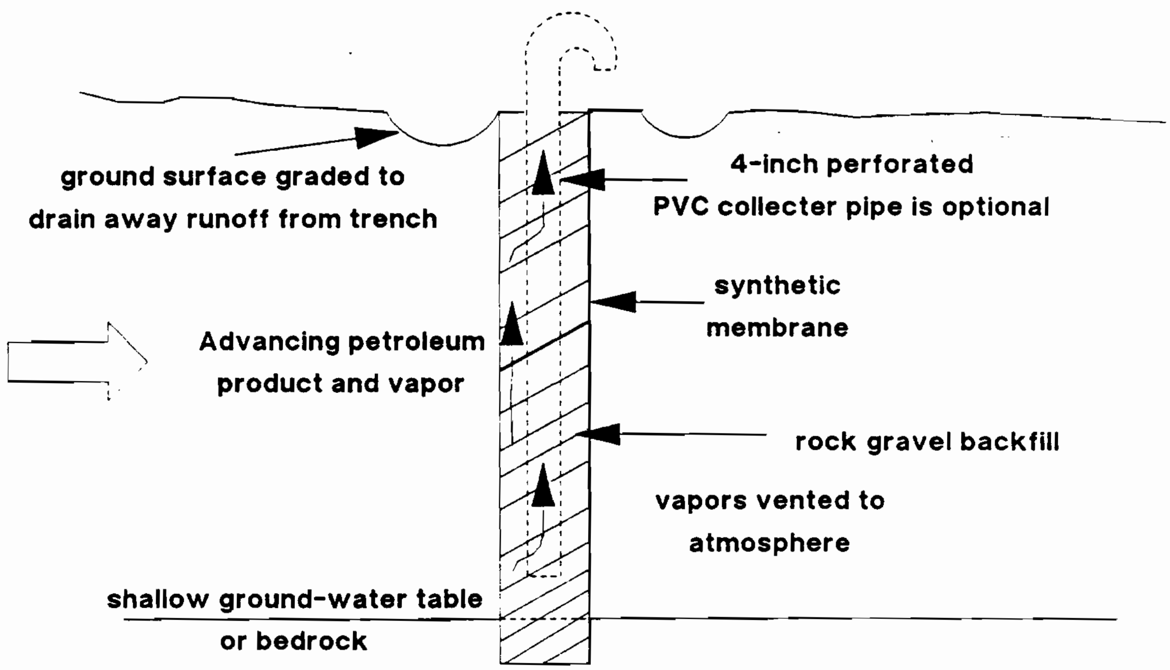
Exhibit 3.1-17

Schematic of Passive Vapor Control Systems

High-Permeability System



Low-Permeability System



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- # Injection and/or induced draft fans to establish air flow through the unsaturated zone;

- # An activated vapor phase carbon unit to minimize vapor emissions where necessary; and

- # Various air flow controls to facilitate system efficiency (e.g., proper balancing of air flow to each venting well when a single fan/blower is used) as well as sampling ports to check progress.

Active vapor systems can be installed using conventional drilling equipment and materials.

Design considerations for active vapor control systems include:

- # **Number and spacing of venting wells.** One or more venting wells can be installed. Spacing between venting wells is a function of areal extent of contamination, soil permeability and porosity, and air flow rate. Requires field testing to measure air flow and pressure drop through the soil. Need to calculate air flow and pressure drop due to frictional losses through the system, and needed blower or fan capacity to meet flow and pressure requirements.

- # **Venting well depth.** Proper depth is function of depth of contaminated zone and site geology.

The operation of active vapor control systems may require permits for the discharge of volatile contaminants into the atmosphere. At a minimum, the vent stack should be located and of sufficient height to minimize exposure to volatile contaminants and to ensure vapors do not collect to explosive levels in enclosed or poorly ventilated areas (e.g., under roof eaves). Operating permit may require monitoring of exhaust emissions. Noise levels from the blower unit may be a concern and may require the construction of baffles and shielding. The blowers will require periodic maintenance. Periodic inspections of the venting wells, air flow, and temperature is advisable to ensure proper system balance is maintained.

As passive vapor control systems have no moving parts, there are no real operation requirements. Maintenance will be required to ensure that drainage is directed away from the top of the backfill so that the surface does not become clogged restricting vapor flow.

Use of either an active or passive vapor control system requires periodic monitoring of contaminant levels in soil and/or ground water.

Costs will be a function of design flow rate, size of piping, degree of automated monitoring, and, if necessary, vapor treatment required. Latter can raise costs

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by an order of magnitude. The major capital costs for active vapor control systems are associated with the venting well installation, blower purchase, and the costs associated with air emission controls. The major cost in a passive vapor control system is construction of the trench. Typical costs for active and passive vapor control systems are listed in Exhibit 3.1-18.

Operation costs for active vapor control systems are low, but vary depending upon degree of automation in the system and whether air emission control system is included. Annual fan operating cost can be estimated from (fan brake hp) (0.746 kW/hp) (8,760 hrs/yr) (electricity costs in $/kW-hr). Maintenance costs are on the order of 4 percent of total installation costs.

Soil venting is a reasonably low-cost method for reducing volatile contamination levels in subsurface soils, especially highly permeable soils with very little or no clay content. Treatment periods can be as short as a few weeks, but are typically more on the order of 6 to 12 months. For spills that have not yet contaminated ground water, this technology may be sufficient to remedy soil contamination to acceptable levels. Ultimate clean-up levels, however, cannot be predicted reliably. Some researchers argue that soil venting systems used in conjunction with free product recovery systems improve the efficiency of the free product recovery operation.

Soil venting systems are less effective for older spills where a large fraction of the volatile components have already volatilized from the spill mass. Soil venting will also be less applicable to fuel oil spills (particularly the heavier No. 4, 5, and 6 fuel oils) as fuel oils contain lesser amounts of volatile constituents in comparison to gasoline. Passive vapor control systems cannot be used when contamination is at a depth beyond which trenches can be completed safely or with readily available trenching equipment. Although technically feasible, the operational requirements of a deep, active vapor control system may make the use of this technique impractical as well. Soil type also has a large influence on the effectiveness of these systems. Low permeability soils, such as silts and clays, restrict the movement of soil vapor thus reducing the effectiveness of this method. More time may be needed to establish the necessary pressure gradient. By the same token, soil vapor control may be less of a concern in such soils.

------ SOIL VENTING SUMMARY ------

APPLICATION:Passive vapor control systems can be used when trench excavation can be completed to the same depth as the contamination. Active vapor control systems can be used where there is the capability to drill venting wells. Preheated air can be injected to increase volatilization rate.

EQUIPMENT: Passive vapor control systems are installed using conventional trenching equipment. Two variations: trench with PVC venting and perforated collection piping or trench lined on

Exhibit 3.1-18

Soil Venting System Costs

	Active Venting	Passive Venting
Typical Cost ($/cubic yard)	$15-20	$10-15
Effectiveness	Reduction in mobility of vapor 99.99% re-removal of VOC's.	Reduction in mobility of vapors.
Limitations	Effectiveness depends on soil characteristics. May require vapor phase treatment of emissions. Care must be taken to avoid explosions.	May require vapor phase treatment. Not as effective as active venting.
Applicability and Relative Use at UST Sites	High in some cases.	High in some cases.

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the downgradient wall with a synthetic membrane barrier to retard vapor migration. Active vapor control systems utilize well drilling equipment, PVC perforated or solid-wall well piping, PVC header piping, valves, vacuum blowers or compressors, and possibly vapor treatment systems.

LIMITATIONS: The use of passive systems is limited by the presence of perched water table or rock strata and is less effective in geographic areas of excessive rainfall and extended freezing temperatures. Active systems can be limited by the presence of saturated or impermeable earth materials. Explosion and worker hazards must be addressed.

COST: Excavation costs of $650 to $1970 per day; gravel backfill of $10 to $16 per ton. The costs for active systems are very site-specific.

REFERENCES:[5,8,15]

c. Enhanced Soil Volatilization

Enhanced volatilization is any mechanical technique that removes volatile organics from unsaturated soil by bringing contaminated soils into contact with clean air. In the process, volatile contaminants in the soil are transferred into the air stream.

There are several variants of this technology that could be used at petroleum spill sites depending upon local/state regulation and work space availability. For example, rototilling contaminated soil into an area of uncontaminated soil is considered enhanced volatilization, but is not allowed under New York State law. Other versions of the enhanced volatilization technology include:

Enclosed mechanical aeration systems. These systems mix contaminated soils in a pug mill or rotary drum. The volatile components are released by the churning action of the soil and pass into the air stream. Emissions are often routed to an air pollution control device (e.g., water scrubber or vapor-phase carbon adsorption system) before they are discharged.

Low temperature thermal stripping. This system is similar to a enclosed mechanical aeration system except that additional heat transfer surfaces provide for heating the soil. Heat is delivered by means of contact with a heated screw-auger device or rotary drum system as the soil mass is mixed. An induced airflow conveys the desorbed volatile organics/air mixture through an afterburner where the organic contaminants

are destroyed. The air stream is then discharged through a stack.

A pug mill mixes, blends, or kneads its contents through the action of an internal mixing unit. A rotary drum achieves a mixing action by virtue of its rotation around its axis. Blowers and/or draft fans are used to induce an air flow within the mixing chamber. Pollution control systems may be necessary, if the loading of volatile contaminants discharged to the atmosphere exceeds allowable limits. These systems are not overly large, but do require sufficient operating space for the handling of the contaminated and processed soil, a concrete pad for operation of the mill/rotary drum, and area for the operation of the ancillary equipment (e.g., air emission controls). Few UST sites are expected to have sufficient work space, but some may and, at these sites, especially when off-site land disposal is not possible or very expensive, a pug mill or rotary drum system may be a viable option.

A low temperature thermal stripping system consists of several conveyor belts, an air preheater, an oil storage tank and heating unit, a heated screw auger conveyor, a combustion air blower, an afterburner, a baghouse for dust, and storage hoppers along with the primary process equipment. Soil is fed via a hopper into the thermal processor and is heated and mixed through contact with the screw auger. Oil traveling down (and back) the full length of the screw auger is used as the heat source. The soil has a residence time in the thermal processor of about 30 to 60 minutes. The exhausted air stream is sent to the afterburner to destroy the organic contaminants.

The low temperature thermal stripping system is like a small-scale incinerator in many of its operating requirements and systems, but operates at far lower temperatures. Accordingly, there is less wear on the system. Operating parameters such as dryer temperature, dryer air flow, soil volume per run, number of passes through the dryer, total dryer retention time, dust control, and handling of collected baghouse particulates must be carefully controlled for maximum efficiency and avoidance of environmental impact. The contaminated soil must be pre-screened to remove large particles. Systems requiring periodic maintenance include the oil heating system, conveyors, and the air emission control systems. Permits may be required in order to discharge any residual organic vapors leaving the afterburner. On the local level, the treatment system may require compliance with building and fire codes and land use ordinances.

A transportable low temperature thermal stripper would have setup costs, including for the associated pollution control equipment, of between $100,000 - $500,000 depending on the need to clear land, construct temporary placement pads, and tie-in utilities.

Operation and maintenance costs for low temperature thermal stripping vary with the size and design of the system (e.g., need for exhaust gas treatment). It is possible for operation and maintenance costs to approach total capital cost for the equipment. The costs to process very small volumes of contaminated soil are prohibitive. It may be most cost-effective for soil volumes in excess of 10,000 tons (i.e. five hundred, 20-ton, dump trucks loads).

Enhanced volatilization systems offer the opportunity to process contaminated soils onsite and return them to the excavation, if they meet the applicable criteria (see Part 1, Section 6.6, Soil Remediation). As such, the costs for transport and off-site disposal are not incurred as well as the cost to obtain large quantities of clean backfill. Excavation of the contaminated soil is still required, however, and all the disadvantages of that method are applicable.

The use of enhanced volatilization techniques is limited in the spill remediation setting given the costs involved to process small volumes of soil. Its use is also limited by soil characteristics that inhibit the mobility of petroleum product constituents from the soil into an air stream, contaminant concentrations that may cause an explosion or fire, and the need to control air quality impacts due to dust and organic vapor emissions. The operation and maintenance of these systems is also fairly sophisticated and requires a fairly large work space area that may not be available at many spill sites.

------ ENHANCED SOIL VOLATILIZATION SUMMARY ------

APPLICATION: Increases the volatilization of organics from unsaturated soil by means of increasing the contact of clean air with the contaminated soil.

EQUIPMENT: There are several variants of this technology. Equipment includes pug mills, soil shredders, and rotary drum soil dryers.

LIMITATION: Large work space areas are required and often extended treatment time periods. Soil characteristics can limit volatilization. Less effective on non-volatile constituents. May need to control organic vapor emissions due to safety and/or health concerns.

COST: Typical costs are in the vicinity of $250 per cubic yard. (1988 dollars.)

REFERENCES: [8,9,15]

d. In-Situ Soil Washing/Flushing

In-situ soil washing or flushing involves flushing water or a water-surfactant mixture (acid, alkalis, and detergents are the more common surfactants) through the contaminated soil zone in an effort to leach the soluble contaminant compounds adsorbed on to the soil particles. Soil washing/flushing can also be conducted in aboveground units after excavating the contaminated soil and creating a slurry mixture for processing (see chemical extraction below). The

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extracted constituents can then be removed from the washing solution by conventional treatment methods.

The effectiveness of a soil washing/flushing system depends on how tightly a petroleum constituent will bind to soil particles. The more volatile and water-soluble petroleum product constituents do not adsorb tightly to soil and are more amenable to treatment via this method. Removal percentages in various tests of aboveground soil washing/flushing systems have been in the range of 96 to 99 percent. Rates of removal for in-situ applications are quite variable ranging from very poor (using water alone) to levels comparable with aboveground systems. If the contaminant has a high water solubility and low affinity to bind to soils, and the earth materials are permeable, an in-situ application of this technology is feasible. Of these factors, the affinity of a compound to bind to soil is the most significant controlling factor.

To design an in-situ application of this technology requires information on the extent and nature of the petroleum-contaminated soil; the site soil characteristics; surface drainage patterns and infiltration rates; ground-water elevations, flow directions, and aquifer characteristics; and field permeability testing of the petroleum-contaminated soils.

In-situ applications utilize a mixing tank; a spray recharge system, infiltration galleries, or injection wells (i.e., gravity or forced delivery of the water-surfactant mixture); interceptor trenches or well points/recovery wells (i.e., gravity of forced recovery of ground water); and a treatment system for the recovered ground water. The type of treatment system selected depends upon the desired quality for the effluent. Typically, an air stripper is used to remove volatiles from the recovered flushing solution and ground water. Volatile contaminants are discharged to the atmosphere and the water effluent may be recycled or discharged in accordance with local/state requirements.

Other traditional wastewater treatment technologies have also been tested for separation of the petroleum contaminants and surfactant. If petroleum product is recovered, this product must be disposed of properly. Since recovery and recycling of the surfactant has proven difficult, applications of this technology must also consider disposal requirements for the remaining effluent.

Permits for the discharge of the washing solution into the ground are required in New York State. On the local level, the treatment system may require compliance with building codes and land use ordinances.

There have been few applications of this technology. The components of the soil washing/flushing systems (excluding the conventional waste water treatment system) may cost from $1500 to $3000 and the well installation costs are typically in the range of $15 to $25 per linear foot. Costs for surfactants may range from $0.65 to $0.88 per pound. In-situ applications do not incur the costs for soil excavation and handling.

The cost of soil washing/flushing conducted in an aboveground system has been reported to range typically between $150 to $200 per cubic yard of soil

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not inclusive of excavation, maintenance, and set up cost. The major cost is the treatment system for the flushing solution.

Cost-effectiveness is improved if it is possible to separate and reuse the surfactant from the recovered ground water. This has proven difficult in field-scale applications of this technology.

In-situ applications of this technology do not incur the costs and disadvantages of soil excavation and disposal. However, this technology has not been applied widely and there is much uncertainty regarding its effectiveness. Gravity-feed systems are most applicable to sites where the overburden soils are thin and fairly permeable, most of the contaminated soil volume is located in the unsaturated zone, and the depth to the bottom of the contaminated zone is less than 15 feet. These systems can become clogged as a result of bacterial growth and may need to be cleaned out periodically.

Gravity-recovery systems are most applicable to sites where the water table is located at shallow depths, i.e., within 15 to 20 feet. For a deeper recovery zone, especially in impermeable soils, forced-recovery systems (e.g., well points, recovery wells, and vacuum well points) are recommended.

The use of surfactants in the flushing solution mixture can reduce soil permeability and decrease the leaching and recovery rate of the injected solution. This factor may be offset by the ability of surfactants under the right soil conditions to facilitate desorption of the contaminants from the soil particles. Prior to any applications laboratory research should be conducted to determine the most effective surfactant for the particular site and spilled material.

------ IN-SITU SOIL FLUSHING SUMMARY ------

APPLICATION: Soils are flushed in place with water or a water-surfactant mixture to desorb contaminants in the soil. The surfactant aids desorption from the soil particles. Downgradient shallow well points or recovery wells are then used to recapture the contaminated flushing solution and ground water for above ground treatment and/or disposal.

EQUIPMENT: Necessary equipment for the installation of well points, trench systems, interceptor ditches, pumps, and/or spray applications system depending upon the particular system design. Also mixing tanks for the water-surfactant solution. The recovered flushing solution and ground water requires additional handling and treatment equipment.

LIMITATION: Soil types and conditions will affect potential recovery of contaminants. The use of surfactants in clay soils reduces soil permeability and may make recovery of the flushing solution more difficult. Permits are required for discharging solution into the ground.

COST: Typical average cost for this technology ranges between $150 and $200 per cubic yard (1988), excluding costs for set-up and maintenance.

REFERENCES:[1,2,3,4,9,15]

e. Aboveground Chemical Extraction

Soil washing/flushing can also be conducted in aboveground units after excavating the contaminated soil and creating a slurry mixture for processing. The extracted constituents can then be removed from the washing solution by conventional treatment methods.

The soils to be extracted must be amenable to breakdown, dewatering, and desorption. Clay content must be less than 20 to 30 percent. The effectiveness of this technology is also highly dependent upon the characteristics of the petroleum constituents. The most significant factor is how tightly a petroleum constituent will bind to soil particles. The more volatile petroleum product constituents do not adsorb tightly to soil and are more amenable to treatment via this method. Removal percentages in various tests of aboveground soil washing/flushing systems have been in the range of 96 to 99 percent.

Older petroleum product spills are less amenable to the application of the chemical extraction technology. This is because there has been more time for loss of the more volatile and soluble petroleum constituents and for more of the product to become adsorbed onto the soil particles.

The excavated soil is first screened for size reduction and the removal of large objects. The contaminated soil is then mixed vigorously with the water/solvent or water/surfactant mixture to create a slurry. The choice of the solvent or surfactant is a function of the solubility of the target contaminant(s) to be removed. The soil slurry is then processed through a filter press or a froth flotation unit to separate out the "cleaned" soil. The water fraction requires additional treatment to remove the extracted contaminants and recover the extraction solution for reuse. The "cleaned" soil may required further treatment (e.g., dewatering) and may be returned to the excavation if it meets the acceptable quality criteria. Permits are required for discharge of the washing solution into the ground may be required. On the local level, the treatment system may require compliance with building codes and land use ordinances.

The cost of chemical extraction conducted in a rented, transportable, system has been reported to range between $150 to $200 per cubic yard of soil not inclusive of excavation, maintenance, and set up costs. The major cost component is the treatment system for the contaminated extraction solution. Costs for surfactants may range from $0.65 to $0.88 per pound. This application of the soil washing technology also incurs the costs for soil excavation and handling.

Aboveground soil washing/flushing systems require excavation of the contaminated soil. While this can be a negative factor, it does allow for a more controlled processing of the soil and removal efficiencies tend to be higher. Extraction solutions can be used in this controlled and contained application that could not be used in in-situ applications of this technology given their adverse effect on the environment. The system itself requires more operating space and is more sophisticated in its operation and maintenance.

------ CHEMICAL EXTRACTION SUMMARY ------

APPLICATION:Excavated soils are washed with a water/surfactant or water/solvent extraction solution in an aboveground treatment system. The extraction solution desorbs contaminants in the soil. Employed as an alternative to the in-situ application of this technology.

EQUIPMENT: Units to screen the soil and mix it with the surfactant/solvent. Fitter press or froth flotation to separate out soil. Process to recover extraction solution from water fraction.

LIMITATION: Soil types and conditions will affect potential recovery of contaminants. Have found it difficult to separate contaminants out from water-surfactant-solvent mixture to allow for recovery and reuse of extraction solution.

COST: Typical average cost for this technology ranges between $150 to 200 per cubic yard.

REFERENCES:[1,2,3,4,9,15]

f. Bioremediation

Bioremediation is the enhancement of the indigenous or of an engineered, introduced, microorganism population in soil and/or ground water to degrade organic contaminants. These microorganisms use the carbon components of organic contaminants for food with the result that organic compounds are decomposed to mostly carbon dioxide and water.

Natural biodegradation rates are usually slow. Bioremediation technology increases the speed at which degradation occurs by supplying greater amounts of nutrients and oxygen to support the biological and biochemical reactions. Microbial degradation can occur in-situ or in an aboveground bioreactor.

In general, the n-alkanes, n-alkylaromatic, and aromatic compounds of the C10 to C22 range in petroleum products are the most readily biodegradable. Some of the compounds in the C5 to C9 range are toxic to some microorganisms in high concentrations. The gaseous alkanes in the C1 to C4 range are biodegradable by only certain microorganisms. Branched alkanes and cycloalkanes in the C10 to C22 range and the n-alkanes, alkylaromatic, and aromatic compounds above C22 tend to be resistant to biodegradation.

Dissolved oxygen levels, soil moisture content, soil permeability, oxidation-reduction potential, temperature, pH, compound availability and concentration, and the availability of nutrients all influence the effectiveness of this remedial technique.

- **Soil moisture**. The moisture contained in the soil is a necessary requirement for microorganism growth. For optimum aerobic activity, a moisture content 50 to 80 percent of the soil's free moisture capacity is needed.

- **Oxygen levels**. The ability of microbes to degrade organic compounds depends upon the level of oxygen found in the soil/water. The presence of oxygen facilitates the oxidation-reduction reaction needed to biodegrade organic chemicals.

- **pH levels**. The pH of the soil or water directly affects the microbial population. A pH of 7.8 (slightly basic) produces an acceptable environment for biodegradation.

- **Chemical factors**. The type of compounds present and their concentration will determine the efficiency of the microbial degradation. Biodegradation is usually limited by the solubility of the target compound in water. If the concentration of the target compound is too low, there may be insufficient food available to sustain biological activity or the microorganisms will switch to another food source. If the concentration of the target compound is too high, however, it may inhibit microorganism growth.

- # **Nutrient Injection**. Inorganic nutrients such as nitrogen and phosphorus are injected into the subsurface to sustain growth and activity of the microbial population.[7]

- # **Temperature**. The degradation of organic chemicals can occur at temperatures from 40^o to 104^{o}F. Biological activity generally increases with an increase in temperature up to an optimum level after which further temperature increases kill the bacterial population.

The few full-scale applications of in-situ bioremediation technology suggest that it is most cost-effective when there are very large areas of soil and/or ground-water contamination requiring treatment. Contaminant levels may show a decrease in as little as two to three months, but the typical treatment time is on the order of six to 18 months.

Bioremediation can be applied to the cleanup of both contaminated soil and ground water. Before this technology can be used, however, various site hydrogeology characteristics must be evaluated (see below) and a feasibility study must be completed to see if the microorganisms will grow and are capable of degrading the specific chemical constituents.

In situations where surface soil contamination is less than three feet below ground surface, the contaminated soil can be conditioned, using the following methods, to support a large microorganism population:

- # The soil is tilled to provide oxygen;

- # A nutrient mixture is applied over the tilled soils (i.e., nitrates, phosphates);

- # A water/microorganism mixture is introduced into the contaminated soil;

- # The soil is retilled and kept moist with water; and

- # The procedure is repeated every 4 to 6 weeks.

This application of bioremediation technology has shown a capability to reduce contaminant concentrations in the soil by 66 percent within the first five weeks of treatment.

As noted above, there are both in-situ and aboveground applications of bioremediation systems. Exhibit 3.1-19 depicts a ground-water pumping system for subsequent microbial degradation in an aboveground bioreactor. Alternatively, gravity-feed (infiltration galleries) or forced-feed (injection wells) delivery systems may be used to introduce microorganisms and/or nutrients and oxygen

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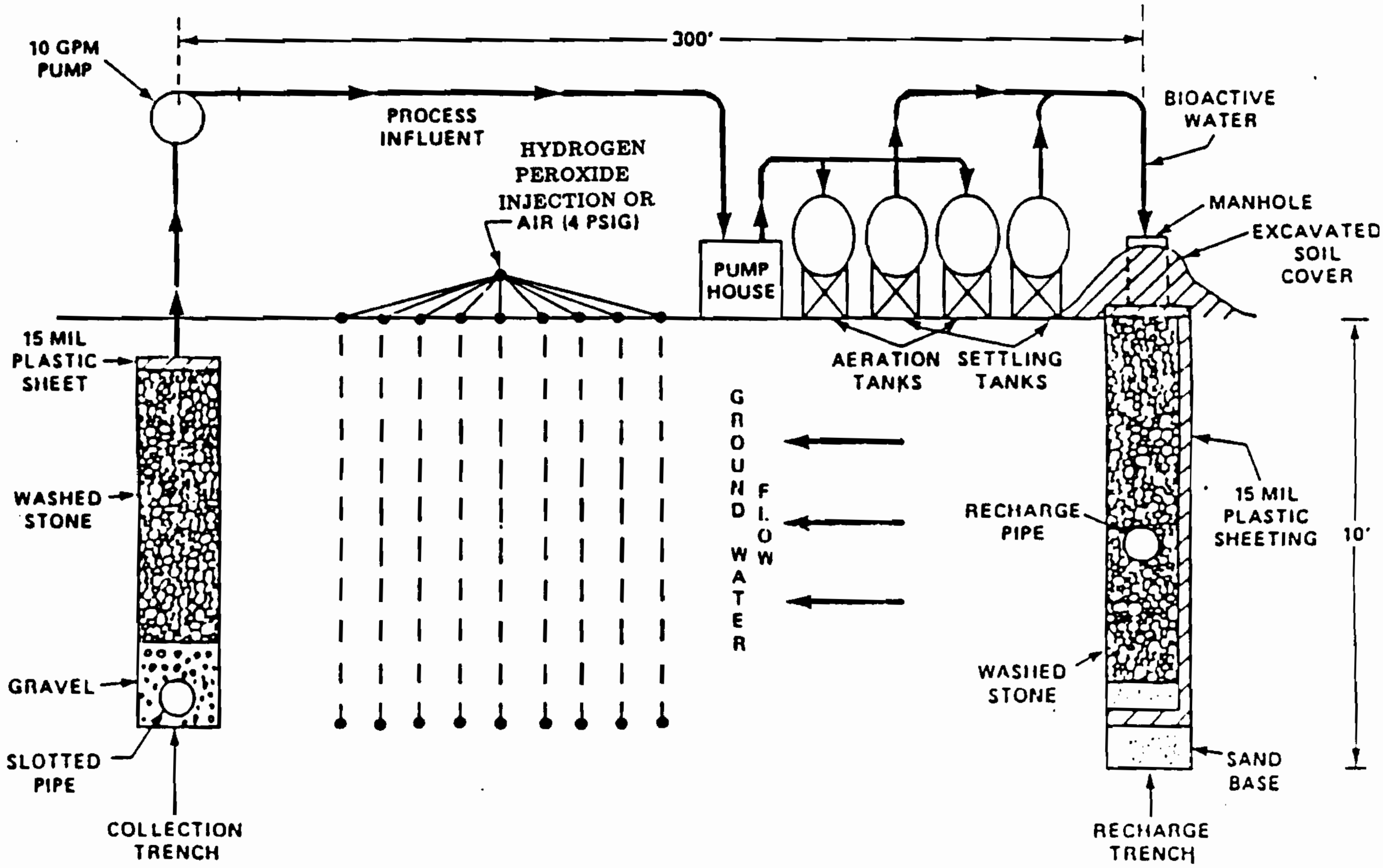
[7] *The New York State Groundwater Standards prohibit the discharge of nitrates into the ground water in concentrations exceeding 20 mg/l (10 mg/l on Long Island).*

Exhibit 3.1-19

In-Situ Bioremediation Treatment System
Basic Process Flow Diagram



(Source: USEPA. *Systems to Accelerate In Situ Stabilization of Waste Deposits*, 540/2-86/002, September 1986.)

(typically in the form of hydrogen peroxide) into the contaminated zone (see Exhibit 3.1-20). The basic operating equipment for an in-situ design would include a recovery well (with submersible pump) to pump ground water; mixing tank for the nutrients and hydrogen peroxide; hydrogen peroxide storage tank; and injection well and pumps (for forced-feed system) or infiltration gallery (for gravity-feed system) for return of ground water-nutrient mixture into subsurface.

Site hydrogeology is the critical design factor for in-situ bioremediation system. For in-situ bioremediation technology to be successful, it is necessary to: (a) achieve hydraulic control so that the area of contamination does not grow larger and the contaminants are recovered effectively, and (b) achieve an even distribution of water flow through the contaminated zone(s). This latter consideration is why bioremediation is less effective in low permeability soils.

The following site hydrogeology conditions must be evaluated:

- Characteristics of soils in the unsaturated zone;
- Hydraulic interconnections and relationships between any multiple aquifer systems;
- Daily and seasonal water table fluctuation patterns; and
- Horizontal and vertical components of ground-water flow as well as the ground-water flow rate.

By understanding these conditions, recovery and injection wells can be located for maximum effectiveness. Optimal well placement is usually decided upon the results of ground-water modeling and pump tests. The necessary pumping rates are site-specific.

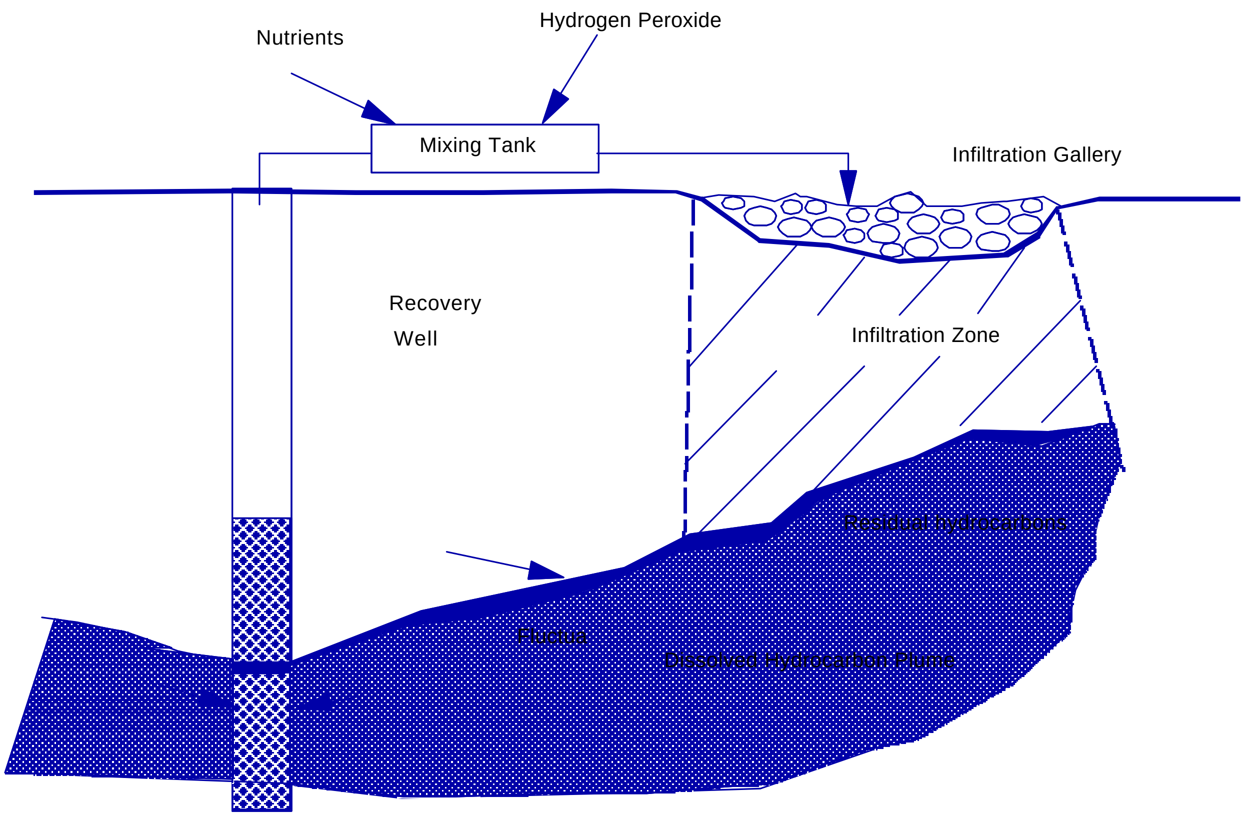
Recovery wells should be placed so that further migration of the product plume is halted and product is drawn toward the well. The injection well(s) should be screened over the entire depth of the contaminated zone. If infiltration galleries are used, they should be located over the source area or in the areas of highest petroleum product concentrations.

Additional treatment systems are usually not needed with in-situ bioremediation designs. Activated carbon treatment may become necessary, however, when target contaminant concentrations are too low to sustain biological activity, and further treatment is needed for the ground water to be discharged.

Maintenance requirements include monitoring water levels periodically (at least once per month) and conducting periodic pump tests to ensure the efficient operation of each well. Wells may need to be redeveloped if the well screens become clogged. Monitoring requirements include periodic soil and ground-water sampling and analysis.

Exhibit 3.1-20

In-Situ Bioremediation System



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The cost of bioremediation is determined by the amount of soil and/or ground water requiring treatment and the concentration and type of contaminants. Total capital costs may range from $20,000 to $200,000. When hydrogen peroxide is used as the oxygen source, capital costs for the injection system may range from $3500 to $5000 for ground-water pumping rates from 10 to 40 gallons per minute (gpm). Capital costs for air sparger system designs are about 3.5 to 4 times more costly. Annual operating and maintenance costs for hydrogen peroxide systems average between $3500 (10 gpm) to $15,000 (40 gpm), and between $5000 (10 gpm) and $10,000 (40 gpm) for air sparger systems. Well installation (PVC casing) may cost $15 to $20 per linear foot. Annual sampling and analytical costs may average about $5000.

In-situ biodegradation is an attractive remedial option for petroleum spills as it is possible to treat both contaminated soil and ground water at the same time, particularly over a large area. Often, bioremediation techniques can be used to effect treatment of contaminated soil and ground water in less time and potentially at less cost than would be possible with more traditional methods like free product recovery and ground-water extraction and treatment. Furthermore, there are usually no residuals from the treatment process that must be handled and the by-products of the biodegradation process should be non-toxic.

Bioremediation must be conducted by a qualified company with sufficient operational experience with this technique. Consult with the Central Office to locate those companies who have the requisite expertise. It is also difficult to predict its effectiveness as so much depends on getting sufficient nutrients and oxygen into the contaminated zone(s), and there are many factors influencing the success of nutrient/oxygen delivery into the subsurface environment.

Other limitations of the bioremediation technique include:

- # Potential variability in the start-up time until the microorganism population becomes acclimated to the contaminant(s);
- # Some petroleum product constituents are not amenable to biodegradation or degrade only very slowly;
- # May not be cost-effective if the contaminated area is small as the start-up costs are high; and
- # May not be applicable to all soil types.

------ BIOREMEDIATION SUMMARY ------

APPLICATION: Naturally occurring or introduced microbial populations are supplied nutrients and oxygen to

NOTES

promote their growth and activity in the subsurface. These microorganisms degrade petroleum constituents present in the soil and/or ground water.

EQUIPMENT: Soil contamination to a depth of three feet would likely utilize equipment to till the surface soil; nutrient application equipment; and water application equipment. The remediation of soil and/or ground water contamination at depth requires equipment to excavate infiltration galleries or install injection wells and recovery wells, pumps, mixing tank, as well as aboveground storage for the hydrogen peroxide (oxygen source). May be used in combination with soil venting technology.

LIMITATION: Contaminants toxic to the microbial population can inhibit or render this process ineffective. Can require an extended start up and treatment time. Low temperatures slow microorganism activity and growth.

COST: Microbial degradation can be a cost-effective alternative to soil excavation and/or other soil treatment methods. Costs can range from $66 to $123 per cubic yard.

REFERENCES: [3,5,7,9,11,15]

g. Incineration

Incineration is the high-temperature oxidation of waste materials or residuals, which, for a petroleum spill site, might include recovered free product and/or contaminated soil. Under controlled waste feed, temperature, and turbulence conditions, destruction efficiencies of up to 99.99 percent are possible.

The most commonly used incinerator designs are described below:

- # **Rotary-kiln incinerators** are designed to handle a wide variety of wastes separately and in combination, without any pretreatment, including gases, liquids, solids, and soils. It is the method of choice for thermal destruction of mixed solid and liquid wastes. However, while this technology has been used widely for handling hazardous waste, its use at UST sites has been minimal.

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- # **Multiple-hearth incinerators** are widely used for the destruction of municipal sewage sludge and coal wastes. Although these incinerators can be used for all forms of wastes, including solids, tars, sludge, soils, liquids, and gases, they are best suited for sludge. Wastes that will generate large amounts of ash when burned create material-handling problems due to the formation of slag. This may be a particular problem in burning contaminated soils.

- # **Fluidized-bed incinerators** can be used for thermal destruction of liquid, solid, and gaseous combustible wastes; however, they are commonly used for slurries and sludge such as wastes from oil refineries and pulp and paper mills. These incinerators are suitable for wastes with a high moisture or ash content.

The principal maintenance consideration with all thermal destruction technologies is replacement of the refractory brick in the primary combustion chamber. The total cost of thermal destruction varies with the type of waste and quantity.

Incineration with a portable unit can be a cost-effective alternative to excavation and disposal for large soil clean-ups. The disadvantages include costs associated with excavation, transportation, and incineration at licensed incineration facilities. Obtaining state and/or local permits for transportable incinerators may result in costly delays.

------ INCINERATION SUMMARY ------

APPLICATION: Excavation of contaminated soil for thermal destruction. Can reduce contaminant levels up to 99.99 percent of original value.

EQUIPMENT: Excavation and covered truck transport equipment. Remaining equipment needs depend upon incineration design utilized. The common types are rotary-kiln, fluidized-bed, and multiple-hearth.

LIMITATION: Requires excavation of contaminants increasing exposure risks. Must have state-wide permit approval to avoid lengthy site-by-site permitting process. Residuals must be disposed of and are unlikely to be usable as backfill. Can be very expensive.

COSTS: The cost for incineration of petroleum-contaminated soil can range up to $1500 per cubic yard.

REFERENCES: [5,15]

h. Asphalt Incorporation

Asphalt incorporation involves using petroleum-contaminated soils as a portion of the total aggregate feed in the production of hot mix asphalt. The soil-aggregate mixture is heated in a dryer and, in the process, volatile contaminants in the soil are volatilized. The remaining heavier petroleum fractions are incorporated into the asphalt product as it cools. The destruction efficiency of this method, however, has never been tested.

The soils must be free of large rocks, wood, and debris. High concentrations of the lighter petroleum contaminants in the soil are somewhat incompatible with asphalt as they are, in effect, solvents that will soften the final product, if they are not sufficiently driven off in the drying process.

Petroleum-contaminated soils are added as a portion of the total aggregate feed to the asphalt batching plant. The total input of such soils must be limited to five percent of the total aggregate feed to ensure that there is less than 10 percent of fine material. Even so, a typical asphalt plant could still handle some 7000 to 8000 tons of soil per year.

Costs incurred are for excavation and transport of the contaminated soil, and the fees charged by asphalt plant operators, which have ben in the range of $50 to $75 per ton.

The primary advantage of this method is its low cost (provided it is cost-effective to excavate the contaminated soil in the first place) and the destruction of the volatile and incorporation of the non-volatile petroleum contaminants. The disadvantages are that this technique is not widely practiced, is not universally accepted by the regulatory agencies, and has not been the subject of extensive testing to establish its effectiveness. Plants may have to be retrofitted to be able to handle and meter delivery of the soil. Plants may only accept soils contaminated with virgin fuel products, i.e., not used or waste oils. Some specifications for paving material disallow the use of asphalt containing soil as unfractured stones left in the product make it less stable. In addition, asphalt batching plants do not operate during the cold weather season.

------ ASPHALT INCORPORATION ------

APPLICATION: Excavation of contaminated soil for incorporation into hot asphalt mixes. As the contaminated soils are heated in the production process, volatile contaminants are driven off the soils. The non-volatile constituents become incorporated into the asphalt matrix as the product cools.

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EQUIPMENT:	Excavation and covered truck transport equipment plus all equipment making up a hot mix asphalt batching operation.
LIMITATION:	Requires excavation of contaminants increasing exposure risks. Input of soil must be limited to no more than five percent of the total aggregate feed. High petroleum contaminant concentrations may effect quality of asphalt product adversely. Volatile emissions from asphalt plant may be a concern.
COSTS:	Fees for acceptance of petroleum-contaminated soil range between $50 to $75 per ton.

3. Spill Cleanup Technologies for Ground Water/Free Product Recovery

The following reviews techniques and technologies used in the recovery of free floating or dissolved product in ground water.

a. Well Points

Well points are generally used in a group or series connected to a header via a riser pipe and installed downgradient of the contaminant plume. The installed well point system is designed to intercept the contaminant plume (see Exhibit 3.1-21). Well points are also used to dewater soils.

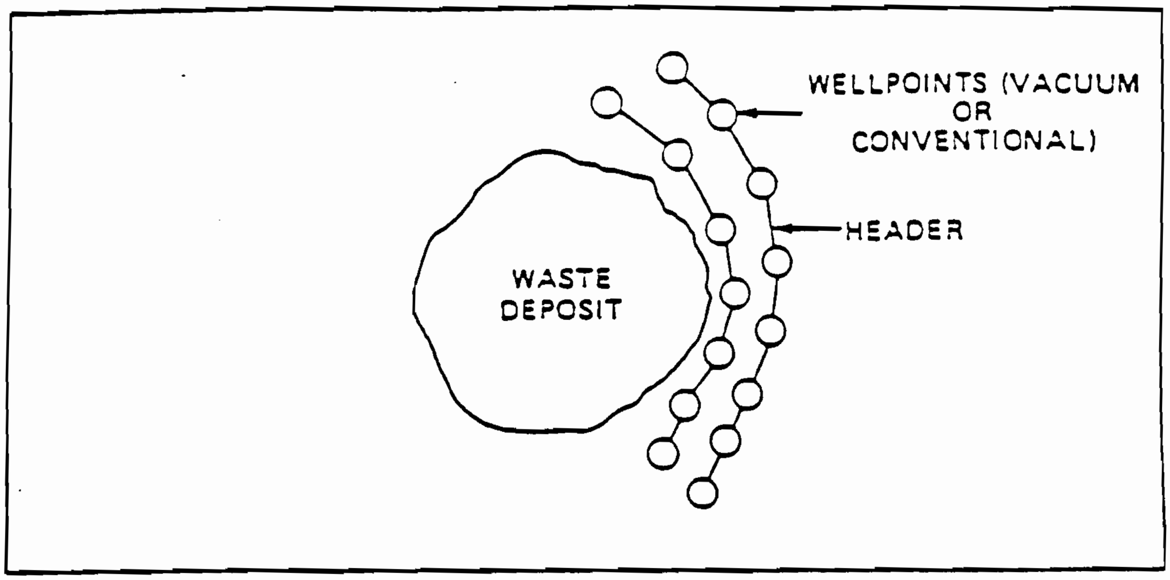
Well points are made from the same types of material as monitoring wells. Therefore, the same factors concerning monitoring well installation apply to the completion of well points (see also Exhibits 3.1-8 and 3.1-9).

Commercially available well points are typically designed with screen openings suitable for use with washed concrete sand filters. This type of filter performs well when the soil penetrated is finer than the concrete sand. If the surrounding soils are very fine and have little cohesion, they may migrate towards the wellpoint. In this instance, mortar sand filters may improve well yields and prevent clogging. For some applications, selecting the filter material and the screen opening specifically for each wellpoint application may be necessary.

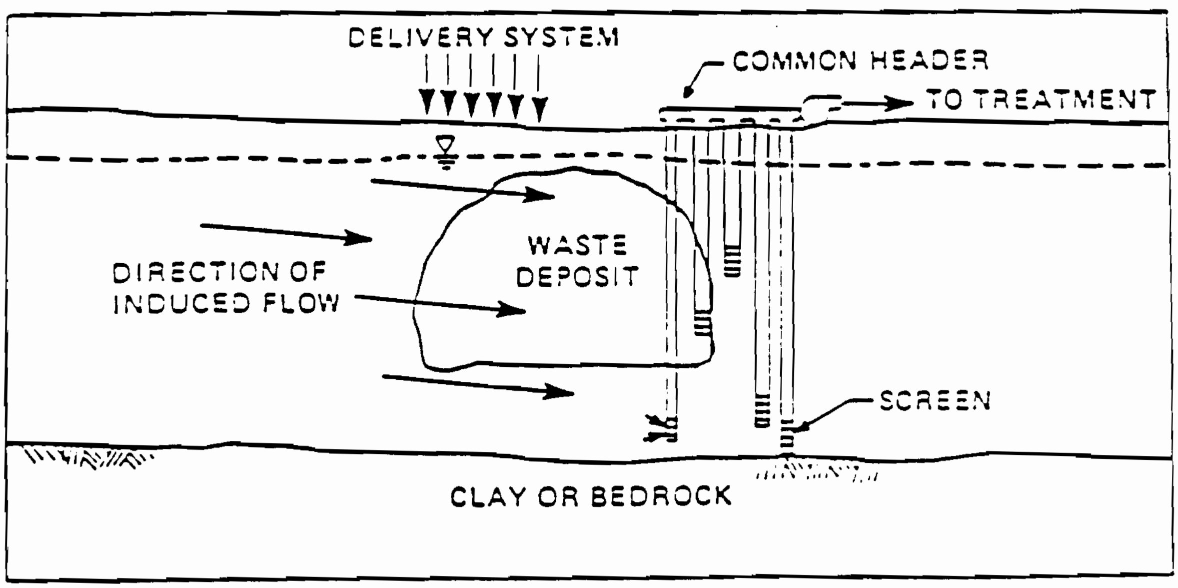
When considering the placement of a well point system, one should consider the hydrogeology of the area and the type of contaminant (i.e., floating or dissolved). In the case of floating product, well points can be set at a shallow depths. In situations where the contaminant(s) are mixed with ground water or are more dense than water (i.e., will sink into the water), the well points can be set at greater depths. In any application of well points, however, the

Exhibit 3.1-21

Well Point System for Forced Recovery



PLAN VIEW



CROSS SECTION

Source: USEPA. *Systems to Accelerate In Situ Stabilization of Waste Deposits*, September 1986.

NOTES

maximum installation depth is 22 feet below the ground surface. Make sure the screens are not set too shallow as dewatering may occur, which reduces the vacuum and the degree of drawdown possible.

The design and installation of well points differ from other types of wells in that they are usually driven, not drilled, into the ground (see Exhibit 3.1-22). Occasionally, several well points may be installed in a large, drilled, borehole with the annular space filled with filter sand. The use of filter sand in the annular space:

- Increases the effective diameter of the wellpoint;
- Decreases the entrance velocity of the water;
- Prevents clogging of the well screen with fines; and
- Provides vertical drainage from overlying layers.

The cost of a well point system is a function of well depth, pumping rates, type of installation, and the materials used. The drilling cost ranges from $950 to $1150 per day, including labor. The equipment costs range from $3 to $6 per foot for the well screens, $50 to $60 for the pumps, and $2 to $4 per linear foot for the PVC piping to construct the header. The total materials cost for a 22-foot well point is about $1200 to $1400 per well.

------ WELL POINTS SUMMARY ------

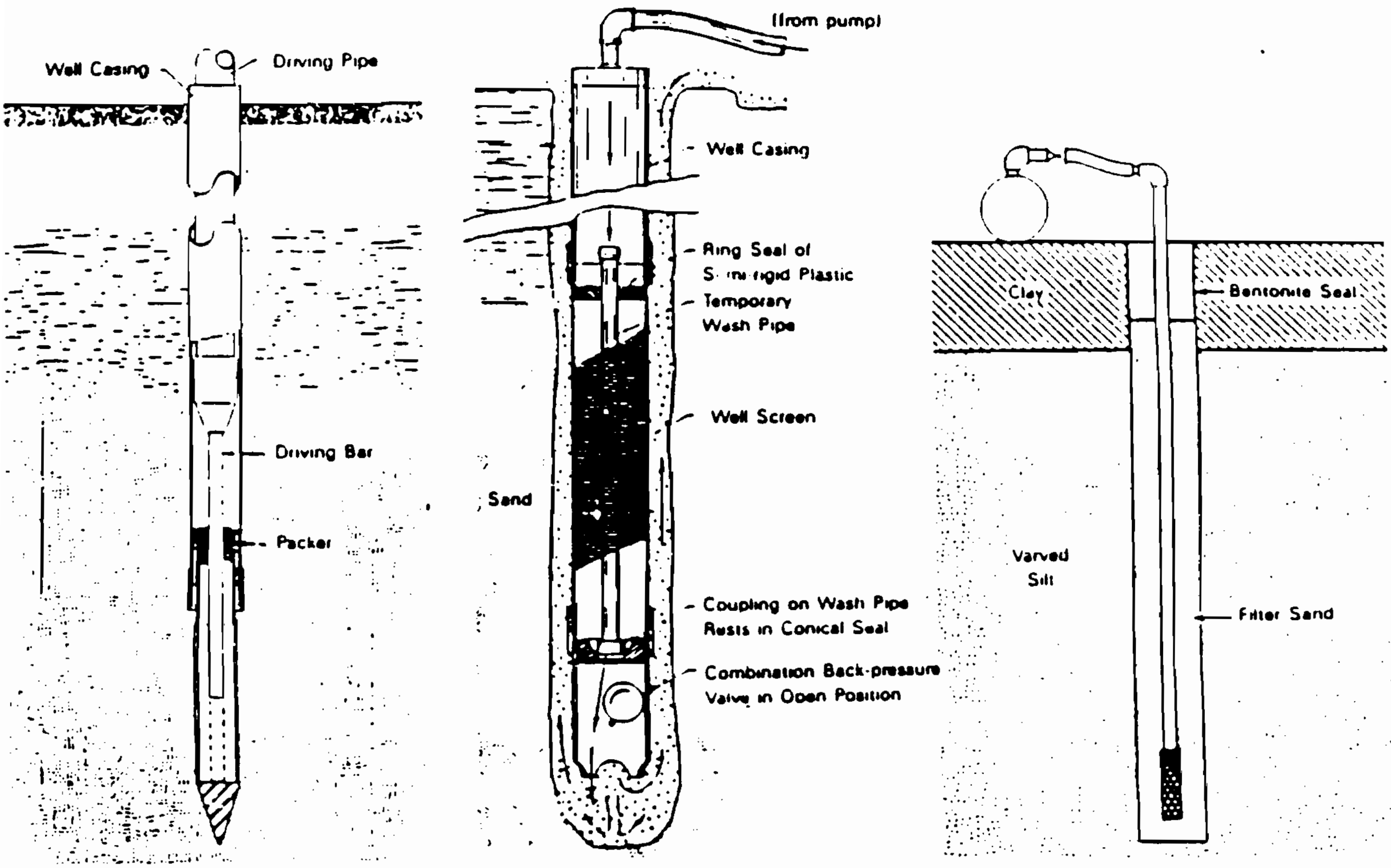
APPLICATION:	Used to lower the water table and effectively collect/control contaminant migration. Also can be used for soil venting.
EQUIPMENT:	Drive point drill rig, pumps, casing, screens, and piping.
LIMITATIONS:	Well points are most effective at depths of 22 feet or less.
COST:	Cost for the installation of well points average $1,200 to $1,400 for a two-inch diameter casing to a depth of 22 feet.
REFERENCES:	[3,6,7]

b. Ejector Wells

Ejector wells use injected pressurized water to lift ground water to the surface for treatment and/or disposal. Ejector wells can pump ground water from depths as great as 125 feet below ground surface.

Exhibit 3.1-22

Driven Well Point, Jetted Well Point, and Drilled Well Point



Source: USEPA. *Remedial Action at Waste Disposal Sites (Revised)*, 625/6-85/006.

NOTES

Ejector wells have two principle designs: single and two-pipe systems. In the single pipe system, the pressurized water flows down between the well casing and the water return pipe. This creates a pressure gradient sufficient to lift ground water to the surface.

The two-pipe system, shown in Exhibit 3.1-23, operates as follows:

- High-pressure supply water (Q_1), stored in a collection tank, moves down the supply pipe through ports in the ejector body to the tapered nozzle where the pressure head is converted to water velocity;

- Supply water exits the nozzle at less than atmospheric pressure creating a vacuum in the suction chamber;

- Ground water (Q_2) is drawn into the chamber through the foot valve because of the pressure differential;

- Supply water and ground water ($Q_1 + Q_2$) are mixed in the suction chamber;

- The mixed water enters a venturi valve where the decrease in water velocity head results in an increase in pressure head;

- The increase in pressure provides sufficient head to return the combined flow to the surface.

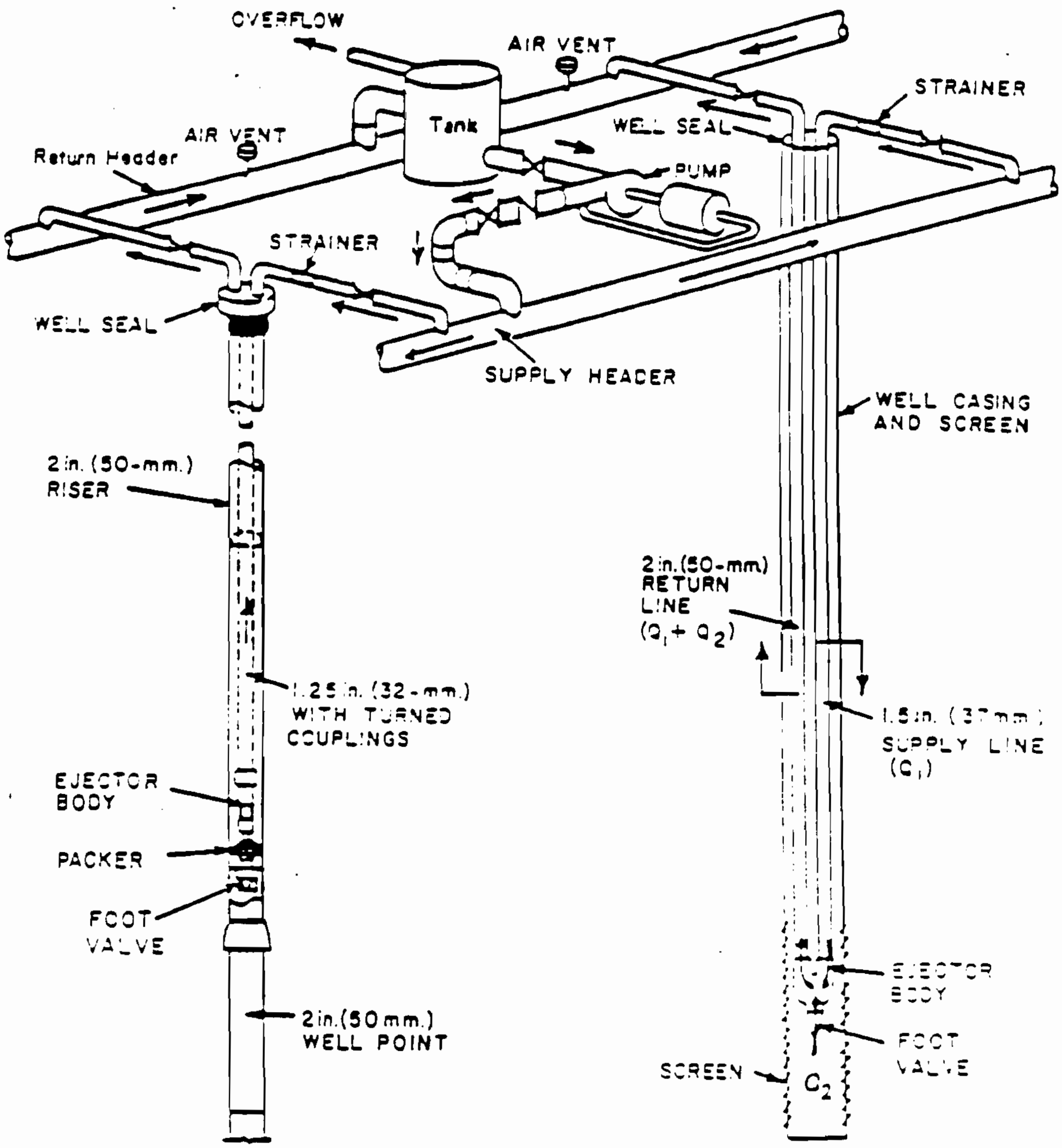
The combined water flow brought to the surface recharges the collection tank with any excess water discharged to the treatment system.

Single-pipe ejector systems ($1200 to $1400 per well) are more cost-effective than two-pipe systems as the former provide for high ground water yields using smaller diameter well casings and less piping. The cost of an ejector well system is based on the: method of installation; cost of the well materials (i.e., screens, riser, pumps, and pipes); and local electricity and labor rates.

Ejector systems are best used as a means to pump ground water to achieve hydraulic control and prevent further migration of a contaminant plume. Alternatively, these systems may be used to divert clean ground water from flowing into a contaminated area. These systems are not well suited, however, for depth-specific ground-water sampling or for product recovery. Ejector wells are also not particularly efficient systems operating at less than 15 percent efficiency.

Exhibit 3.1-23

Components of One-Pipe and Two-Pipe Ejector Wells



Typical Single-Pipe Ejector Installed in a 2-in. (50-mm) Wellpoint

Typical Two-Pipe Ejector Installed in a 6-in. (150-mm) Well

Source: USEPA. *Remedial Action at Waste Disposal Sites (Revised)*, 625/6-85/006.)

------ EJECTOR WELLS SUMMARY ------

APPLICATION: Ground-water extraction from depths up to 125 feet.

EQUIPMENT: One or two pipe well system, pumps, well screens, casing, and risers.

LIMITATION: Operates at a maximum 15 percent efficiency.

COST: Ranges from $1400 to $1600 per well, including drilling and well construction.

c. Ground-water Pumping

Ground-water pumping techniques involve the active manipulation and management of ground water in order to contain or remove a contaminant plume, or to adjust ground-water levels in order to prevent the formation of a contaminant plume. The control of the ground-water flow is then combined with treatment systems (i.e., air stripping, carbon treatment) to remove contaminants from the ground water.

Ground-water pumping lowers the water table in the vicinity of each well. As the pumping rate increases, the hydraulic gradient increases and ground water flows towards the well. The lowered water table is called a cone of depression and by overlapping these zones of influence, it is possible to affect ground-water flow direction. The change in ground-water flow direction may allow for capture of contaminants to prevent any further migration downgradient, or the flow of clean ground water through a contaminated area is minimized.

The design of any given ground-water pumping system is a function of a variety of subsurface geology factors, the planned treatment system, and desired cost efficiency. In general, the pumping wells are located so that their zones of influence overlap each other and cover the entire area to be controlled. The pumping rates must be set to achieve sufficient hydraulic control and yet not overpump the system. Monitoring wells are used to check the zone of influence of each well as evidenced in changes in the water levels while the pumps are operating.

The cost of a ground-water pumping system depends on the number and type of wells installed, the pumping rate, and the type of treatment system installed and operated. Installation costs for a variety of pumping wells are provided above in the sections on monitoring wells, well points, and ejector wells. Operation and maintenance costs are a function of the type of pumps, the pumping rate, electricity costs, the type of treatment system, and costs for handling any treatment residuals.

NOTES

Ground-water pumping can effectively contain and remove contaminants from ground water and prevent the spread of contaminants towards sensitive receptors (e.g., water supply wells) downgradient. Use of such a system can effect a reduction in contaminant levels at a rate faster than might be seen if the aquifer were left to cleanse itself naturally. The disadvantages are that a ground-water pumping system may be very expensive to operate and may have to be operated for several years before clean-up levels are reached. Treatment of the removed ground water is necessary as is the handling of all treatment residuals. In some areas, the handling of treatment residuals (e.g., air stripper effluent) may be problematic (e.g., there are no sewers or streams to receive the treated effluent).

------ GROUND-WATER PUMPING SUMMARY ------

APPLICATION:	Ground-water pumping is practiced to control, divert, or remove contaminants in ground water.
EQUIPMENT:	Well point, ejector well systems, and pumping wells can all be used in a ground-water pumping system.
LIMITATIONS:	Long-term projects can be very costly. Requires handling of liquid effluent. Ground water may require treatment before it can be discharged.
COST:	Cost is a function of the type of pumping system installed and the treatment system needed. Installation costs range from $1200 to $1650 per well. Operation and maintenance costs are very site-specific, but probably average around 5 to 10 percent of the total capital cost.
REFERENCES:	[6]

d. Ground-water Reinjection

There are three basic applications of reinjection wells. They can be used to inject clean water into an aquifer and raise the water table to create a barrier in the path of a migrating contaminant plume. Reinjection wells may be used as part of an in-situ soils washing system or in-situ bioremediation system. Ground-water reinjection systems are also used to dispose of treated ground water from a treatment system, particularly in settings where there are no sewers or streams to receive the treatment system discharge. See Section 1-6.7 for a discussion of problems in the handling of effluent from ground-water treatment systems.

NOTES

The design of a reinjection well (see Exhibit 3.1-24) is similar to an extraction well with a few variations. Pumps, casings, and filter packs are selected and installed as discussed for monitoring wells and other pumping wells. However, the installation of a reinjection well requires the following:

- A downspout to prevent air entrapment from cascading water when the well is operated at a low pumping level;
- An air vent to release trapped air when the pumps start up;
- A longer well screen (some two to three times longer) than used in a pumping well to provide more area for water to be injected into the aquifer formation; and
- A concrete or grout seal to prevent ground water from flowing along the casing to the surface when the well is pressurized.

As with pumping wells, reinjection systems also must be developed properly. A reinjection well, however, will typically require more frequent redevelopment to maintain an efficient operation. The operation of an injection systems does not work to keep the well developed as the operation of a pumping well does. Pump maintenance requirements for reinjection and pumping wells are similar.

The installation cost for a reinjection well is about the same as incurred for a large diameter monitoring well. Equipment costs are slightly higher given the longer well screens and higher capacity pumps.

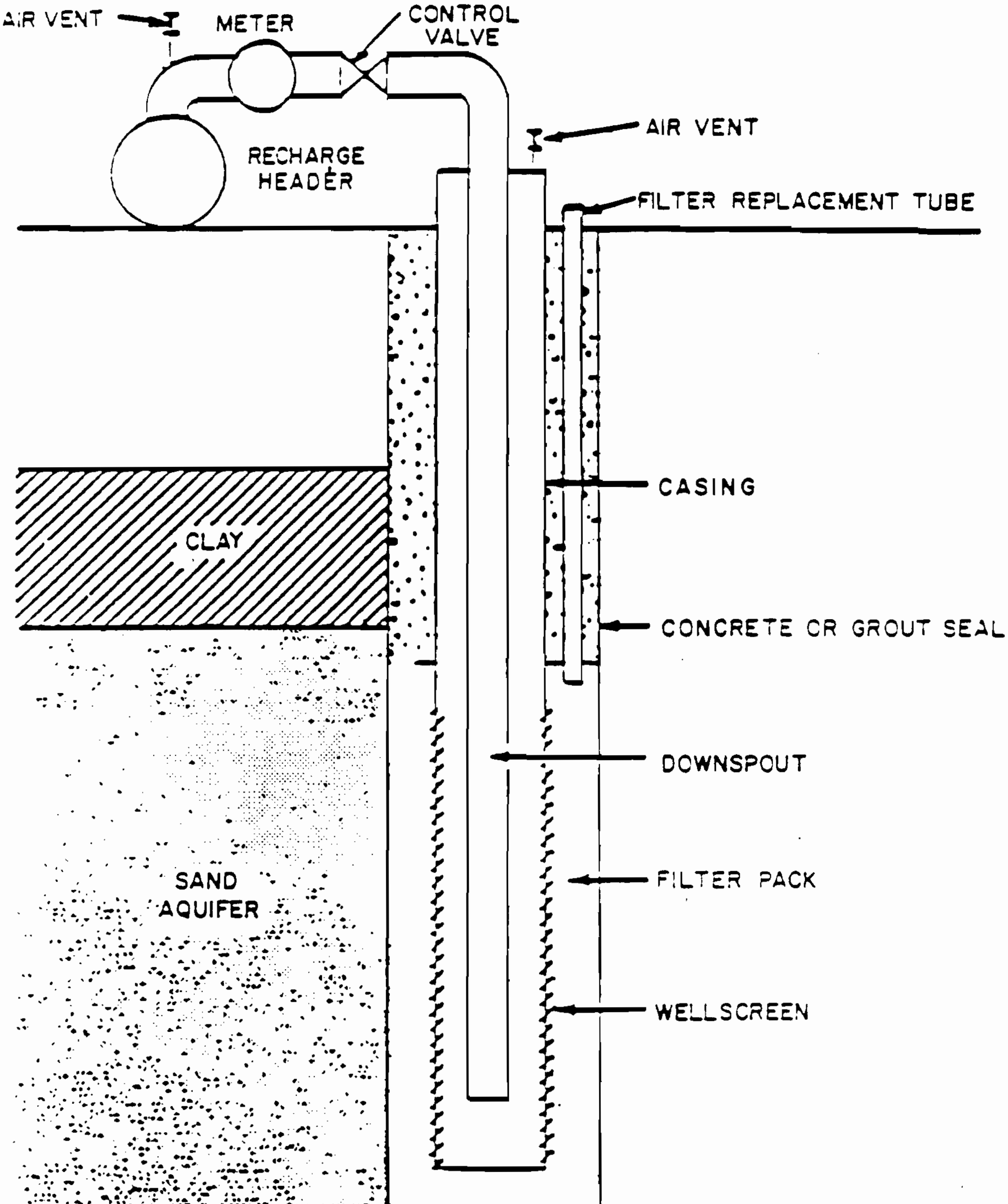
Reinjection wells, in some locales, may be the only option for disposal of large quantities of treated effluent. They are also needed in some geologic settings to improve delivery of soil washing solutions and nutrient-hydrogen peroxide solutions into the subsurface. Reinjection wells can only be used, however, in those geologic settings where soil permeabilities are high enough to accept the high flow rates. The injection of any material into the subsurface frequently also requires a special permit, as it does in New York State.

------ GROUND-WATER REINJECTION SUMMARY ------

APPLICATION: Pumping and reinjection wells are used in combination to achieve hydraulic control for contaminant plume management. May be used to flush contaminants in the subsurface down to be captured by recovery wells. Reinjection wells are also used to dispose of treated effluent from the operation of a treatment system.

Exhibit 3.1-24

Basic Injection Well



Source: USEPA. *Leachate Plume Management.* Office of Research and Development, 540/2-85/004, November 1985.

NOTES

EQUIPMENT: Typical well components plus air vents and header recharge piping.

LIMITATIONS: May require special permits. Not feasible in all geologic settings, especially where soil permeabilities are low. Poor design may result in splitting the contaminant plume.

COST: Installation cost is consistent with the installation of other types of wells ($1200 to $1400 per well). Operation and maintenance costs may be higher than pumping wells.

REFERENCES: [4,6]

e. French Drains/Interceptor Trenches

Interceptor trenches are excavated down and a few feet into the water table for the purpose of intercepting free product and contaminated ground water. Their use is limited, therefore, to settings where ground water is located near ground surface and within the reach of traditional excavating equipment (15 feet). These trenches should be located in and across the path of the migrating plume.

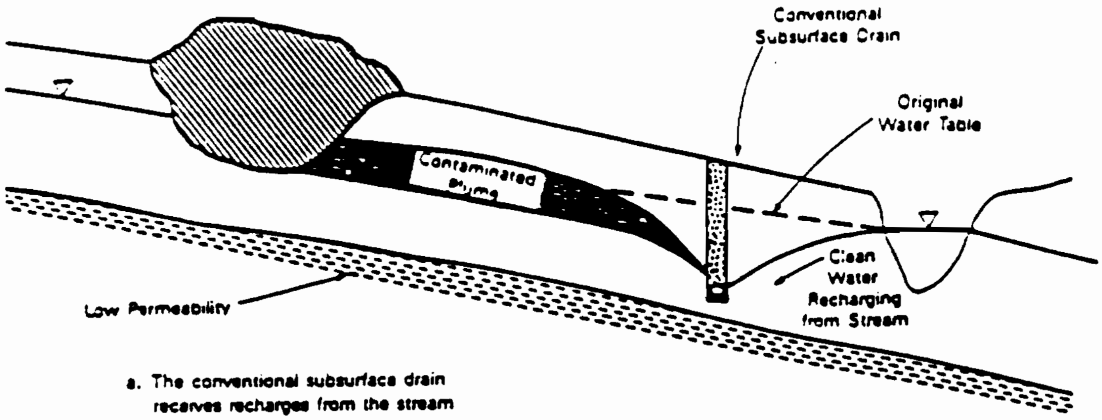
Interceptor trenches are effective in both high- and low-permeability earth materials, and may be more effective in the latter settings than wells as more area can be intersected with a trench. An interceptor trench functions essentially as a long line of closely spaced pumping wells. Interceptor trenches are particularly suited for capture and recovery of floating product when ground water is very near ground surface.

Interceptor drains are installed downgradient of the contaminant plume and perpendicular to the ground-water flow direction (see Exhibit 3.1-25). There must be a careful consideration of the geologic setting in which the trench will be installed. For example, in stratified soils that differ greatly in their hydraulic conductivities, the bottom of the trench should be a layer of impermeable soil (i.e., clay). If the trench was cut through this impermeable soil layer, there is a danger that a significant percentage of the ground water would move laterally and bridge over the drain and continue downgradient. Similarly, if soil layers or pockets of highly permeable soil underlie the trench bottom, the ground water may flow beneath and pass the interceptor trench. For more on trench design and installation, see Attachment 3.1-1.

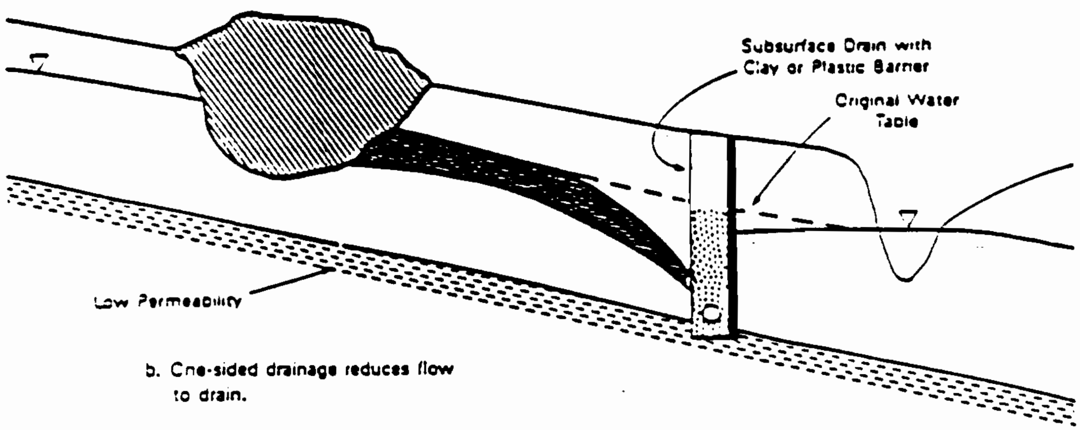
Trench excavation can be accomplished through the use of trenching machines and/or backhoes. Wall stabilization using wood or steel is generally required to prevent cave-ins during installation.

Exhibit 3.1-25

Subsurface Drain for Reducing Flow from Uncontaminated Sources



a. The conventional subsurface drain receives recharges from the stream as well as the leachate plume, resulting in larger collection and treatment.



b. One-sided drainage reduces flow to drain.

Source: USEPA. *Remedial Action at Waste Disposal Sites (Revised).* 625/6-85/006.

NOTES

If piping is incorporated into the design of an interceptor trench, the design must ensure that water arriving at the drainline can be conveyed without a buildup of pressure. The drainage gradient chosen should be great enough to result in a flow velocity that prevents siltation, but will not cause turbulence.

Filters and envelopes are installed in trenches along areas where soils have a high percentage of fine material. The primary function of a filter is to prevent soil particles from entering and clogging the drain. The filters are made of fine meshed fabric or other geotextiles. The function of an envelope is to improve ground-water flow and reduce the flow velocity into the drains by providing a material that is more permeable than the surrounding soil. Envelopes may also be used to provide suitable bedding for a drain and to stabilize the soil material on which the drain is being placed.

The pumping system is designed to remove the contaminated ground water that collects by gravity flow into the drainage sump. Pumps may also be used to drawdown the water table and accentuate the gradient of flow into the trench.

Installation costs depend primarily on the depth of excavation, stability of soils, extent of rock fragmentation required, and ground-water flow rates. The principal material costs include pipes, gravel, manholes, pumps, and other accessories for the drainage sump.

The installation costs for a interceptor trench can be much higher than for installation of a pumping system, especially if rock must be excavated and the depth of the trench requires shoring. The operation and maintenance costs, however, are generally less than incurred with a pumping system provided the trench is properly designed and maintained. Lower operation and maintenance costs become significant when plume containment and product removal operation is expected to be required for a long period of time.

Exhibit 3.1-26 summarizes the costs associated with the installation of interceptor trenches.

For shallow contamination problems, trench systems can be a more cost-effective option than pumping, particularly in earth materials with low or variable hydraulic conductivity. A trench system will intercept more of the preferential flow paths that might not be intersected unless a large number of very closely spaced wells were installed. The installation of an interceptor trench also affords an opportunity to examine subsurface soil types over a wide area. Interceptor trenches may be preferred when ground water removal is required over a period of several years due to the lower (compared to a pumping system) operation and maintenance costs.

The use of an interceptor trench system is limited to depths reachable with excavation equipment, i.e., no more than 15 feet usually. Interceptor trenches, therefore, are not suited to the capture and removal of ground-water contamination at depth. Although it is technically feasible to excavate a trench to almost any

Exhibit 3.1-26

1988 Unit Costs for Trench Excavation and Associated Activities

Item	Assumptions	Unit Cost	Source
Trench Excavation			
Trencher, ladder type	gas, 5 ft deep, 8-in wide	\$522/day	(1)
	diesel, 8 ft deep, 16-in wide	\$700/day	(1)
Backhoe, hydraulic	4 ft wide trench, damp sandy		
	1 yd^3 capacity, 12 ft deep: 90 LF/day (LF=linear ft)	\$2.36/yd^3	(2)
	1.25 yd^3 capacity, 14 ft deep: 90 LF/day	\$2.27/yd^3	(2)
	2.5 yd^3 capacity: 18 ft deep: 115 LF/day	\$1.82/yd^3	(2)
Dragline	1.5 yd^3 capacity, 65 yd^3/hr	\$5.20/yd^3	(1)
	1.75 yd^3 capacity, 35 yd^3/hr	\$3.23/yd^3	(1)
Clamshell	0.5 yd^3 capacity, 20 yd^3/hr	\$3.47/yd^3	(1)
	1.0 yd^3 capacity, 35 yd^3/hr	\$3.23/yd^3	(1)
Rock Fragmentation			
Jackhammer	---	\$42/hr	(2)
Track-mounted air drill	---	\$80/hr	(2)
Well Stabilization			
Sheet Piling	includes pull and salvage:		
	15 ft excavation, 22 lb/ft^2	\$7.70/ft^2	(1)
	25 ft excavation, 38 lb/ft^2	\$9.00/ft^2	(1)
	40 ft excavation, 38 lb/ft^2	\$8.30/ft^2	(1)
Wooden shoring	includes wales, graces, and spacers; pull and savage:		
	14 ft excavation	\$6.25/ft^2	(1)
	20 ft excavation	\$7.27/ft^2	(1)

Exhibit 3.1-26

1988 Unit Costs for Trench Excavation and Associated Activities (continued)

Item	Assumptions	Unit Cost	Source
H-piles H-piles with 3-in wood sheeting horizontal between piles;	includes removal of wales and braces:		
	15 to 22 feet	$20 to 23/ft^3$	(1)
	23 to 35 feet	$22 to 26/ft^3$	(1)
	36 to 45 feet	$26 to 29/ft^3$	(1)
	53 to 57 feet	$31 to 33/ft^3$	(3)
Dewatering			
Sump Hole	includes excavation and gravel:		
	with 12-in corrugated pipe	$21.19/ft^3$	(1)
	with 15-in corrugated pipe	$27/ft^3$	(1)
	with 18-in corrugated pipe	$30/ft^3$	(1)
	with 24-in corrugated pipe	$41/ft^3$	(1)
Opening pumping	Pumping 8 hrs. attended		
	8 hrs: includes 20 ft of suction hose and 100 ft of discharge hose:		
	2-in diaphragm pump	$380/day	(1)
	4-in diaphragm pump	$420/day	(1)
	3-in centrifugal pump	$383/day	(1)
	6-in centrifugal pump	$463/day	(1)
Submersible centrifugal sump pump	Bronze, without installation:		
	1/4 hp, 22 gpm, 10 ft head	$215 each	(1)
	1/2 hp, 68 gpm, 10 ft head	$350 each	(1)
	1/2 hp, 94 gpm, 10 ft head	$463 each	(1)
	Cast iron, without installation:		
	1/4 hp, 23 gpm, 10 ft head	$100 each	(1)
	1/3 hp, 35 gpm, 10 ft head	$112 each	(1)
	1/2 hp, 68 gpm, 10 ft head	$237 each	(1)
Diaphragm pump	Cast iron starter and level control, without installation:		
	2-in discharge:		
	10 gpm, 20 ft head	$328 each	(1)
	60 gpm, 20 ft head	$430 each	(1)
	120 gpm, 20 ft head	$807 each	(1)
	160 gpm, 20 ft head	$1,264 each	(1)
Wallpoint dewatering		---	---
Groundwater cutoffs See Sheet Piling, above	---	---	

Exhibit 3.1-26

1988 Unit Costs for Trench Excavation and Associated Activities (continued)

Item	Assumptions	Unit Cost	Source
Grade Control			
Automatic laser control		\$150/day	(1)
Backfill			
Dozer backfill, no compaction	Up to 300 ft haul, 900 yd^3	\$1.80/yd^3	(1)
Dozer backfill, air tamped	Up to 300 ft haul, 235 yd^3	\$5.86/yd^3	(1)
Compacted backfill, vibrating roller	6 to 12 inch lifts, 700 yd^3	\$1.65/yd^3	(1)
Compacted backfill, sheepsfoot roller	6 to 12 inch lifts, 650 yd^3 \$	1.79/yd^3	(1)

* Prices reflect March 1988 price index

depth, the costs of shoring, dewatering, and hard rock excavation tend to be prohibitive at depths greater than 30 feet. However, in stable, low-permeability soils where little or no rock excavation is required, interceptor trenches may be cost-effective up to depths of 100 feet.

------ DRAINS/INTERCEPTOR TRENCH SUMMARY ------

APPLICATION:	Used to intercept, contain, and remove contaminated ground water. May also be used as part of a passive vapor control system.
EQUIPMENT:	Interceptor trenches are installed with traditional excavation equipment (e.g., backhoes) and backfilled with a permeable material. May require shoring for side wall stabilization. Recovery wells or sump pumps may be incorporated as part of the design. Designs may also incorporate a impermeable synthetic membrane on the downgradient wall to block flow of contaminants beyond the trench.
LIMITATION:	Are depth-limited as a function of capabilities of excavation equipment. Construction cost are very high for trenches constructed in rock formations.
COST:	Costs vary with geologic material, construction materials, depth, and trench size.
REFERENCES:	[1,4,6]

f. Carbon Adsorption

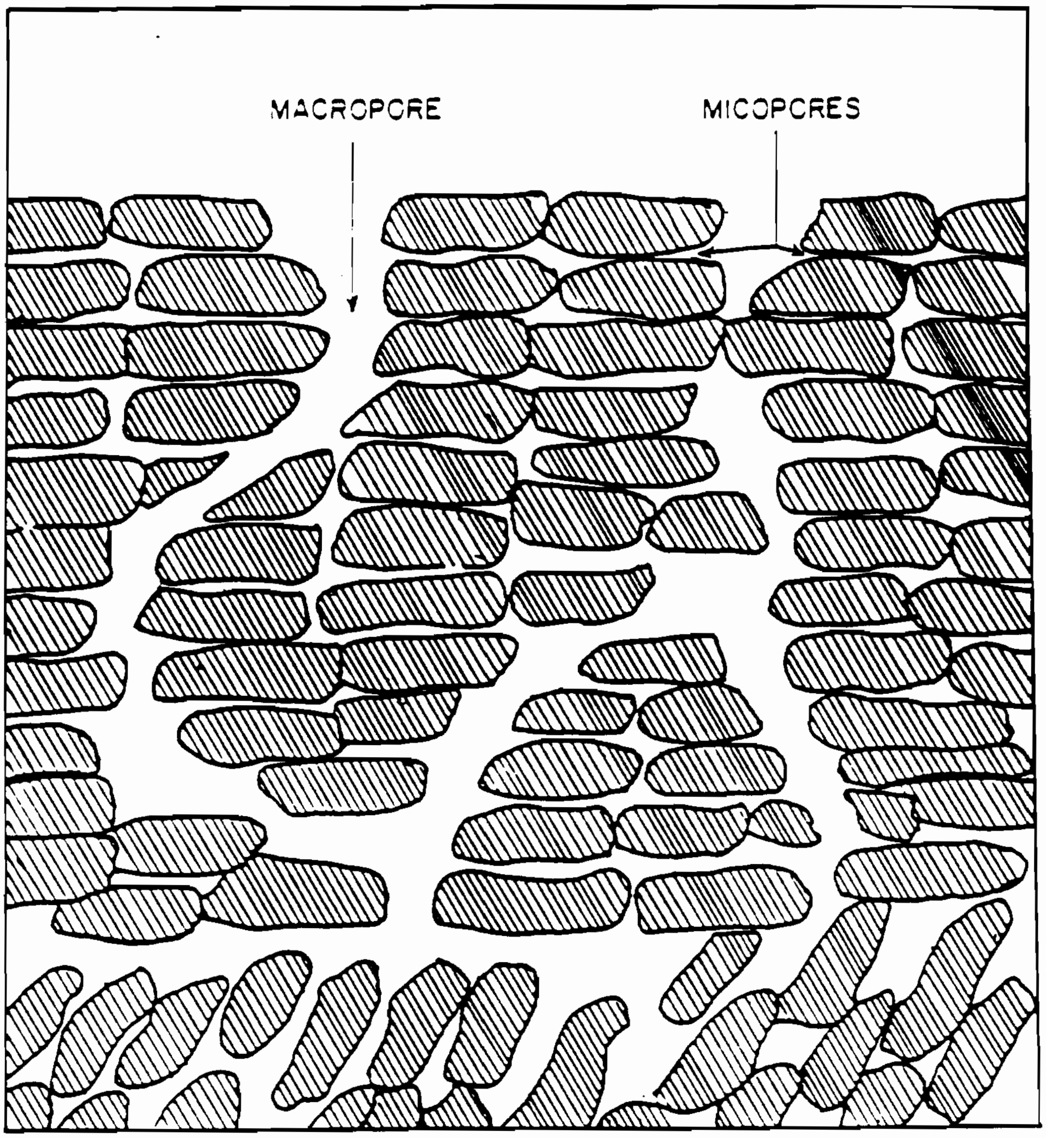
The process of adsorption onto activated carbon involves sending a waste stream (vapor or aqueous) through a series of packed bed carbon reactors. Organics in the waste stream are adsorbed onto the internal surfaces of the carbon granules; a surface attraction process (see Exhibit 3.1-27). Activated carbon is used as an absorbent because of its large internal surface area. The typical range for surface areas of commercially available activated carbon is 1,000 to 1,400 square meters per gram.

Activated carbon is a general term that refers to a group of substances with strong adsorption properties. Activated carbon can be made from several different sources, including bituminous coal (most common), coconut shells, lignite, wood, tire scrap, and pulp residues. Granular activated carbon is produced in three steps:

- **#** Dehydration step. Removes water through heating the material to 170^{o}C.

Exhibit 3.1-27

Diagram of Granular Activated Carbon Internal Pore Structure



Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.)

NOTES

Carbonization. Increasing the temperature further drives off other vapors (e.g., CO_2, CO, and CH_3COOH decomposition takes place).

Activation. Occurs by enlarging the existing pores via the introduction of superheated steam into the system, and the ashes produced during the carbonization step are removed.

Most effective on low-solubility organics, but is capable of treating a wide range of organics in varying concentrations. A large number of case studies have demonstrated the ability of activated carbon technology to remove a variety of petroleum constituents to non-detectable levels (i.e., an overall removal efficiency of 99.9 percent). The greatest concentration of solute in a waste stream treated on a continuous flow basis is 10,000 ppm total organic carbon (TOC). A one percent TOC concentration is currently considered to be the upper limit.

Carbon adsorption is not extremely susceptible to fluctuations in the contaminant concentrations or in the influent flow rate. Carbon adsorption is sensitive to suspended solids and oil-and-grease concentrations in the influent stream. High suspended solids concentrations and oil and grease levels above 10 ppm require pretreatment. Carbon beds can also be poisoned by high heavy metals concentrations and can be adversely affected by the presence of MTBE, a gasoline additive.

In ground waters containing significant levels (above 5 milligrams per liter) of iron and manganese, pretreatment is recommended to remove these compounds prior to treatment in the carbon beds. If the iron and manganese are not removed, they will precipitate out of solution to clog the carbon pores and cause a rapid head loss.

The factors to consider in judging the applicability of carbon adsorption treatment for any given waste stream are:

Increasing carbon chain length;

Increasing aromaticity;

Decreasing polarity;

Decreasing branching;

Decreasing solubility;

Decreasing degree of dissociation; and

Increased temperatures can decrease the rate of adsorption.

NOTES

Exhibit 3.1-28 summarizes the treatability of several petroleum product contaminants. Additional technical information on carbon adsorption technology can be found in Attachment 3.1-2.

Most ground-water treatment applications of carbon adsorption technology utilize carbon beds arranged in series and through which water flows from the top to the bottom of each unit (downflow mode). This is the configuration shown in Exhibit 3.1-29. These are typically portable, skid-mounted, units that can be deployed rapidly, which makes them especially attractive for use in spill cleanups.

In general, the downflow, fixed-bed, series mode has proved to be the most cost-effective arrangement, relative to other unit configurations (e.g., downflow in parallel, moving beds, upflow-expanded beds, etc.), and capable of producing the lowest effluent concentrations. Connecting the units in series increases the service life between regeneration of the lead bed. The piping arrangement should allow for one or more beds to be regenerated while the other columns remain in service. These units may also be connected in parallel to increase contact time as well as the overall hydraulic capacity.

To design a carbon adsorption system properly for each application requires conducting field tests and pilot plant studies. Through these tests, it is possible to accurately predict system performance, longevity, and the operating economics.

In designing a carbon adsorption system, it is first necessary to decide upon the empty bed contact time (EBCT). The EBCT is defined as the volume of carbon divided by the flow rate, and relates directly to the size of the unit needed (i.e., a larger EBCT requires more carbon). The EBCT is inversely related to rate of carbon use, that is, the higher the EBCT, the lower the rate of carbon use in the bed.

The cost-effectiveness of this technology is enhanced by a lower carbon usage rate and a smaller unit size. A typically used minimum EBCT value for gasoline spills is 15 minutes. For a standard 20,000-pound supply of carbon in a 10-foot diameter column, this EBCT results in a liquid loading rate of 2 gallons per minute per square foot. Experience has shown that this configuration results in a good removal rate and high operational flexibility should influent characteristics change.

The type of carbon utilized (virgin carbon or regenerated carbon) must be considered in the design criteria. Virgin carbon is normally used in cases where the effluent is to be used for drinking purposes. Regenerated carbon, which costs significantly less than virgin carbon, is normally acceptable for applications where the effluent is to be discharged to surface or ground water.

The temperature of the influent stream will affect the adsorption process. Adsorptive capacity decreases as the temperature increases. The effect of temperature in applications for treating ground water,

Exhibit 3.1-28

Carbon Influent and Effluent

Organic Compounds in Groundwater	**Influent* Concentration Range**	**Carbon Effluent Concentration Achieved**
Diisopropyl ether	20-34 ug/l	<1 ug/l
Tertiary methyl-butylether	33 ug/l	<5.0 ug/l
Benzene	0.4-11 mg/l	<1 ug/l
Toluene	5-7 mg/l	<10 ug/l
Xylene	0.2-10 mg/l	<101 ug/l

*Analyses conducted by Calgon Carbon Corporation conformed to published U.S. EPA protocol methods. Tests in the field were conducted using available analytical methods.

Exhibit 3.1-29

Two-Vessel Carbon Adsorption System

FEED WATER

REGENERATED/MAKEUP
ACTIVATED CARBON

REGENERATED/MAKEUP
ACTIVATE CARBON

BACKWASH
EFFLUENT

BACKWASH
EFFLUENT

ADSORBER 1

ABSORBER 2

Backwash Feed

BACKWASH FEED

Valve Closed
Valve Open

TREATED EFFLUENT

SPENT CARBON

Source: USEPA. *Remedial Action at Waste Disposal Sites (Revised)*, 625/6-85/006.

however, is minimal as ground-water temperature is generally constant throughout the year.

The thermal destruction properties of the contaminants to be removed should be determined prior to selecting activated carbon adsorption as a treatment method. This will determine the efficacy of removing and destroying these contaminants later in a carbon regeneration furnace.

There are three distinct operating zones in an activated carbon adsorption unit (see Exhibit 3.1-30). The equilibrium zone, located at the influent end of the tank, is the area where the carbon has become saturated with the contaminants. The area where the carbon retains its complete adsorptive capacity is at the downstream end of the carbon tank. The mass transfer zone (MTZ) is the area between these two zones, and is where most of the adsorption is taking place.

As the total volume of water treated increases, the MTZ moves downward through the column. The leading edge of the MTZ, at some point in the service life of the bed, reaches the end of the column (see Exhibit 3.1-31). This will be detected through an
increase in the residual concentrations of the target contaminants in the effluent exiting the unit. When the contaminant concentration in the effluent reaches a given concentration (usually based on effluent standards), "breakthrough" is said to have occurred and the carbon should be replaced. Because each compound has a unique adsorptive capacity and because influent concentrations vary, different compounds will break through at different rates.

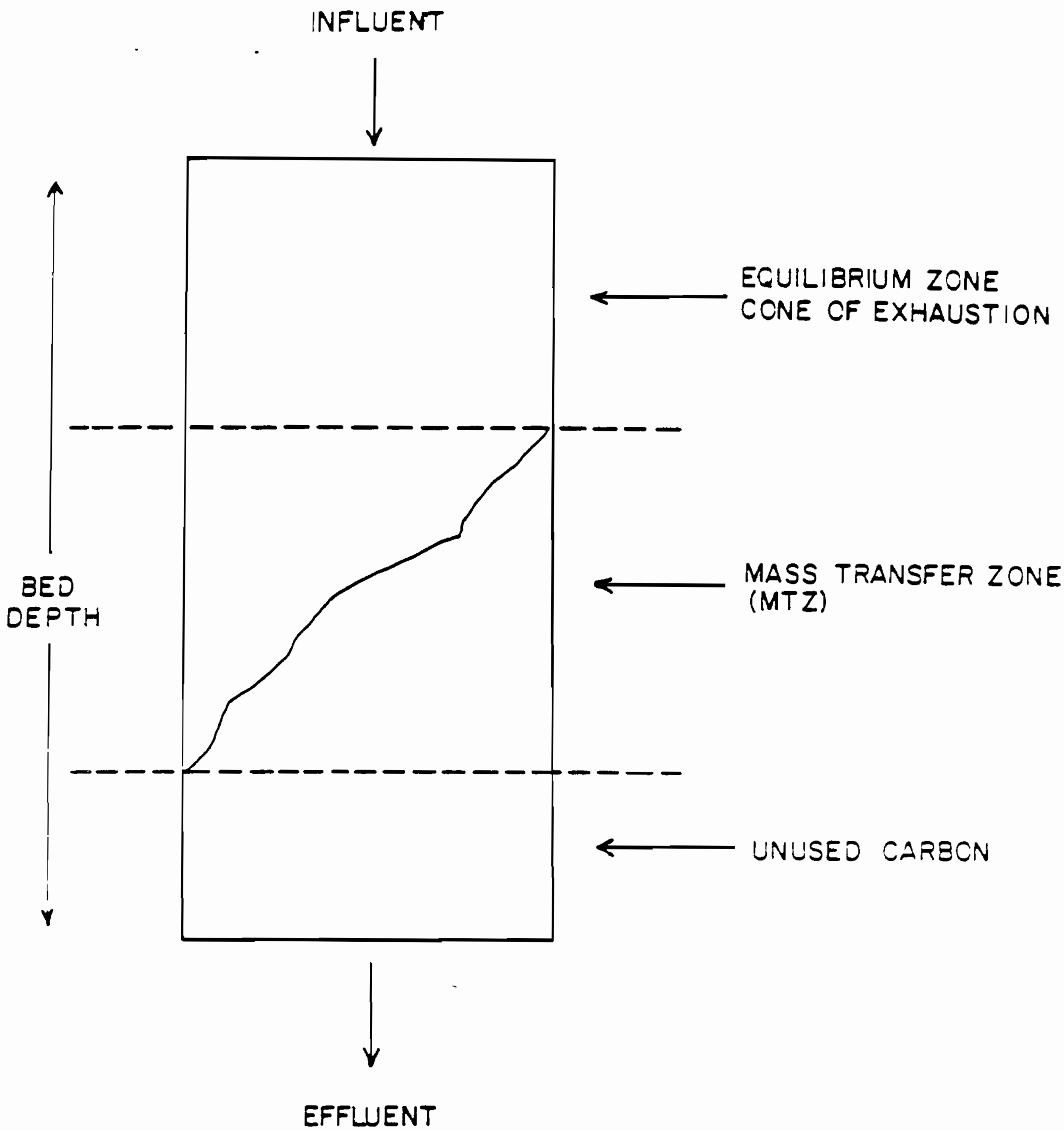
The breakthrough characteristics are an important parameter in deciding whether carbon adsorption is cost-effective for a particular application. If breakthrough occurs rapidly, then the costs for carbon replacement and/or regeneration will be high.

Other operation and maintenance requirements for the activated carbon technology are minimal, if appropriate automatic controls have been installed. Proper operation includes monitoring for desorption or displacement. Desorption is the reverse of adsorption and may occur with a sudden decrease in the influent concentration. Previously adsorbed contaminants desorb to maintain an equilibrium in the solution and the effluent concentration may, for a while, be greater than the influent concentration. The phenomenon of displacement may also occur if more strongly adsorbable contaminants appear in the influent and displace the previously adsorbed compounds. This may be a particular problem in treating ground water contaminated with a multi-constituent contaminant like gasoline.

Carbon adsorption beds are excellent media to support biological growth. While bacterial growth may clog the carbon bed pores, some biodegradation also takes place improving removal efficiencies.

Exhibit 3.1-30

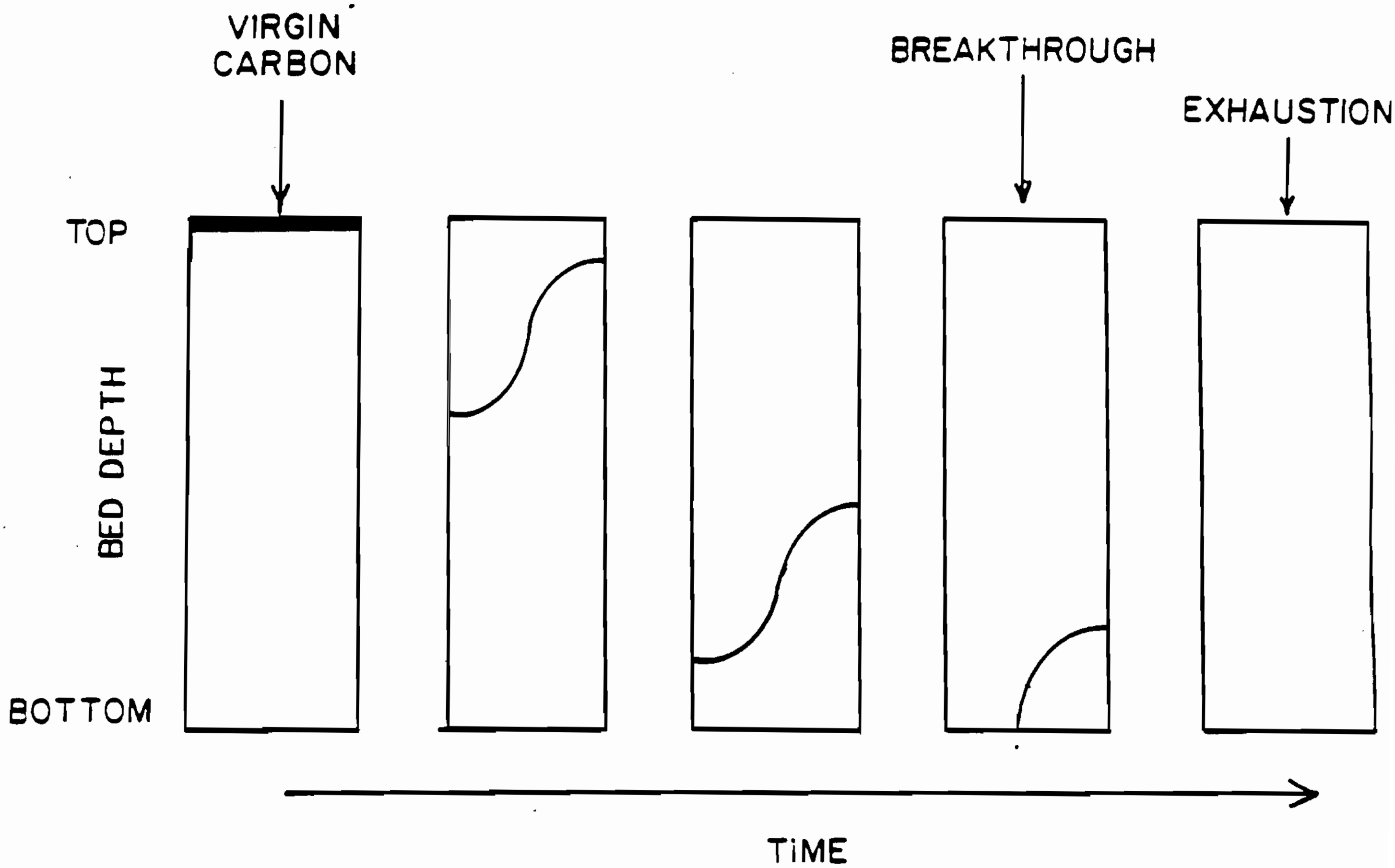
Idealized Diagram of Zones within Carbon Adsorption Unit



Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.)

Exhibit 3.1-31

Breakthrough and Exhaustion in an Operating Carbon Adsorption Unit



Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.)

NOTES

The cost of carbon adsorption units is a function of the size of the contact unit, which, in turn, is influenced by the concentrations of the target and non-target organic compounds in the influent stream and the desired level of target compounds in the effluent stream. The housing, concrete foundation, and all the necessary pipes, valves, and nozzles for the operating unit plus the initial change of carbon are typically included in the construction costs. The operation and maintenance (O&M) costs include the electricity and carbon replacement as needed. We have assumed a replacement frequency of once per year in Exhibit 3.1-32. Not included in this summary are costs for unloading spent carbon from and loading fresh carbon into the contact unit.

Several manufacturers market transportable, activated carbon adsorption systems. A trailer-mounted carbon adsorption treatment unit can be shipped to a treatment site within 24 to 48 hours. Systems can be configured with either single or multiple pre-piped contact vessels and can handle influent flows up to 200 gallons per minute. Costs (1989 dollars) for two, 10-foot diameter, 10-foot high, skid-mounted contact units capable of handling up to 200 gallons per minute are presented in Exhibit 3.1-33.

Some manufacturers will accept spent carbon for regeneration; others will not. Disposal costs for the spent carbon will have to be added if regeneration is not possible.

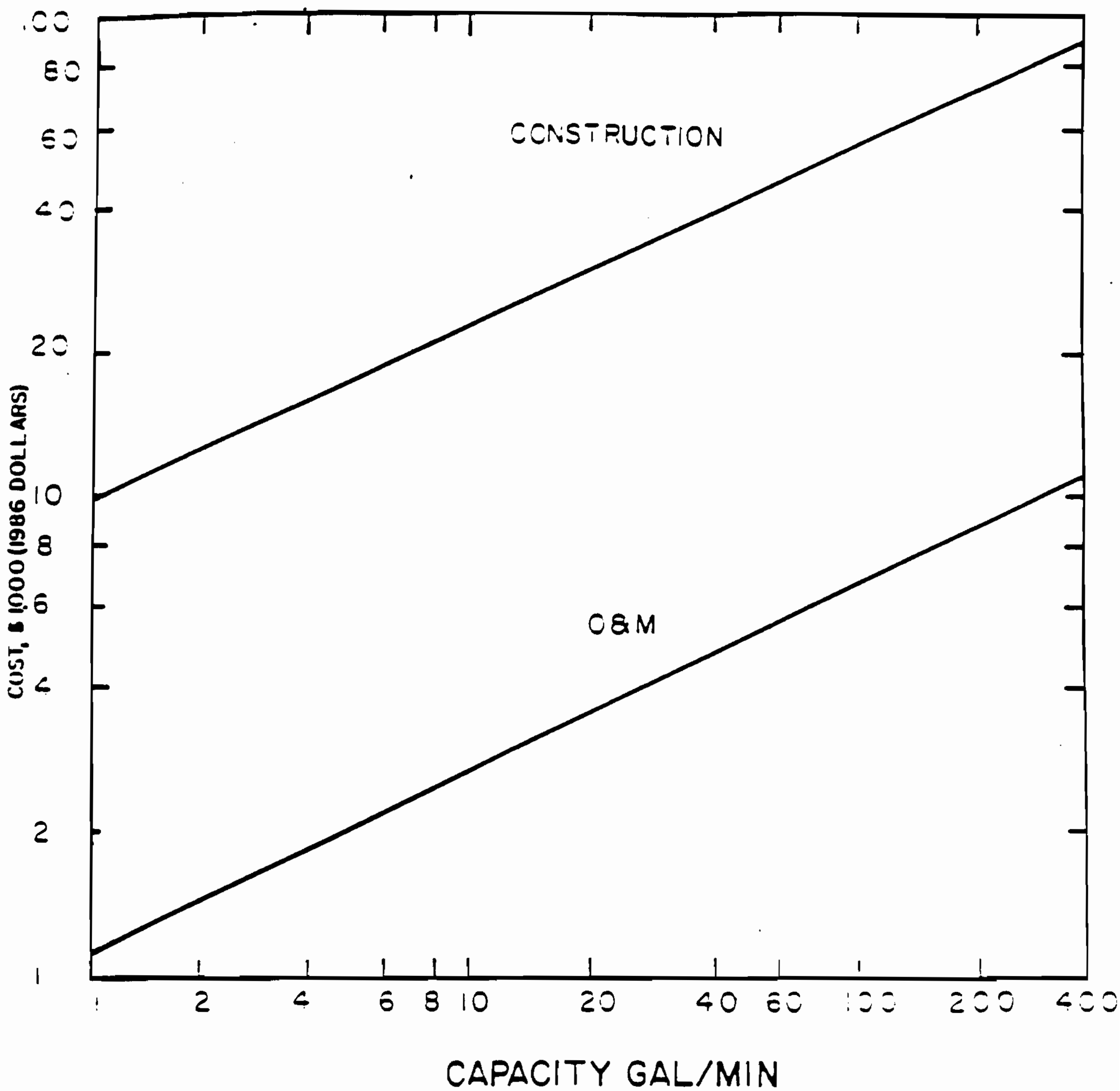
Carbon adsorption is very effective for the removal of the low-solubility organic constituents found in petroleum products. It can be deployed at a treatment site fairly quickly and the technology is readily available. Removal efficiencies are generally very high, and a high quality effluent can be produced, which may expand one's options for discharging that effluent at a particular treatment site. It is relatively tolerant to changes in contaminant concentrations in the influent. Carbon adsorption may also be easily used in combination with other treatment methods (e.g., air stripping).

Carbon adsorption is less suitable for the removal of the highly soluble, highly polar, low molecular weight compounds. These compounds either do not adsorb to any significant extent, or they breakthrough the carbon bed very quickly. Methanol is an example of a compound that is not readily removed using carbon adsorption.

The biggest limitation to the use of the activated carbon process is the high capital and operating cost. The most significant factor in this regard is the replacement frequency for the carbon bed. This operating costs can be reduced by pretreatment of the influent stream.

Exhibit 3.1-32

Estimated Costs of Various Sizes of Carbon Adsorption Units



Source: USEPA. *Underground Storage Tank Corrective Action Technologies, EPA/625/6-87/015*, January 1987.

Exhibit 3.1-33

Typical Unit Costs for a Mobile Carbon Adsorption Unit (1986 dollars)

Cost	Consist of:
$25,200	Delivery, supervision of installation and start up (incl. freight to and from site).
$15,300	Delivery and removal of one truckload of carbon (2,000 lbs).
$5,100	Rental fee (per month)

------ CARBON ADSORPTION SUMMARY ------

APPLICATION: Effective technology for the treatment of a wide range of organics and some metals and inorganic species. Used for treatment of liquids and vapor phase.

EQUIPMENT: A downflow or upflow fixed-bed (packed-bed) carbon reactor vessel connected in series or parallel.

LIMITATION: High suspended solids, high heavy metal, and/or high oil and grease (greater than 10 ppm) concentrations requires pretreatment. The disposal or regeneration of spent carbon must be considered and may be expensive.

COSTS: Depends on size of contractor vessel, which is dictated by the desired reduction in target compounds concentrations exiting in the effluent stream.

REFERENCES: [1,2,3,4,5,6,8,10]

g. Air Stripping

Air stripping is a proven, effective means of removing volatile organic compounds (VOCs) from contaminated ground water. Air stripping is most effective for removing low molecular weight, nonpolar, compounds with moderate to low solubility in water (e.g., benzene, toluene, xylene, and other aromatics). Exhibit 3.1-34 summarizes data on removal efficiencies achieved with air strippers for various organic contaminants at various air-to-water ratios.

The air stripping process is a form of an enhanced volatilization technique and is also referred to as controlled disequilibrium. Clean air introduced into the system results in a net mass transfer of contaminants from the liquid phase to the gaseous phase. By continually replenishing the contaminant-free air stream, contaminants concentrations in the water stream are eventually reduced to low levels. Attachment 3.1-3 contains additional technical information on the basic principles of air stripping.

There are four basic air stripping equipment configurations, as shown in Exhibit 3.1-35:

- Diffused Aeration;
- Coke-Tray Aeration;
- Cross-Flow Tower; and

Exhibit 3.1-34

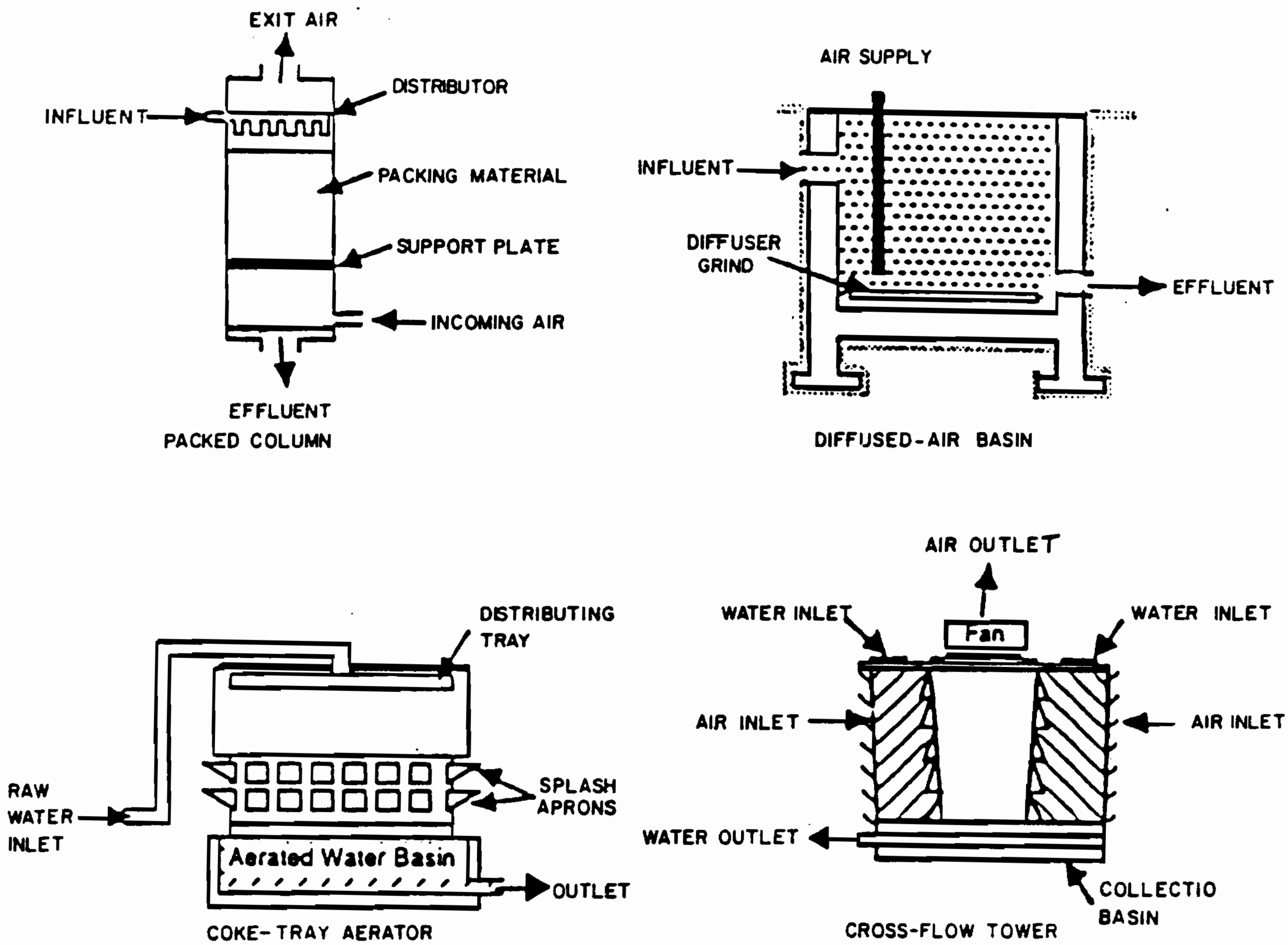
Removals Achieved for Various Organic Contaminants at Various Air-to-Water Ratios

Organic Contaminant	Air-to Water Ratio	Influent (ug/liter)	Effluent (ug/liter)
1,1.2-Trichloroethylene	9.3	80	16
	27.0	75	16
	44.0	218	40
	75.0	204	36
	96.3	80	3
	125.0	204	27
	156.0	813	52
1,1.1-Trichloroethane	9.3	1200	460
	27.0	90	31
	96.3	1200	49
	156.0	1332	143
1,1-Dichloroethane	9.3	35	9
	96.3	35	1
1,2-Dichloropropane	27.0	50	<5
	146.0	70	---
	156.0	377	---
Chloroform	27.0	50	---
	146.0	57	---
Diisopropylether	44.0	15	---
	75.0	14	---
	125.0	4	---
Benzene	22.0	1000	5
Ethylene dibromide	880.0	100	5

Source: USEPA. Underground Storage Tank Corrective Action Technologies, 625/6-87/015, January 1987.

Exhibit 3.1-35

Air Stripping Equipment Configuration



Source. USEPA. *Underground Storage Tank Corrective Action Technologies*, EPA/625/6-87/015, January 1987.

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- Packed Tower.

Of these, the most common application is the packed air stripping tower equipped with an air blower. As shown in Exhibit 3.1-36, contaminated ground water flows down and through the packing material in the tower while clean air flows upward (i.e., countercurrent flow). The packing material acts to increase the effective surface area for the mass transfer of the volatile contaminants from the water and into the air. The contaminated air is then vented through the top of the tower while the "cleaned" water exits the bottom of the tower.

The packed tower, countercurrent flow configuration tends to be the most effective system for treating VOCs in ground water because:

- It provides the greatest liquid interfacial area;
- High air-to-water volume ratios are possible because of the low air pressure drop through the tower; and
- A vapor treatment system can be added easily to control VOC emissions.

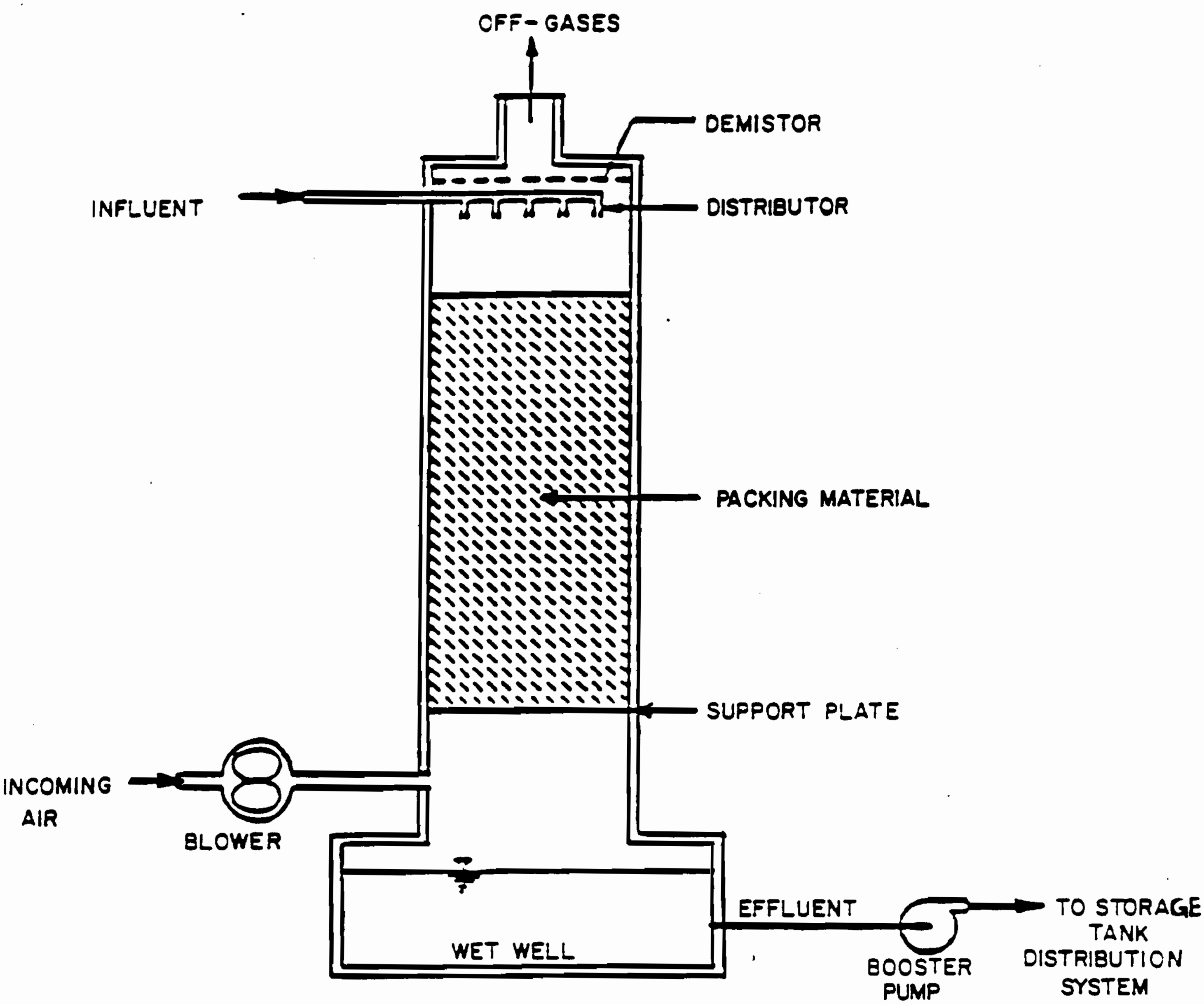
Proper design of an air stripper for VOC removal from ground water consists of two steps. In step one, the cross-sectional area of the tower is determined from the physical properties of the air flowing through the tower, the characteristics of the packing material, and the air-to-water flow ratio. It is calculated by dividing the air flow rate by the air velocity. The key element in this calculation is establishing the proper air velocity. A general rule-of-thumb is that air velocity should be 60 percent of the air velocity that results in the flooding condition. Flooding refers to the condition created when the air velocity is high enough to hold up the descending water in the column to the point where the water becomes the continuous phase rather than the air. If the air-to-water ratio is held constant, the air velocity determines the flooding condition. The selection of the proper air-to-water ratio is based on the results pilot-scale treatability studies.

The second step is calculating the tower height. The proper tower height if a function of the physical properties of the contaminant and the stripping air. This calculation is discussed in Attachment 3.1-3.

The arrangement of the packing material in the tower can affect removal efficiency. The two alternate arrangements are referred to as "randomly dumped" and "stacked" packing. A "randomly dumped" arrangement refers to small plastic, metal, or ceramic packing material arbitrarily arranged in the tower to provide a high surface area as well as a high void volume. A "stacked packing" arrangement looks like a bundle of tubes standing on end. Exhibit 3.1-37 lists physical characteristics of several common dumped and stacked packings.

Exhibit 3.1-36

Diagram of Packed Tower Aerator



Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.

Exhibit 3.1-37

Physical Characteristics of Common Packing Materials

Dumped Packings **Type**	**Size (in.)**	**Surface Area (sf/cf)**	**Void Space (%)**	**Packing Factor (1/ft)**
Glitsch	OA	106	89	80
Mini-Rings	1A	80.3	92	30
(Plastic)	1	44	94	28
	2A	41	94	28
	2	29.5	95	15
	3A	24	95.5	12
Tellerettes	1"(#1)	55	87	40
(Plastic)	2"(2-R)	38	93	18
	3"(3-R)	30	92	16
	3"(2-K)	28	95	12
Intalox	1"	63	91	33
Saddles	2"	33	93	21
(Plastic)	3"	27	94	16
Pall Rings	3/8"	104	87	97
(Plastic)	1"	63	90	52
	1 1/2"	39	91	40
	2"	31	92	25
	3 1/2"	26	92	16
Raschig Rings	1/2"	111	63	580
(Ceramic)	3/4"	80	63	255
	1"	58	73	155
	1 1/2"	38	71	95
	2"	28	74	65
	3"	19	76	37
Jaegar	1"	85	90	28
Tri-Packs	2"	48	93	16
(Plastic)	3 1/2"	38	95	12
Stacked packing				
Delta	---	90	98	---
(PVC)				
Flexipac	Type 1	170	91	33
(Plastic)	Type 2	75	93	22
	Type 3	41	96	16
	Type 4	21	98	9

Source: USEPA. Cleanup of Release From Petroleum USTs: Selected Technologies, 530/UST-88/001, April 1988.)

NOTES

The randomly dumped packing arrangement has been used more often, although the stacked arrangement offers some advantages. According to manufacturers, stacked packings are less susceptible to biological and mineral fouling due to their higher (in some cases) void space and the fact that stacked packings do not have horizontal surfaces.

It is important to recognize that the removal efficiency of an air stripping tower is fixed by the design and will not change over the life of the unit unless fouling or some other operational problem occurs. This is different than using carbon adsorption technology in that removal efficiency decreases over time with each carbon bed until it is changed.

Several other factors should be considered when designing an air stripping tower:

- The environmental setting around the location of the air stripper. If the air stripper is to be located in or near a residential area, the tower, blower, and pumps may need to be enclosed for aesthetic reasons as well as to control noise levels. Zoning laws may also affect stripper design. Many communities have maximum height limitations.

- Prevailing wind patterns of the area. One of the assumptions made in designing an air stripper is that the influent air is free of VOCs. In order to ensure this condition is met, the air intake must be designed to prevent "short-circuiting" between the tower effluent and influent air.

- Proper distribution of the influent water throughout the packing. A common design problem is channeling along the wall of the tower. This is known as the "sidewall effect". Channeling is a function of the lower flow resistance along the wall due to a greater void volume. To avoid this problem, the influent water is redistributed by side wipers along the tower wall and installed every 20 feet of packing. In general, this problem is more severe with smaller diameter columns.

- The need for a mist eliminator. This screens captures any water entrained in the effluent air before it exits the tower and are fairly inexpensive ($200 to $300).

- The effect of influent water quality on the material used to construct the air stripper. Aluminum is often the construction material of choice because it does not rust. However, fiberglass-reinforced plastic (FRP) or stainless steel are used when the influent water is expected to be fairly corrosive. Any resins used in the manufacture of a FRP tower should be of a potable water or food grade and have EPA and FDA approval. Carbon steel is generally not used because it tends to rust. If carbon steel is used, the steel should be coated with a potable water-grade coating. Concrete is sometimes, but rarely used.

Installation of an air stripper unit usually requires field assembly of the equipment or placement of shop-fabricated and packaged mobile unit. Installation of the complex internal components of the tower is the most labor-intensive task. Overall, however, the installation of an air stripper is relatively simple and can be done by most mechanical contractors.

An air stripping tower does not destroy volatile contaminants; it simply transfers them from the liquid to the gaseous phase. It is possible that the dilution that occurs in the tower and in the atmosphere will be sufficient to produce ambient concentrations below acceptable levels. Otherwise, it is necessary to add vapor phase treatment to meet emission standards.

New York State regulates the discharge of volatiles to the atmosphere currently on a case-by-case basis. For air strippers exceeding this limit, off-gas air pollution control is required (see Part 2, Section 3, proper Management of Spill Residuals and Debris). Typically, carbon adsorption is used to treat the vapor-phase contaminant. Exhibit 3.1-38 shows the amount of a particular volatile contaminant or of
total volatiles that would be released to the air at the stated flow rates and removal efficiencies. Attachment 3.1-3 provides additional information on calculating air emission rates from air strippers.

Maintenance of the air stripper is required to ensure maximum removal efficiency. The system must be checked periodically for air and/or water leaks. The packing material must be checked for fouling either due to inorganics precipitating out of solution or due to bacterial growth. Fouling problems can usually be detected through an increase in the contaminant concentrations in the effluent, but ultimately the system must be shut down for the packing to be cleaned and/or replaced. It may be necessary to pretreat the influent water to avoid problems with fouling.

Air stripping is generally a more cost-effective technology for the treatment of ground water as compared carbon adsorption. The costs for air stripping can vary widely, however, as these costs are highly site-specific.

Capital costs include design and construction of the air stripper and ancillary equipment onsite (plus contingencies and permit fees). These costs include those for the tower and packing material; air blowers; pumps; piping and valves; electrical equipment; a clearwell and holding tank (if needed); site preparation (as necessary); VOC emission controls, if required; construction costs for equipment housing, if required; and miscellaneous costs such as painting, plumbing, and cleanup.

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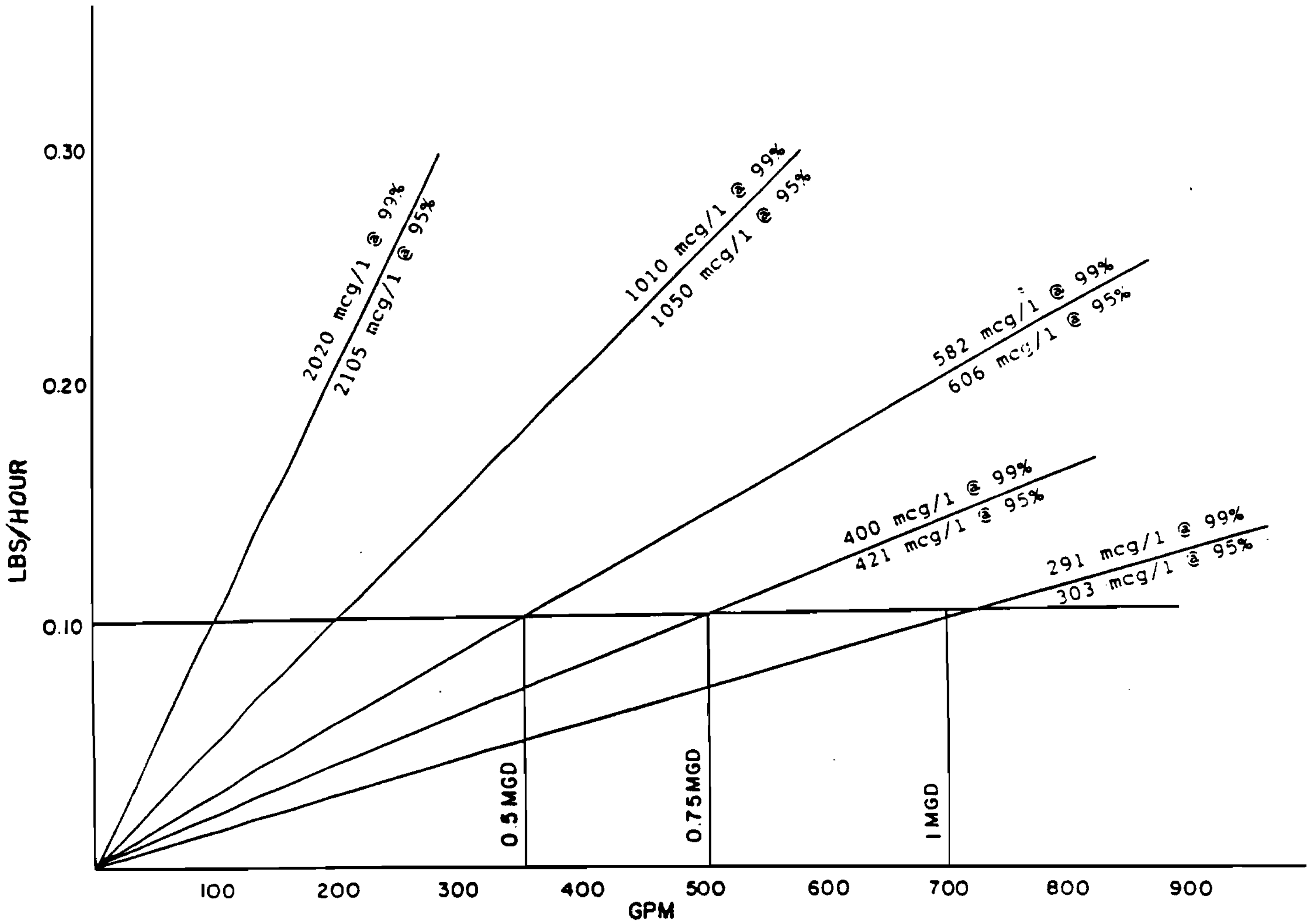
Exhibit 3.1-38

Representative Volatile Organic Compound Discharge Rates
From an Air Stripper



Source: USEPA. *Cleanup of Releases from Petroleum USTs: Selected Technologies*, 530/UST-88/001, April 1988.

NOTES

Operation costs consist of the costs for electrical power to run the pumps and blowers, and any costs for water pretreatment, including the treatment chemicals. Overall, the total marginal cost per 1000 gallons of water treated in an air stripper will range between $0.05 to $0.25. The total clean-up costs will be a function of the length of the cleanup; the flow rate to be treated; the desired removal efficiency and/or final concentration goal; the selected air-water ratio; the physical properties of the limiting contaminant; the residual concentration remaining in the aquifer; and the need for vapor-phase treatment.

The cost of the process equipment (tower, packing, pumps, and blowers) accounts for 20 to 75 percent of the overall capital cost, with the higher number including the installation of VOC emission controls. Typical capital and operation and maintenance costs for air stripping towers at underground storage tank sites can be obtained from the spill response contract documents.

Air strippers are effective in removing many petroleum product constituents from ground water at fairly low cost ($0.05 to $0.25 per 1000 gallons). It is a readily available technology and can be installed fairly quickly at a spill clean-up site. Only the more volatile constituents (e.g., benzene, toluene, xylene, and ethylbenzene) are removed, however. Less volatile constituents, such as ethylene dichloride (1,2-dichloroethane) are not readily removed as are most highly water soluble, high-polarity, and high molecular weight compounds. This makes air stripping a less viable technology for the treatment of older spills in ground water where most of the volatile constituents may have already volatilized out of the contaminant plume.

High concentrations of iron and manganese and/or suspended solids in the influent water can pose a major operational problem for the use of air strippers. Iron and manganese facilitate the growth of bacteria on the packing, which causes a decrease in the mass transfer rates and higher gas pressure drops. The presence of toluene in the influent is also thought to contribute to this problem, as do suspended solids if they become trapped in the packing material. A stacked packing arrangement tends to clog less frequently because there are no horizontal surfaces on which hydroxides may precipitate or bacteria can grow. Pretreatment of the influent water may be necessary to avoid fouling problems and this increases the operating cost.

The transfer of volatile contaminants from one medium (ground water) to another (air) may be a problem for the use of air strippers in some locales (e.g., nonattainment areas for VOCs or ozone). Treatment of the off-gas, if required, is expensive. Treatment methods include vapor-phase carbon adsorption (most common), incineration, and catalytic oxidation.

Air strippers are noisy, which may a problem with their use in or near residential areas. One solution is to surround the tower with walls extending above the tower.

NOTES

------ AIR STRIPPING SUMMARY ------

APPLICATION: Proven and effective means of removing volatile organic compounds (VOCs) from contaminated ground water. Most effective for low-molecular-weight, non-polar compounds with moderate to low water solubilities.

EQUIPMENT: The packed tower (or packed column) countercurrent system is the most frequently employed equipment configuration for treating ground water contaminated by petroleum products such as gasoline.

LIMITATIONS: VOCs emitted from the tower may require a permit and/or vapor treatment. Local zoning laws must be considered in addressing noise levels, height limitations, and/or the aesthetics of an installation. May not achieve the desired or required reduction in contaminant concentrations. May require pretreatment of influent stream to precipitate out high iron content and/or reduce bacterial growth.

COST: Extremely cost-effective in comparison to other clean-up technologies (e.g., carbon adsorption). Total cost is very site-specific, and is usually determined on a volume-treated basis. Typical costs per 1000 gallons treated range between $0.05 to $0.25.

REFERENCES: [1,2, and 15]

ATTACHMENT 3.1-1

TRENCH EXCAVATION

Trench excavation is one of the most critical elements in determining the cost-effectiveness of drains. The need for extensive rock fragmentation may result in exclusion of drains as a cost-effective remedial action.

Trench excavation is usually accomplished by the use of either trenching machines or backhoes. Cranes, clamshells, and draglines are also used for deep excavation. This equipment, however, sees very limited use at leaking UST sites.

Trenchers or ditchers are designed to provide continuous excavation in soil and well-fragmented or weathered rock. They consist of a series of buckets mounted on a wheel (bucket-wheel type) or a chain sprocket and ladder (bucket-ladder type). In continuous trenching, the wheel or ladder is lowered as the revolving buckets excavate the trench to the appropriate depth. The trench assembly may be mounted on wheels or on semi-crawler or full-crawler frames. The trencher moves forward simultaneously as the trench is excavated, resulting in a trench of neat lines and grades. The bucket wheel types are generally used to dig shallow trenches for agricultural drainage. The maximum depth for a large wheel trencher is about 8.5 feet. Different sizes of bucket-wheel type trenchers are available for various depths and widths. Buckets may be changed to fit the type of soil being excavated.

The factors that influence the rate of trenching include soil moisture, soil characteristics (such as hardness, stickiness, stones) and the depth and width of the trench.

Generally, continuous trenching in suitable materials is accomplished much faster than trenching via backhoe. Hourly production rates for wheel and ladder trenches operating at 100 percent efficiency are given in Table. Actual efficiencies may range from 20 to 90 percent depending upon the above mentioned factors.

Trenchers can be equipped with back-end modifications to provide shoring, install a geotextile envelope, lay tile or flexible piping, blind the piping, and backfill with gravel or excavated soil.

Backhoes can excavate earth and fragmented rock up to one-half of the bucket diameter to depths of up to 70 to 90 feet. The crane and clamshell can be used for deeper excavations or when access excludes the use of the backhoe. Excavation of a trench through soils containing numerous large boulders or hard rock layers results in considerable delays and substantially increases the cost of construction. Typically, these materials must be fractured to facilitate their removal.

The most commonly used method for fragmenting rock in petroleum contamination site work involves the use of the rotary or percussion drills, backhoe-mounted pneumatically driven impact tools and tractor-mounted mechanical rippers. The Hobogoblin has a low production rate of about six cubic yards per hour while mechanical rippers have considerably higher production rates than the other methods. However, their use is limited to depths of 6 feet or less and are not suitable for highly consolidated rock. The depth limitation can be overcome to some extent if the ripper can enter the trench to rip lower lifts, but this becomes uneconomical since the trench width clearance increases the volume of material to be excavated. Blasting, though commonly used in the construction industry for rock fragmentation, is not recommended for petroleum contamination site work.

Grade Control

Proper grade control in a subsurface drain ensures against ponding of water and provides for a nonsilting velocity in the drainage pipe. Proper grade control can be accomplished using either automatic laser or visual grade-control systems. Laser systems are adaptable to a wide range of earthmoving equipment including trenchers and backhoes.

Dewatering

Proper installation of drains (i.e., maintenance of grade, placement and alignment of pipes) generally requires dewatering to achieve a dry environment. Three basic options are available for dewatering: open pumping, predrainage using wellpoints or well systems, and ground-water cutoff. These techniques may be used separately or in combination. Open pumping involves construction of a sump hole or pit at the lowest point of the excavation so that water can flow towards and collect in the pit. A centrifugal submersible pump or a diaphragm pump can than be used to pump the accumulated water from the sump holes. Any contaminated water is subsequently treated. Open pumping is applicable only to shallow trench excavations with stable soils of low hydraulic conductivity where ground-water seepage into the excavation is minimal. It is often used together with predrainage where wells or wellpoints have reduced seepage to a manageable volume.

Wellpoints and deep wells can be used to lower the water table near a trench excavation. Wellpoints are one of the most widely used and most versatile dewatering technologies.

Ground-water cutoff barriers such as steel sheet piling, concrete, or a bentonite slurry wall may also be used together with wells and wellpoints to reduce the size of the required predrainage system.

Wall Stabilization Methods

Trench excavations generally require the use of wall stabilization methods to prevent cave-ins during installation of drain pipes. With shallow trenches in stable soils, the need for shoring can be eliminated by cutting the trench with sloped walls so that a stable angle is attained (usually a 1.5 [horizontal] to 1 [vertical] slope).

Shoring, which involves supporting the trench wall with wood or steel structures, is the most commonly used method of wall stabilization. Shoring methods for supporting shallow trenches involve the use of slipshields (constructed on-site by welding I-beams between two parallel pieces of sheet steel) and adjustable aluminum bracing. For trenches which are deeper than about 10 feet, steel sheet piling or steel H-pipes with horizontal wooden beams between them can be driven and braced to support the trench walls.

Drain Installation

Once trench excavation is completed, the components of the subsurface drain can be installed. This process includes laying the pipes, filter, and envelope material as well as backfilling and installation of auxiliary components.

Placement of Envelope and Filters

Gravel envelopes are installed around the pipe drain to increase flow into the drain and reduce the buildup of sediments in the drain line. They may be placed by hand, backhoe, or by a hopper cart or truck. In continuous trencher drain installation machines, gravel filling may be ongoing along with other operations.

Filter fabrics are sometimes installed around the gravel envelope to prevent fines from clogging the envelope and drain pipe. When constructing a drain using a fabric filter wrapping, the fabric is installed first, followed by the bedding, the pipe, and the envelope in that order. The fabric filter is then wrapped around the top of the envelope prior to backfilling with soil. Fabric filters can be installed manually or by machine.

Backfilling

After the gravel envelope has been installed, the trench must be backfilled to the original grade. Prior to backfilling, the drain should be inspected for proper elevation below ground surface, proper grade and alignment, broken pipe, and thickness of the gravel envelope. The inspector should insure that pipe drains and manholes are free of deposits of mud, sand and gravel, or other foreign matter, and are in good working condition. Unstable soils may preclude all but spot checks before backfilling.

ATTACHMENT 3.1-2

GRANULAR ACTIVATED CARBON ADSORPTION PROCESS

"Granular Activated Carbon (GAC), has a higher affinity for nonpolar compounds than for polar compounds due to the surface chemistry of the carbon. The polarity of a compound depends on the chemical and physical structure of its molecules. Polar compounds behave more like ionic compounds, while nonpolar compounds are more neutral electrically. Most components of gasoline, particularly benzene, toluene, and xylene, are nonpolar. The molecular structure of a compound will also influence its ability to adsorb on GAC. Molecules which are branched or have attached functional groups, such as chlorine, fluorine, or nitrogen, adsorb well. Pesticides generally exhibit extremely high adsorbability, due in part to their complex molecular structure [6]."

This adsorption process (mass transfer of a solute from the bulk liquid to the carbon surface) occurs in three phases. More information on these phases can be found in reference [8].

During remediation the micropore surfaces eventually become saturated with organics. The carbon becomes "spent" and must either be replaced with virgin carbon or removed, thermally regenerated, and replaced.

The time it will take to reach "breakthrough" or exhaustion of the carbon media is dependent on influent concentrations and flow rates.

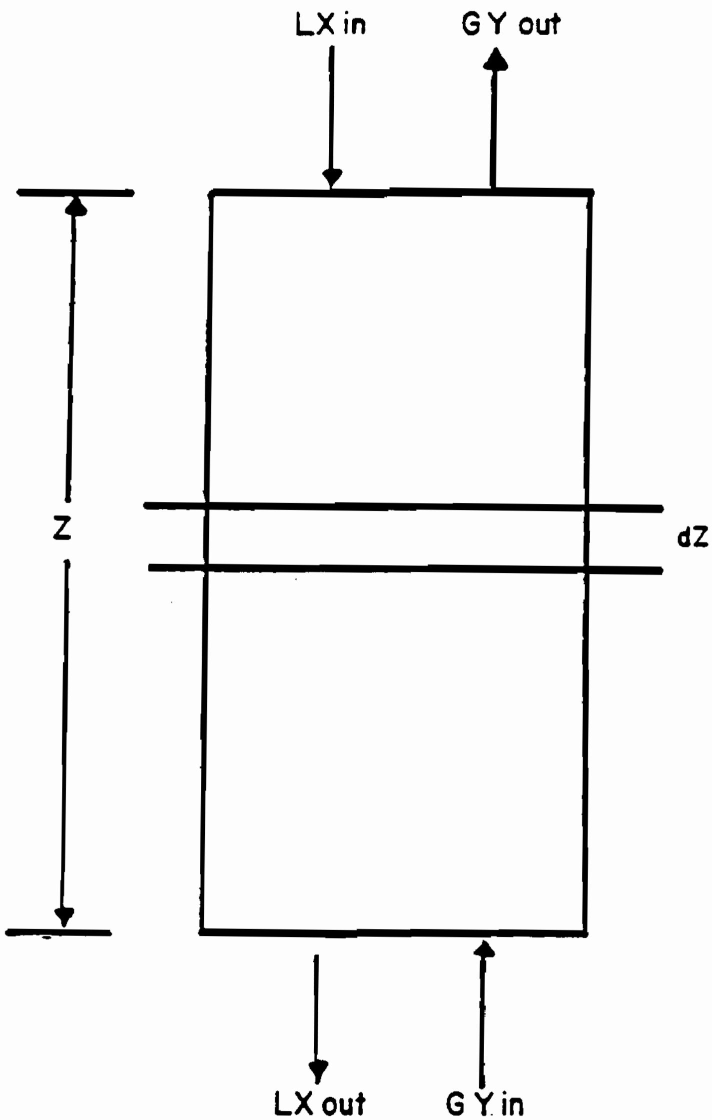
The carbon capacity is influenced by a variety of factors:

- # the solute to be absorbed
- # the adsorbent (carbon) itself
- # the water temperature
- # the pH of the liquid, and other things

The basic tool for understanding the evaluation of activated carbon treatment is the adsorption isotherm. The isotherm is a function that relates the amount of solute adsorbed per weight of adsorbent to the solute concentration remaining in the liquid at equilibrium [6]. It is important to note that equilibrium conditions may require long periods to achieve. Isotherms are usually determined for a single-solute solution (i.e. one compound). If more than one compound is present in the water, as is usually the case at gasoline contamination sites, the isotherms are useful only for comparative purpose, and cannot be used for design [6].

Exhibit 3.1-39

Differential Element for an Air Stripping Tower



MASS BALANCE:

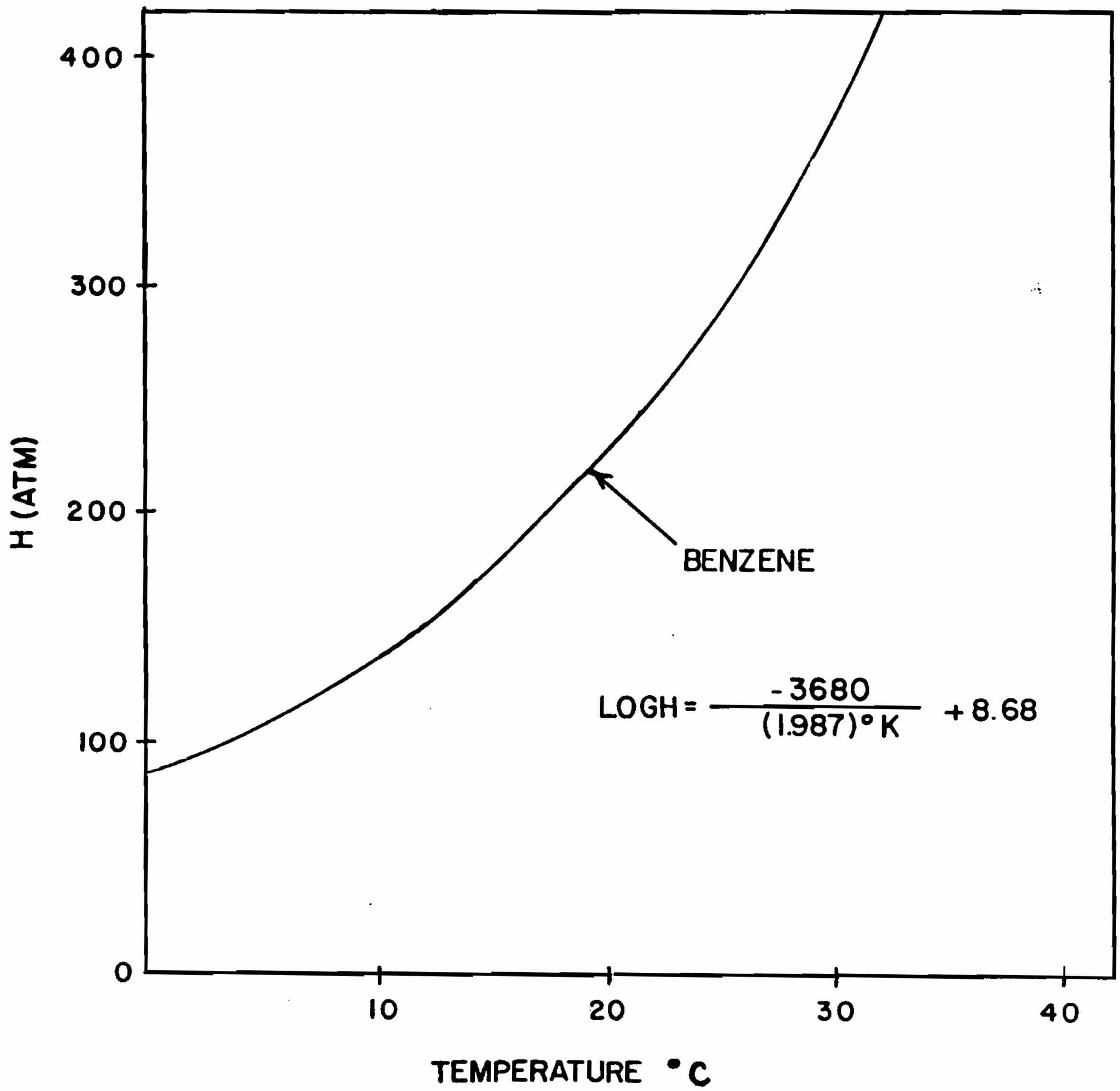
$LX_{in} = GY_{out}$

LEGEND:
L = volume liquid
G = volume gas
X = concentration in liquid
Y = concentration in gas
Z = depth of packing

Source: [8]

Exhibit 3.1-40

Temperature Dependence of Henry's Law Constant



Source: [8]

The master design equation must have all the variables (Henry's constants, stripping factor, mass transfer rate coefficient, and gas pressure drop) determined. This discussion only elaborates on Henry's constants, however, the mathematical derivation for the other three variables are fully enumerated in reference.

There is no single procedure that must be followed when designing an air stripping tower. Regardless of the procedure followed, values are first required for the flow rate, influent and effluent concentration, operating temperature, and the Henry's constant for the limiting contaminant. After these initial values are determined, a suggested general design procedure is:

- Select the packing material;
- Select a reasonable stripping factor;
- Select a reasonable gas pressure drop;
- Based on the chosen air-water ratio, calculate the required liquid loading rate;
- Find the tower diameter;
- Find the height of transfer unit;
- Find the number of transfer units;
- Find depth of packing. Use an appropriate safety factor (1.2 is common); and
- Determine the most cost-effective combination of parameters based on present worth calculations.

Calculation of Air Emission Rates

A recent USEPA publication entitled "Estimating Air Emissions from Petroleum UST Cleanups" contains a discussion of a general method for calculating air emission rates from air strippers. A portion of that document has been adapted and included below.

A typical site investigation will generally result in several ground-water contaminant concentrations, each sampled at a different location. In order to estimate the maximum emission rate using the following exhibits, the maximum ground-water concentration should be used. If an average ground-water concentration is used instead, the estimated emission rate will represent a long-term average of the actual emission rate (perhaps over the first six months of operation).

The procedure presented below relies on information pertaining to the design of the air stripper (such as pumping rate and removal efficiency), along with field measurements of the contaminant concentration in ground water. The procedure was checked against examples published in the literature to ensure that realistic estimates were obtained.

Emissions from air strippers tend to be less than the emissions from excavated soil piles and vacuum extraction systems; however, they tend to be the longest in duration. Air stripper emission rates depend, in part, upon the pumping rate and removal efficiency of the system. **For systems pumping at less than 100 gallons per minute (gpm) and having removal efficiencies between 85 and 99.9 percent, VOC emissions will range from 0.5 to 4 pounds per hour. Benzene emissions will generally be between 0.1 to 0.5 pounds per hour** [emphasis added].

Exhibit 3.1-41

Estimated Air Stripper Emission Rates for Gasoline VOCs
Removal Efficiency = 99.99 Percent

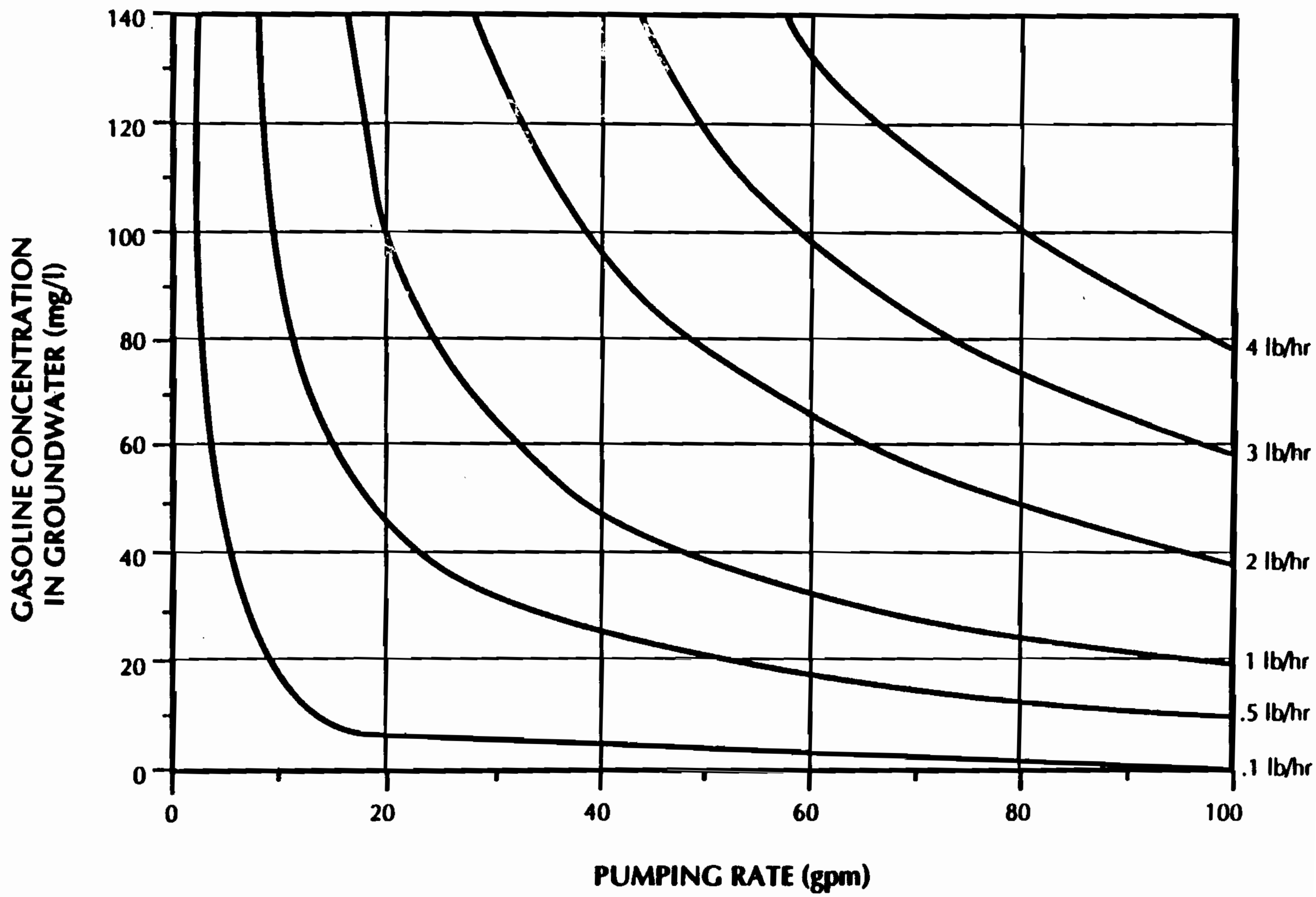


Exhibit 3.1-42

Estimated Air Stripper Emission Rates for Benzene
Removal Efficiency = 99.99 Percent

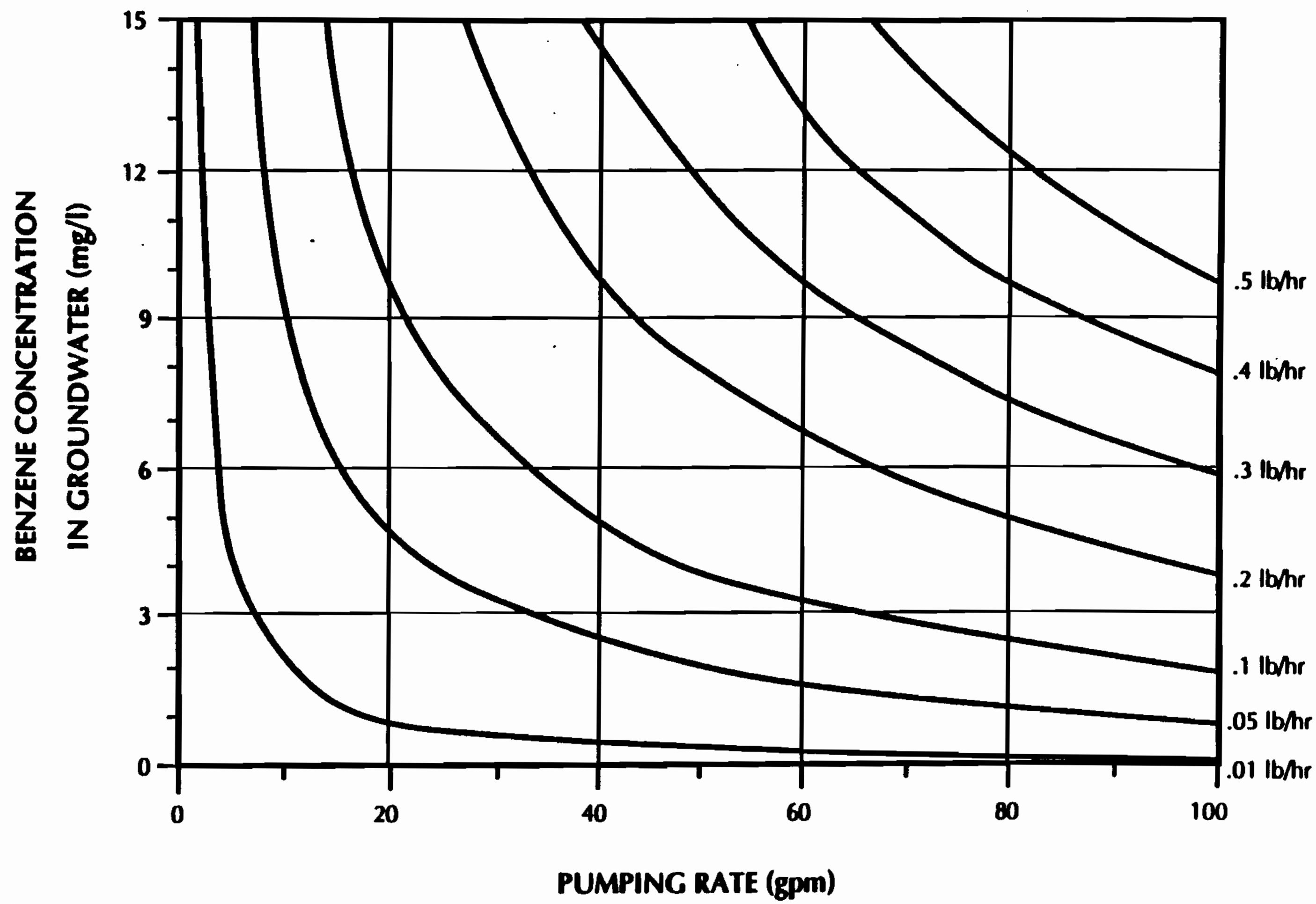


Exhibit 3.1-43

Estimated Air Stripper Emission Rates for Gasoline VOCs
Removal Efficiency = 95 Percent

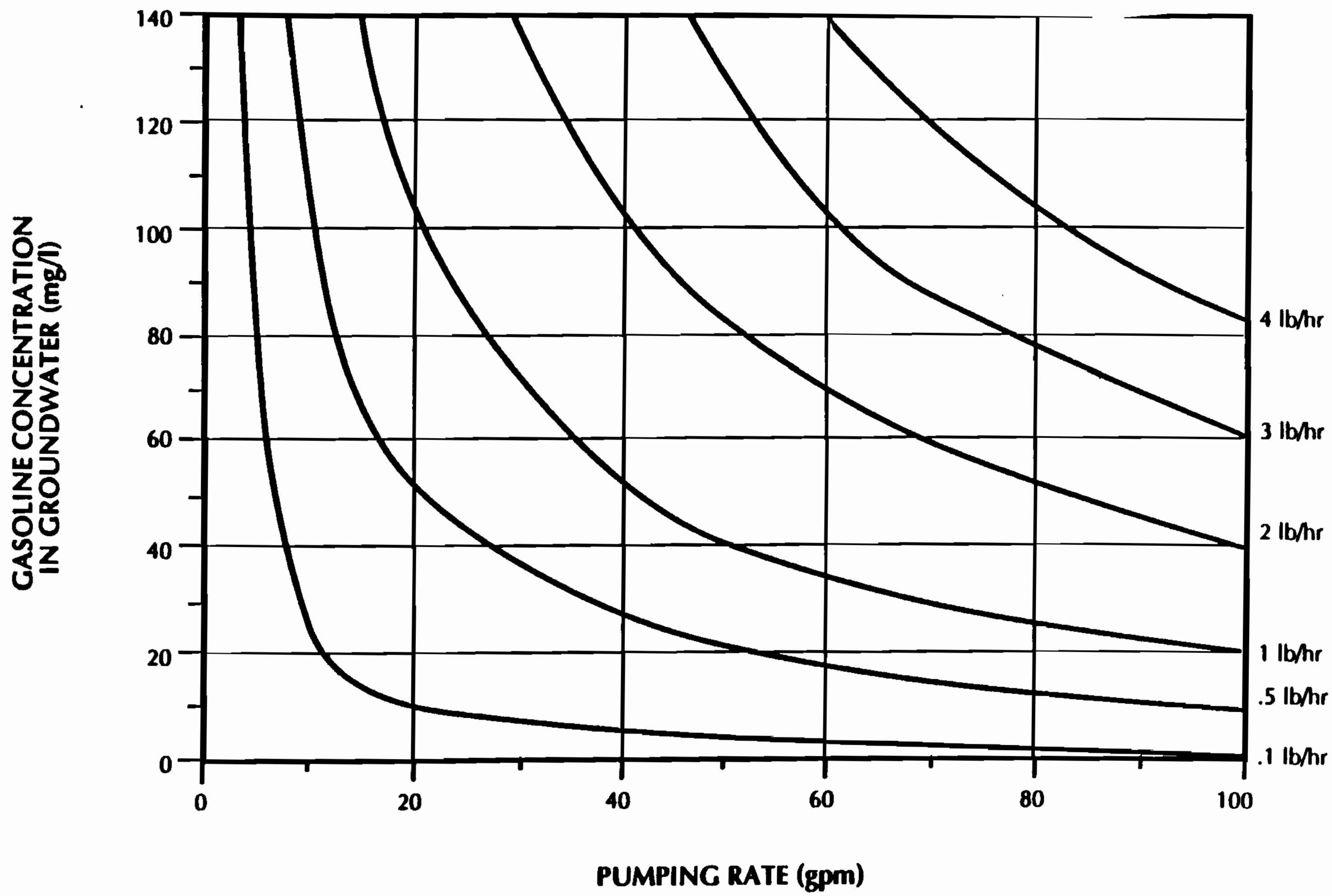


Exhibit 3.1-44

Estimated Air Stripper Emission Rates for Benzene
Removal Efficiency = 95 Percent

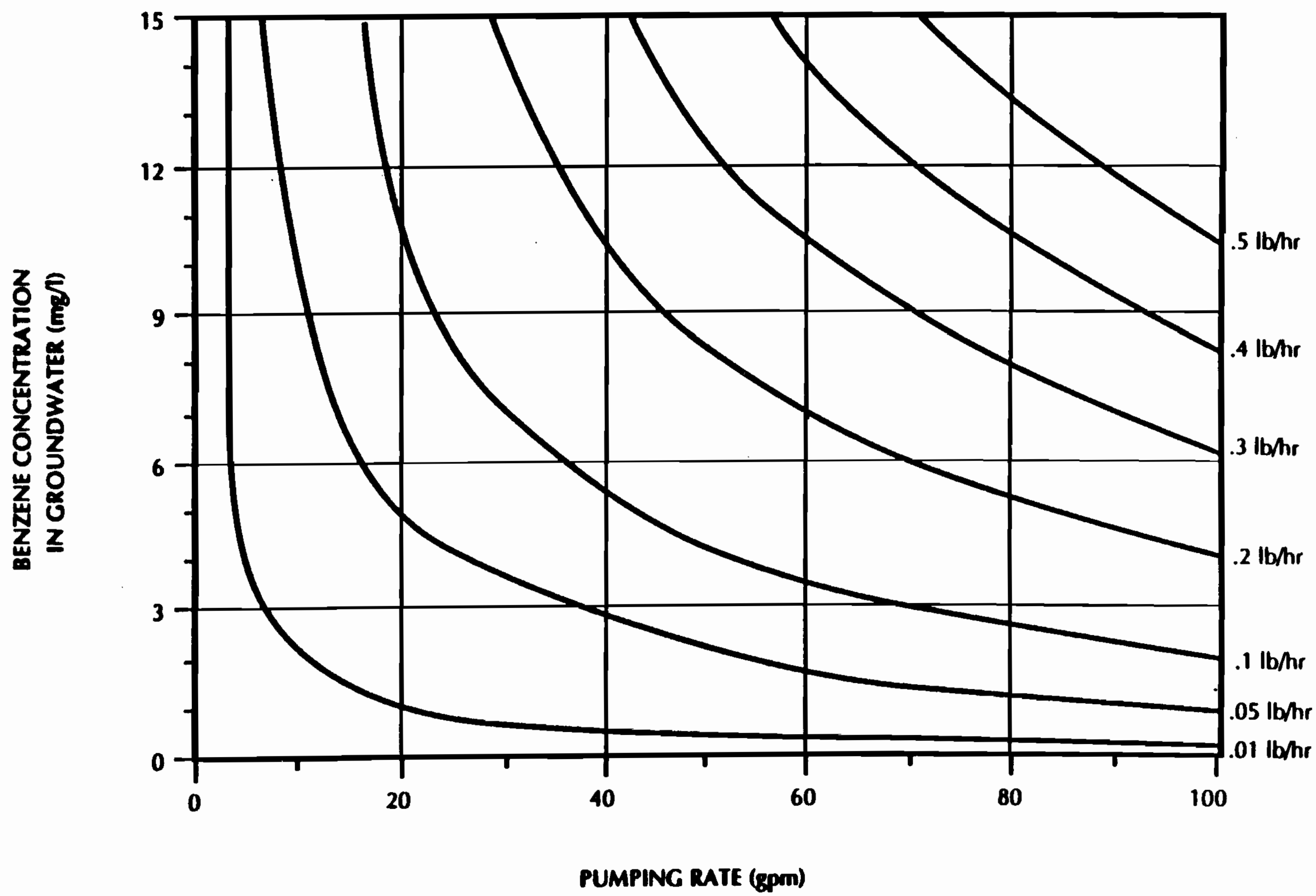


Exhibit 3.1-45

Estimated Air Stripper Emission Rates for Gasoline VOCs
Removal Efficiency = 85 Percent

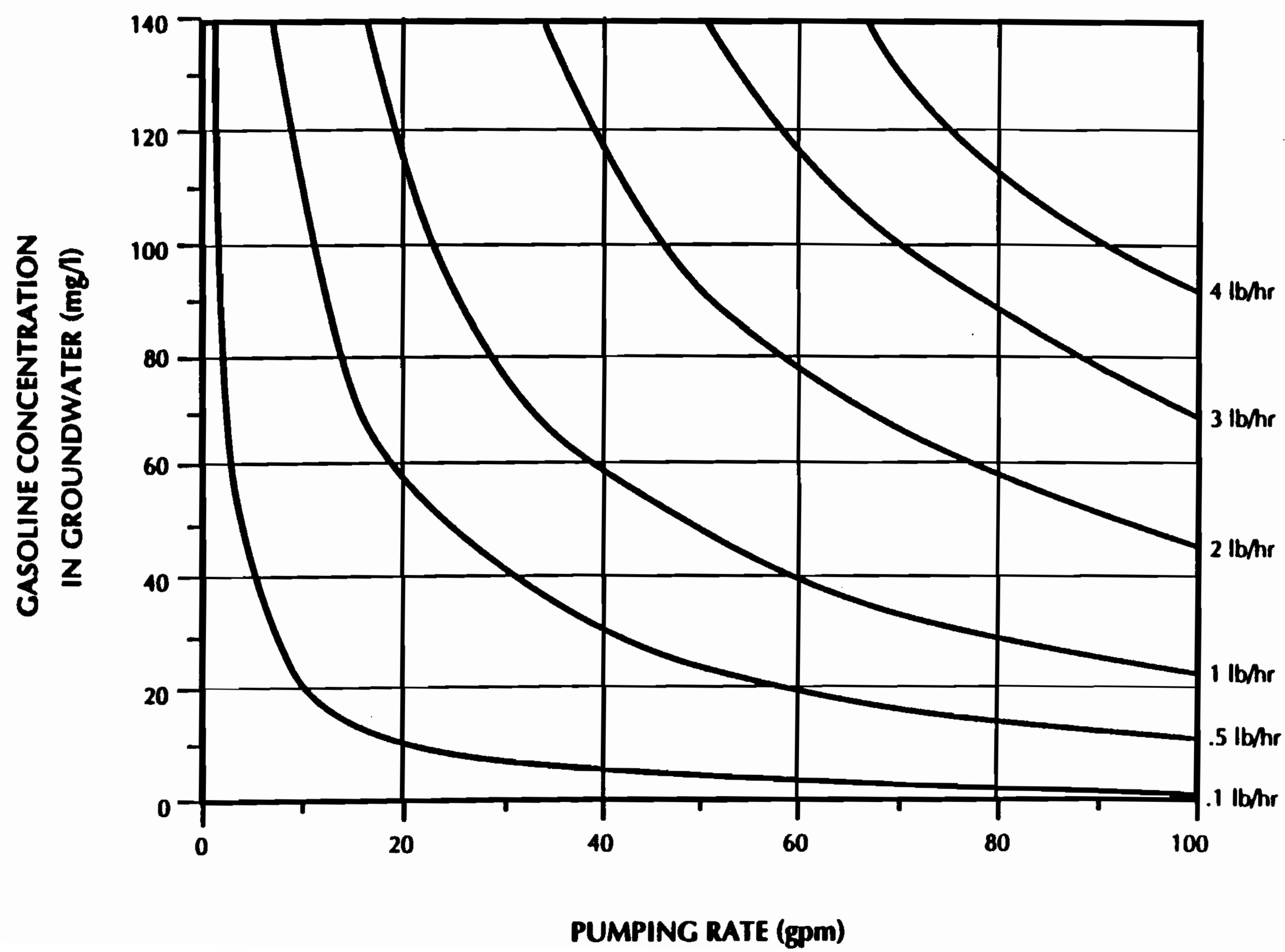


Exhibit 3.1-46

Estimated Air Stripper Emission Rates for Benzene
Removal Efficiency = 85 Percent

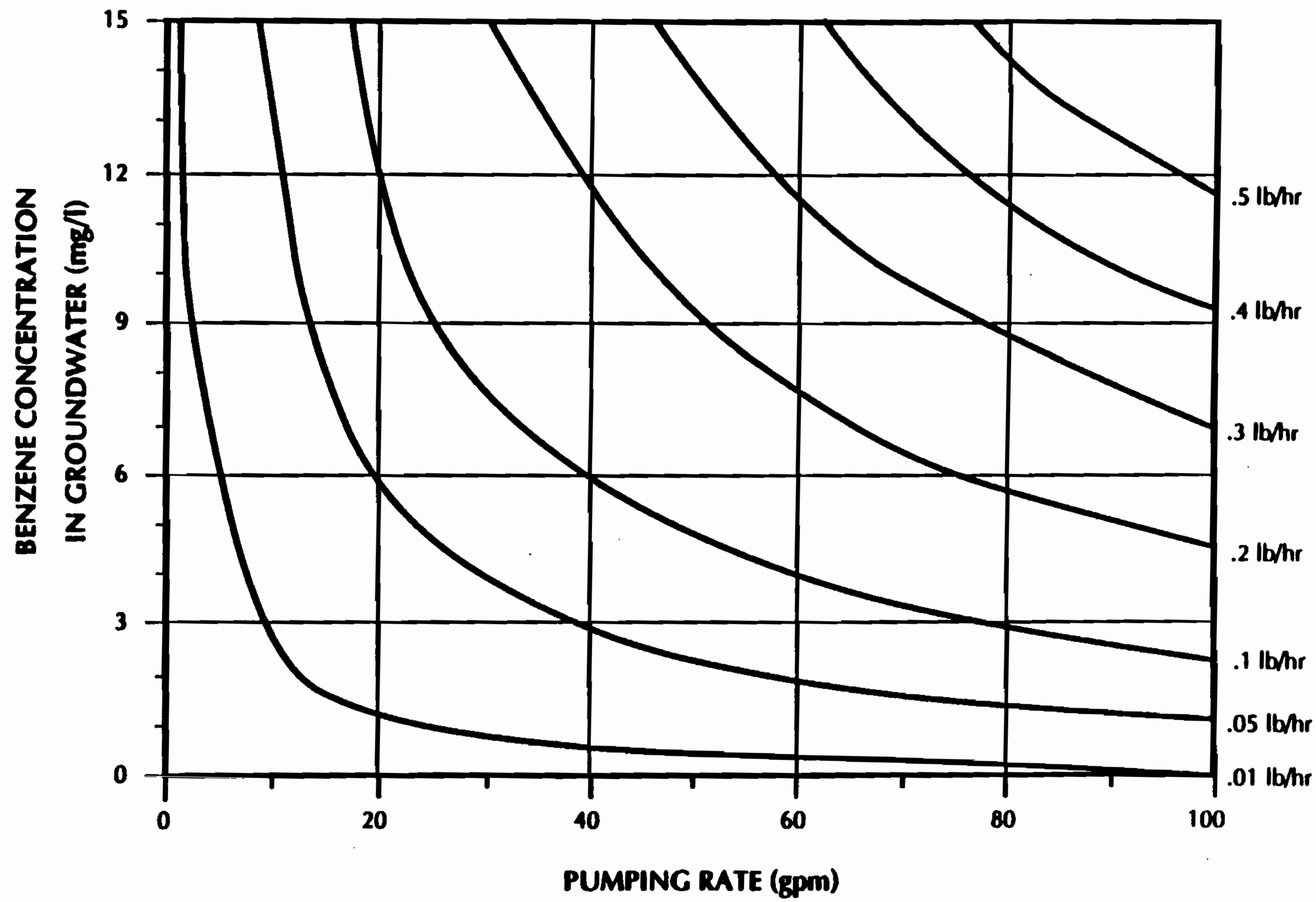


Exhibit 3.1-46

Estimated Air Stripper Emission Rates for Benzene
Removal Efficiency = 85 Percent

(5) Using the exhibit selected, locate the pumping rate of the well on the x axis, and the concentration of the contaminant in the water on the y axis. The intersection of these two points will fall on or near a curve having a specific emission rate. This curve can be used to estimate the emission rate under the prescribed pumping rate and contamination levels.

(6) If the pumping rate of the air stripper is greater than 100 gpm, the equation below can be used to calculate the air emission rate:

$$ER = (Q \times C \times RE \times (5.042 \times 10^{-4}))$$

where: ER = the emission rate in pound per hour;
Q = the ground-water pumping rate in gallons per minute;
C = the concentration of the contaminant in ground water in milligrams per liter;
RE = the removal efficiency expressed as a fraction of one; and

5.042×10^{-4} is a constant having units of (pounds liters minutes/milligrams gallons hour) and is derived in the following manner:

$$\frac{2.2 \text{ lbs}}{10^6 \text{ mg}} \times \frac{1000 \text{ liters}}{261.8 \text{ gals}} \times \frac{60 \text{ min.}}{1 \text{ hr}} = 5.042 \times 10^{-4}$$

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