Utah Department of Environmental Quality
Division of Environmental Response and Remediation

Underground Storage Tank Consultant Certification Manual

2009

UTAH DEPARTMENT OF ENVIRONMENTAL QUALITY
DIVISION OF ENVIRONMENTAL RESPONSE AND REMEDIATION

UNDERGROUND STORAGE TANK CONSULTANT CERTIFICATION MANUAL 2009

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MANUAL INTRODUCTION

The Utah Division of Environmental Response and Remediation (DERR) has developed this manual as a study guide and reference for environmental consultants who want to become Utah-certified Underground Storage Tank (UST) consultants. The manual provides information on UST laws and regulations, the Petroleum Storage Tank Fund, site investigation techniques, site safety, remediation technologies, and fate and transport to prepare environmental consultants for the DERR UST Consultant Certification Examination.

It is assumed that environmental consultants using this manual will have several years of experience with USTs and be familiar with much of this information. The manual is not intended to be an instructional text for those individuals wishing to “learn the business”. For more detailed information, the novice reader should obtain and review the documents in the Reference Section of the manual.

MANUAL ORGANIZATION

The DERR UST Consultant Certification Manual is divided into 9 chapters. Summary information and supporting materials are included in each chapter. Original source materials reproduced in the manual are from the public domain or reproduced with permission of the publisher. Reference for the original source materials are listed at the end of the manual. Rules, guidance documents and some other reference materials are presented as internet links in the following chapters. This will ensure that UST Certified Consultants will have access to the most current and up-to-date information. It is up to the consultant to follow the links and familiarize themselves with the material contained in those links. If links become broken, please notify the DERR.

DEPARTMENT OF ENVIRONMENTAL QUALITY

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Salt Lake City, Utah 84114-4810
(801) 536-4400
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Division	Regulatory Authorities
Division of Air Quality 150 North 1950 West Salt Lake City, Utah 84114-4820 (801) 536-4000	Federal Clean Air Act Utah Air Conservation Act
Division of Drinking Water 150 North 1950 West, 2nd Floor Salt Lake City, Utah 84114-4830 (801) 536-4200	Federal Safe Drinking Water Act Utah Safe Drinking Water Act
Division of Environmental Response & Remediation 168 North 1950 West, 1st Floor Salt Lake City, Utah 84114-4840 (801) 536-4100	CERCLA (Superfund) RCRA Subtitle I SARA Title 3 (Emergency Planning and Community Right to Know Act) Underground Storage Tank Program Voluntary Cleanup Program
Division of Radiation Control 160 North 1950 West, 2nd Floor Salt Lake City, Utah 84114-4850 (801) 536-4250	Federal Atomic Energy Act Utah Radiation Control Act
Division of Solid and Hazardous Waste 288 North 1460 West, Cannon Building Salt Lake City, Utah 84114-4880 (801) 538-6170	RCRA Utah Solid and Hazardous Waste Act Utah Used Oil Management Act Waste Tire Recycling Act
Division of Water Quality 288 North 1460 West, Cannon Building Salt Lake City, Utah 84114-4870 (801) 538-6146	Federal Clean Water Act Utah Water Quality Act

UTAH'S UNDERGROUND STORAGE TANK PROGRAM OVERVIEW

The Utah State Underground Storage Tank program is a regulatory branch of the Department of Environmental Quality (DEQ). Its primary goal is to protect human health and the environment from contamination resulting from leaking underground storage tanks (USTs). The UST staff oversees: UST notification, installation, inspection, removal and compliance with State and Federal UST regulations concerning release prevention and remediation.

What are Underground Storage Tanks?

And UST is a tank system, including piping connected to the tank that has as least 10 percent of its volume underground. Federal and state regulations apply only to those USTs containing petroleum products or certain hazardous chemicals. USTs not regulated include:

- ♦ Farm or residential tanks 1,100 gallons or less, used non-commercially.
- ♦ Tanks storing heating oil used on the premises.
- ♦ Flow-through process tanks.
- ♦ Emergency spill and overflow tanks.
- ♦ Tanks holding 110 gallons or less.
- ♦ Others as described in the Federal Register.

Why Worry About An UST Release?

Utah obtains more than 50% of the population's drinking water from ground water. Currently, there are more than 3000 leaking UST sites in Utah. These sites have resulted in contaminated ground water and in some cases, explosive situations. Many more USTs in Utah could leak or have yet to be discovered in the future, adding to the existing problems.

What Do the UST Regulations Accomplish?

The Environmental Protection Agency (EPA), with the help of the regulated industry, developed regulations concerning UST owners and operators. The goals of these regulations are:

- ♦ To **prevent** leaks and spills.
- ♦ To **find** leaks and spills.
- ♦ To **correct** the problems created by leaks and spills.
- ♦ To ensure the **owners and operators** can pay for clean up associated with leaking USTs.
- ♦ To ensure the **Utah** has a regulatory program that complies with the Federal regulations.

The EPA phased-in many of the requirements over a 10-year period beginning, December 22, 1988. By December 22, 1998, all operating facilities were required to be upgraded with corrosion protection, spill and overfill equipment, and regularly monitored for a release. Non-operational facilities must be properly closed.

For more information regarding the EPA UST regulations, please visit "Frequently Asked question (FAQs)" at EPA's OUST HomePage.

The Utah UST Program

As a result of the federal mandate, the State of Utah amended the Solid and Hazardous Waste Act in 1986, which established the Utah UST Program. UST owners and operators were required to register all USTs. In 1989, the Underground Storage Tank Act was enacted; it details the duties and responsibilities of the Executive Secretary (UST), the Solid and Hazardous Waste Control Board, and the Utah UST Program Authority. The act established the Petroleum Storage Tank (PST) Fund and provides certain requirements for UST owners and operators. A DERR organization chart shows the various groups and individuals within the DERR. The chart is located on the DERR's website: http://www.environmentalresponse.utah.gov/public/orgchart.htm.

EXECUTIVE SECRETARY (UST): The Executive Secretary (UST) is an individual who has the authority to administer the UST Program as established by the Utah Legislature. The Executive Secretary answers to the Utah Solid and Hazardous Waste Control Board, which consists of approximately ten individuals, appointed by the Governor.

THE UST SECTION: the UST Section of the Division of Environmental Response and Remediation (DERR), is a group of environmental scientists whose task it is to oversee the regulated public in issues that concern the operational life of USTs up to proper closing of UST systems. The UST staff has tracked about 15,000 USTs and currently regulates approximately 4,300 USTs at more than 1,500 different facilities. UST staff members perform compliance inspections, issue compliance notices, and serve as expert witnesses at administrative hearings. Outreach classes and seminars are taught through out the state.

THE LUST SECTION: The Leaking Underground Storage Tank (LUST) Section of DERR oversees remediation of contamination from USTs. LUST scientists and engineers review and re-establish clean-up guidelines. When responsible parties are not available or are unable to pay for the remediation of a LUST site, the LUST staff is required to define the degree of hazard, possibly take action with LUST-TRUST money to abate the hazard and remediate the site, and recovery costs incurred from responsible parties. Often, responsible parties seek the guidance of the LUST staff to insure clean up in a timely and economical fashion.

ADMINISTRATIVE SUPPORT SECTION: The Administrative Support Section oversees collection of UST fees and monitors expenditures. Accountants and technicians answer questions concerning billings and distribute funds where appropriate.

CHAPTER 1
Regulations for Certified UST Consultants

1.1 REGULATIONS FOR CERTIFIED UST CONSULTANTS

The United States Environmental Protection Agency (EPA) has estimated that several million underground storage tanks (USTs) contain petroleum or hazardous chemicals. Many of these UST systems are currently leaking or are expected to leak in the future. In 1984 the United States Congress responded to the problem of leaking USTs by adding Subtitle I to the Resource Conservation and Recovery Act (RCRA). Subtitle I required the EPA to develop regulations to protect human health and the environment from leaking USTs. The EPA promulgated UST regulations under Title 40, Code of Federal Regulations (CFR), Parts 280 and 281 (EPA September 23, 1988).

The Utah legislature enacted the Underground Storage Tank Act (UAC 19-6-401 through 429) in 1989, which established the UST program and authorized the Solid and Hazardous Waste Control Board to adopt implementing regulations. The Utah UST program adopted by reference Title 40, CFR, Parts 280 and 281. The USTs regulated under Utah's program are the same as the USTs regulated under Subtitle I of RCRA (Parsons and others, 1993).

The US Environmental Protection Agency has delegated authority to administer the underground storage tank program to the Utah Department of Environmental Quality. Title 40, CFR, Part 282.94 details the approval of State UST Programs and the Utah State Administered Program.

Utah Administrative Code (UAC) R311-200 through 212 are the Administrative Rules for the DERR, specifically relating to the UST program. UAC R311-201-2 requires that persons who provide consulting services regarding USTs, inspect UST systems, test UST systems, conduct groundwater or soil sampling, or install or remove USTs must be certified to do so (DERR, 1999). Consultants who seek certification from Utah must be trained in accordance with the Occupational Safety and Health Administration (OSHA) training in accordance with Title 29, CFR 1910.120 [R311-201-4].

UAC 57-25-101 through 115 is the Uniform Environmental Covenants Act. This Utah law allows a property owner to voluntarily, with the approval of the executive director, restrict the use of the property by imposing environmental institutional controls to mitigate the risk posed to the public health, safety, or welfare, or the environment.

UST Consultants are responsible for knowing the aforementioned rules and regulations. The regulations and the website links where they are available are located in Table 1-1.

Chapter 1
Regulations for Certified UST Consultants

TABLE 1-1 Applicable Regulations for Certified UST Consultants

	Regulation	Location
	Federal Regulations	
1	40 CFR Part 280 Technical Standards and Corrective Action Requirements for Owners and Operators of USTs	http://www.epa.gov/OUST/fedlaws/cfr.htm
2	40 CFR Part 281 Approval of State UST Programs	
3	40 CFR Part 282.94 Approval of State UST Programs, Utah State Administered Program	
4	29 CFR Part 1910.120 Occupational Safety and Health Standards, Hazardous Waste Operations and Emergency Response	http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9765
	Utah State Regulations	
5	UAC 19-6-401 through 429 Utah's Underground Storage Act	http://www.le.state.ut.us/~code/TITLE19/19_06.htm
6	UAC R311-200 through 212 Administrative Rules for the DERR	http://www.rules.utah.gov/publicat/code/r311/r311.htm
7	UAC 57-25-101 through 114 Uniform Environmental Covenants Act	http://www.hazardouswaste.utah.gov/Rules/Adobe/Acts/57-25uniformEnvironmentalCovenantsAct.pdf

CHAPTER 2
Petroleum Storage Tank (PST) Fund

2.1 INTRODUCTION

The State of Utah established the Petroleum Storage Tank (PST) Trust Fund to help underground storage tank (UST) owners, operators, and responsible parties meet federal requirements for financial assurance and to help pay the costs of investigation, abatement, and cleanup of leaking USTs. Specific rules about accessing the PST Fund can be found in the Utah Underground Storage Tank Rules R311-207.

The Petroleum Storage Tank Trust Fund Claims Packet (Jan. 11, 2005) gives information about submitting claims for reimbursement. The packet is located on the DERR's website at: **http://www.undergroundtanks.utah.gov/pst.htm**.

CHAPTER 3
UST/LUST Requirements

3.1 REQUIRED FORMS AND DOCUMENTS

The DERR has developed standardized formats for required forms and written reports. All forms and reports that are submitted to the DERR should follow these formats to expedite the review process. All UST Certified Consultants are required to know the information contained in the referenced material in Table 3-1.

TABLE 3-1
Applicable Documents for Certified UST Consultants

	Name of Document	Location
	UST	
1	Underground Storage Tank Closure Plan	http://www.undergroundtanks.utah.gov/ust_forms.htm
2	Underground Storage Tank Permanent Closure Notice	
3	Notification Form for Underground Storage Tanks, EPA Form 7530-1 (Rev. 11-98)	
	LUST	
4	Leaking Underground Storage Tank (LUST) Subsurface Investigation Report Guide	http://www.undergroundtanks.utah.gov/remediation.htm
5	Leaking Underground Storage Tank (LUST) Corrective Action Plan Guide	
6	Supplemental Information for a Corrective Action Plan for Monitored Natural Attenuation	
7	Leaking Underground Storage Tank (LUST) Risk Assessment Proposal Guide	

CHAPTER 4
Initial LUST Site Abatement Actions

4.1 SPILL AND RELEASE RESPONSE REQUIREMENTS

It is prudent practice for petroleum UST owners/operators to develop a plan to respond to a surface spill. Before an emergency occurs, the owner/operator should establish a relationship with an emergency responder company in the local area of the USTs. A Spill Response Resource List can be found on the DERR's website at: **http://www.superfund.utah.gov/spills.htm**. The list contains spill responders known in the Utah area, the types of services they offer in responding to petroleum spills, and the geographic area that they service. The responsible party and the UST Consultant should verify the capabilities listed for any of the companies listed.

The DEQ must be notified within 24 hours of a discovery of most releases of petroleum into the environment. Releases are reportable if:

- The release is not cleaned up within 24 hours;
- The release is greater than 25 gallons; or
- The release affects waters of the state.

4.2 ABATEMENT REQUIREMENTS

4.2.1 Free Product Removal

Free-phase hydrocarbons, also referred to as free product or LNAPL, may be encountered during an initial abatement action or emergency response to a known petroleum spill or release. Reporting and removal of free product are important steps early in the process of containment of petroleum product. Quick action can reduce the amount and duration of long-term cleanup from even more difficult conditions if the free product is allowed to smear through the soil and groundwater.

A common type of product removal system used in initial abatement actions is product skimming. The reason skimming is used in this application is that it is easy to use in trenches, excavations (such as an UST excavation), or wells (2-inch diameter or greater); no groundwater is produced; capital costs are low to medium; and operations and maintenance costs are low. However, skimming is limited because of the small volumes that are recovered and the limited area of influence.

Skimming may be used in an initial response, especially for shallow releases, and then be replaced by a more aggressive method later in the cleanup process. Skimming may also be used where long-term hydraulic control of the dissolved plume is not required, as skimming will not typically control the liquid hydrocarbon plume. Skimming may be used where a small amount of petroleum is lost and exists in permeable material that acts as conduits for recovery. To be

CHAPTER 4
Initial LUST Site Abatement Actions

effective, hydraulic conductivity of the material should be greater than 10^{-4} centimeters per second to ensure sufficient influx to the skimmer.

The selection of skimming equipment depends upon the size of the recovery installation and the expected rate of recovery of free product. Passive skimming equipment includes bailers, filter canisters, and absorbent materials. Expect a lower rate of recovery and smaller area of influence. Active mechanical skimming equipment includes floating skimmers, pneumatic pumps, and belt skimmers. Active skimming will speed the rate of recovery and increase the area of influence. In either case, disposal of free product and/or the absorbent materials will require disposal. A more complete description of free-product recovery methods is included in EPA's *How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites* (1996), which can be found on the EPA's website at: **http://www.epa.gov/OUST/pubs/fprg.htm**.

Utah's reporting requirements for free product removal are adopted by reference from Title 40 CFR 280.64, which is located at the EPA's website at: **http://www.epa.gov/swerust1/fedlaws/cfr.htm#ustform**. A summary of the reporting requirements for free product removal is also located in the Leaking Underground Storage Tank (LUST) Corrective Action Plan Guide referenced in Chapter 3.

4.2.2 Excavation Dewatering and Vacuum Trucks

Free product recovery may be utilized in open excavations, such as following a UST removal. Excavations should be managed according to OSHA guidelines. Free product can be removed from an open excavation using skimmers, pumps, or vacuum trucks. The advantages to using vacuum trucks is that the implementation is quick and simple and no additional water storage tank is required. The vacuum truck can remove a mixture of water and free product and handle the disposal as one waste stream that often can be recycled.

4.2.3 Vapors in Utilities, Basements, and Buildings

The risk of vapors in utilities, utility conduits, basements, and buildings should be considered during an immediate abatement action. Monitoring for vapors or free product in utility conduits may be accomplished by lowering a vapor meter into a manhole or by a utility company lowering remotely operated television camera into their sewer line, for example. Air samples may also be collected from manholes or structures for laboratory analysis and characterization of the vapors present.

Once petroleum hydrocarbon vapors are positively detected, the explosive limits of the petroleum compounds should be considered. Ventilation using intrinsically safe blowers can assist in removing vapors present at toxic or explosive levels.

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Initial LUST Site Abatement Actions

4.2.4 Contaminated Soil Excavation and Aeration

Excavation of contaminated soil may be appropriate for smaller abatement actions or for excavation during a UST removal operation. The DERR Guidelines for the Disposition and Treatment of Petroleum Contaminated Soils are found on the DERR's website at: **http://www.undergroundtanks.utah.gov/remediation.htm**. The policy statement describes general management practices and the process to use soil aeration as an option for petroleum-contaminated soil management. Soil Aeration is also discussed in Chapter 9.

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Site Safety

5.1 GENERAL SITE HEALTH AND SAFETY

Health and safety on a LUST site is of paramount importance for numerous reasons including:

- Prevents of work-related injuries, illnesses, and property damage.
- Prevents of exposure of the public to harmful substances.
- Increases overall productivity and maintains project schedules.

Petroleum products are toxic, carcinogenic and flammable. Therefore, these products should be handled with a great deal of care. Petroleum products can enter the body through the typical four routes of exposure:

- Inhalation
- Skin or eye absorption
- Injection
- Ingestion

Maintaining a safe work environment is essential whether the tasks be soil and groundwater sampling, UST removal, or remediation. All tasks need to be assessed in light of the degree of potential hazard and the possible routes of exposure. This hazard assessment should form the basis of the health and safety plan to be discussed later.

Whereas petroleum products may pose a significant health hazard due to chronic health effects, the general safety hazards associated with LUST sites frequently pose much greater risk of acute health effects.

5.2 HEALTH AND SAFETY REGULATIONS

It is important to realize that LUST work is covered by various regulations at the federal level, including the OSHA Hazardous Waste Site Operations and Emergency Response (HAZWOPER) Standard, 29 CFR 1910.120. The work may also be covered by various state and local regulations. These regulations may be triggered depending upon the degree of hazard posed, for example if the UST leaked and there is a significant exposure to airborne contaminants, respiratory protection may be required.

Exposure to airborne contaminants is covered by the OSHA Respiratory Protection Standard, 29 CFR 1910.134. If entry into a tank is required, or if the excavation is considered a confined space, the work may be covered by the OSHA Confined Space Entry Standard, 29 CFR 1910.146. Most standards require that the employer:

- Develop a written program to address the hazards in a general manner as part of an employer program, and also site-specific procedures.

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- Conduct a hazard assessment to identify the site-specific hazards and then respond to them appropriately.
- Provide employee training.
- Provide appropriate personal protective equipment.
- Establish emergency response procedures.

The employer should search the OSHA Web Page at: **http://www.OSHA.gov** for guidance on these and other subjects, including specific applicability of the requirements listed below.

5.3 SPECIFIC HEALTH AND SAFETY REQUIREMENTS

The following section describes how to reduce the hazards on an UST site. These are also issues that are covered as requirements under the OSHA HAZWOPER Standard, 29 CFR 1910.120.

5.3.1 Training

Employees can not be expected to perform site work properly if they are not properly trained. The HAZWOPER standard requires employers to provide 40 hours of hazard training at the time of initial assignment, 8 hours of refresher training annually, and a minimum of 3 days actual field experience under the direct supervision of a trained, experienced supervisor [29 CFR 1910.120 (e)(3) and (4)(i)]. This training must cover items such as:

- Components of the Standard
- Medical surveillance
- Hazard assessment
- Personal protective equipment
- Site control
- Site characterization
- Air quality monitoring
- Excavation and trenching
- Hazard communication
- Decontamination
- Drum handling
- Illumination
- Emergency response procedures

This training must then be supplemented by site-specific training at the time of assignment to a project. This is essential to provide employees with the actual hazards to be encountered and the exposure control strategies to be followed.

Although the content of the annual refresher training can vary, it should provide a meaningful update of the initial training. Items that might be included:

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- OSHA news.
- The previous year's injuries and illnesses and steps taken to minimize recurrence.
- Changes in monitoring equipment.
- Review of hazard assessment.
- Addressing contractor issues.

Additional initial training is required for employees who may perform management or supervisory roles, or emergency response activities. The supervisory worker must attend at least 8 additional hours of specialized training at the time of job assignment. [29 CFR 1910.120(e)(4)]. Emergency response workers shall be trained in how to respond to expected emergencies [29 CFR 1910.120(e)(7)].

5.3.2 Medical Surveillance

The HAZWOPER Standard requires that certain categories of employees receive physical examinations at a minimum of three milestones: at initial assignment, annually (unless an occupational physician working closely with the company believes that the physical examination could be performed every other year and still sufficiently monitor employee health status), and at termination. The physical examination must be at no cost to the employee.

Firms should work closely with an occupational physician that understands the firm's area of work and the hazards that employees are likely to face. The physical examination should then be tailored to address those exposures. If the firm's work involves potential silica exposure such as during drilling, then a chest X-ray should be included. Other items to be considered include spirometry for lung function, blood tests, urine screening, hearing testing, and perhaps drug and alcohol screening, as may be required by the US Department of Transportation. Other tests for "wellness" such as cholesterol may be also included by conscientious employers.

There are basically three determinations the physician may provide to the employer: pass, fail, or pass with limitations. As the responses imply, a “pass” response means that the employee may perform the work outlined by the employer to the physician without limitations on activity. A “fail” response indicates that the employee's condition does not allow him/her to perform the assigned duties. “Pass with limitation(s)” indicates that the physician believes that the employee's duties should be limited in some way. It is essential that the employer understand these limitations to be sure that the employee is not directed to overstep these limitations (or overstep them on his or her own). Other professionals such as safety or industrial hygienists may need to be involved in determining permissible activities. Of course, employee relations or human resources professionals may also need to be involved to ensure that the employee's rights are not compromised.

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5.4 UST SITE HEALTH AND SAFETY PLAN

The HAZWOPER Standard requires employers working on sites with hazardous substances and wastes to develop site-specific health and safety plans (HASPs). The HASP is composed of various sections that outline the work and address the associated hazards.

The following paragraphs briefly explain the sections of the HASP. An UST HASP should include a discussion of the following topics:

5.4.1 General Information

General Information should include the name and location of the facility, work plan objectives, and proposed date(s) of work. This section lists the names of all the main project participants. This is a most important reference page in times of emergency as well as during routine business.

5.4.2 Planned Site Activities

A brief description of planned activities should be included in this section. The HASP should be revised if significant changes in these activities occur. In this section the general scope of work should be briefly described. This should explain the purpose of the work. The tasks to be performed during the work should be listed in the order in which they will occur. This section forms the basis of the hazard assessment. Next to each task, list the hazard and proposed means of avoiding the hazard. This section should be expanded if needed. Site workers should be aware of the possible dangers associated with drilling, excavation, free-product recovery, and groundwater sampling.

5.4.3 Contaminant Characteristics

List contaminants of concern, type of contaminant, physical and chemical properties, and the hazards it poses to human health and the environment. It is important to consider contaminants that might be emitted by facilities adjacent to the work site. Previous sampling media, *e.g.*, soil, groundwater, air, and the results should be noted.

5.4.4 Site Description

A site description should include the current and historical use of the site and surrounding area. In this section, issues adjacent to the work site should be described. Keep in mind that these aspects may not only be influenced by the work on the work site, they may also influence the work site. The sites that could be impacted by the work site include receptors, such as neighborhoods, schools, lakes, etc. Potential sources, such as adjacent factories or leaking tanks from other sites might impact the work site. These should not be overlooked because they may influence the ambient conditions being monitored on the work site.

5.4.5 Hazard Evaluation and Mitigation

This section should include a listing of known visible hazards, man-made or natural, and any unseen-but-suspected hazards. Site workers should be aware of the possible dangers associated with LNAPL recovery and groundwater sampling. All aspects of hazard mitigation pertinent to the site should be addressed. These may include fire and personal exposure to petroleum hydrocarbons or other organic vapors; heat and cold stress, noise, and heavy equipment use. As noted earlier, these hazards may pose the greatest hazards to workers on the site. They should be very carefully considered and precautions to be taken should be described. This section should be expanded as necessary. Also include fire suppression procedures.

5.4.6 Site Safety Work Plan

The site safety work plan should include a discussion of general safety, worker training, and medical surveillance requirements, and relevant documentation.

5.4.7 Excavations and Trenching

Excavation and trenching are integral to much of the UST work. Excavations and trenches can pose confined space and fall hazards. Confined space and fall restraint procedures should be included. Shoring regulations must also be addressed to avoid collapsing of the sides. Shoring should be considered even when individuals will not enter the excavation. Depending upon the types of soils, sidewalls can collapse at distances of 5 to 10 feet or more from the edge of the excavation. Competent persons must design shoring plans and in some jurisdictions these plans must be approved and stamped by licensed Professional Engineers. The OSHA informational booklet entitled Excavations, OSHA Publication 2226, (2002), explains ways to protect workers from excavation hazards. The publication on excavations can be located on OSHA's website at: http://www.osha.gov/Publications/OSHA2226/2226.html.

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5.4.8 Personal Protection Equipment

A listing and description of the personal level of protection required for each activity or work. The level and types of personal protective equipment (PPE) which will be used to address personal exposures must be described. This section should be specific with respect to makes and model numbers of PPE should be included in this section. A change in on-site conditions may also dictate a change in PPE.

5.4.9 Monitoring/Surveillance Equipment

This section should include a listing of all monitoring and surveillance equipment to be used at the site with a discussion of exposure and explosive concerns. This portion of the plan should explain how airborne contaminants will be monitored at the site. There are a number of aspects to be considered when developing the air monitoring plan. These include:

- Employee exposures within the work (exclusion) zone.
- Potential contaminants leaving the exclusion zone or site that could impact adjacent sites.
- Airborne contaminants that might enter the site from adjacent facilities.
- Note recognized exposure limits and action levels. Describe what will happen if either the action level or exposure limits are surpassed, *e.g.*, upgrade PPE, evacuate the site, notify regulators, etc.
- The types of instruments that will be used and their limitations.
- Confined space monitoring issues, if applicable.
- Note also the measurement of percent lower explosive limit (LEL) to avoid fire hazards.

5.4.10 Decontamination

Personnel and equipment decontamination procedures should be addressed in this section. For site personnel, contamination-reduction phases and personal hygiene for site operations, cleanup operations, and soil/groundwater sampling operations would be needed. Decontamination procedures for equipment used during well installation, tank removal, and groundwater sampling should also be addressed. Equipment as well as personnel decontamination should be explained in detail in a stepwise fashion. Do not overlook equipment used to conduct air sampling, or clean-up activities. Also note the presence of personal hygiene facilities.

5.4.11 Safety Equipment Checklist

This section should include a listing of all personal protection, monitoring and surveillance, and decontamination equipment to be used at the site. Any other miscellaneous equipment that may be needed and used on site should also be listed.

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5.4.12 Site Safety Briefing Attendance Sheet

This section will document the personnel assigned to be on site and personnel from agencies, utilities, or other companies who have read, reviewed, or attended the on-site safety briefing. The sheet should include the date and time of the briefing and the individual conducting the meeting, and the name and company of each attendee. All subcontractors and clients involved in the operation should be included. It is helpful to obtain and include cellular phone numbers as well as traditional telephone numbers. Documentation of proper training and medical surveillance should also be obtained.

5.4.13 Investigation-Derived Waste Disposal

This section should discuss the disposal procedures for all drill cuttings, soil, wastewater, and disposable protective clothing generated during site operations. It would also be appropriate to describe the disposition of decontamination water and any other special concerns. This section must describe the types of waste expected to be generated from the site work, be they solid or liquid. Note the types of containers to be used. It would be appropriate to list the waste haulers and facilities to which the waste will be sent. Temporary staging areas and precautions can also be included in this section.

5.4.14 Emergency Information

Emergency information should include applicable phone numbers, names, and addresses of local and emergency resources; and emergency contacts including CHEMTREC, National Response Center, and RCRA Hotline. Any work limitations and required notification should also be discussed.

5.4.15 Evacuation/Emergency Response Plan

This section should be clearly labeled to allow for quick reference in the event of an emergency. One should be very clear about how evacuation would take place. Written as well as pictorial directions must be included. These directions must be tested prior to starting the project to be sure they "work." The locations of hospitals, shelters, and barriers to evacuation such as fences, security stops, one-way streets all should be shown and discussed in the HASP.

5.4.16 Attachments

The health and safety plan should include a map to the nearest medical facility. Forms and other relevant information should be attached to the HASP. This may include material safety data sheets (MSDSs), injury investigation, air and groundwater sampling forms, site audit checklists, site equipment checklists, daily safety meeting agenda and minutes forms, etc.

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5.5 SAFETY MEETINGS

Several meetings should be planned to discuss safety. These need not necessarily be stand-alone meetings. These may be incorporated into other job meetings. In fact, this is encouraged so that workers see safety as an integral part of production and not something extra to be discussed if there is time. These meetings are described below:

5.5.1 Pre-Start-up Meeting

This meeting should be used to discuss all aspects of the project well in advance of the start. This allows time for details to be worked out and additional safety equipment to be obtained if necessary. Special attention should be given to working out the personnel who will be responsible for enforcing safety and attending to health and safety issues at the site. Make note of who will be contacted in the event of an emergency.

5.5.2 Start-up Meeting

This meeting, often held on the day the job starts or day before, discusses the final safety staff and contacts, describes the emergency response procedures, lays out the PPE, air monitoring and other relevant issues.

5.5.3 Daily Meetings

A safety meeting should be held at the beginning of every day the project continues. The scope of the day's work should be described along with the associated hazards and safety precautions. This offers workers the opportunity to ask questions before proceeding with work.

5.5.4 Project Close-Out Meeting

Projects that last several weeks should have a project close-out meeting to discuss issues that have occurred during the course of the job. This meeting gives participants the opportunity to discuss how to improve safety and general work performance on future jobs.

5.6 INCIDENT INVESTIGATION

All companies should have a program to avoid work-related injuries and illnesses. This program should include the writing of standard operating procedures and job safety analyses. These documents should be used as training tools to teach employees the hazards of doing work and how to avoid them. Employees should be encouraged by training to stop before they begin each task in the field and consider potential hazards and how to avoid them. Companies should investigate "near misses" with the same intensity as actual incidents because the next time the "near miss" might in fact be an incident. This approach tends to improve procedures and practices so that "near misses" are prevented. If all "near misses" were eliminated, then actual incidents would be all but avoided in their entirety.

In the event of an incident, whether property damage or personal injury, the investigation must focus on establishing the route cause of the incident. It should not focus on placing blame as this is usually an ineffective means of avoiding similar incidents in the future. Nearly all incidents occur as a result of insufficient training, tools, time management, motivation, or in rare situations, acts of nature.

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Requirements and format guidelines for Subsurface Investigation Reports are presented in the *LUST Subsurface Investigation Report Guide* (Chapter 3). In accordance with Utah UST Rule R311-201-2 (Chapter 1), leaking underground storage tank (LUST)-related work must be overseen by a Utah-Certified UST Consultant in the event the owner/operator does not conduct and manage the investigative and cleanup work in house. Soil and groundwater sampling must be performed by a Utah-Certified Groundwater and Soil Sampler.

6.1 EXPEDITED SITE ASSESSMENT

An expedited site assessment (ESA) is a process of rapidly delineating the extent of soil and groundwater contamination, determining potential exposure pathways, and identifying potential receptors at LUST sites. An ESA utilizes rapid soil sampling methods (direct-push hydraulic borehole rigs), installation of small diameter groundwater monitoring wells (1 to 2 inch diameter), on-site surveying and determination of groundwater flow direction, field analytical methods (mobile laboratories), and on-site decision-making by experienced personnel. The goal of an ESA is to complete a subsurface investigation in one mobilization.

Conventional site assessment processes can involve several mobilizations because decisions regarding the placement of additional soil boreholes or monitor wells are usually made back in the office following data evaluation. The field work is usually conducted by less experienced field technicians who collect samples for off-site laboratory analysis.

For more detailed information on ESAs, the reader should review the U.S. EPA's guidance document entitled *Expedited Site Assessment Tools For Underground Storage Tank Sites* (EPA, 1997).

6.2 BACKGROUND RESEARCH

Before conducting a subsurface investigation at a LUST site, background research on the current and historical uses of the site and surrounding area should be performed. The following examples illustrate the usefulness of this information.

- Review DERR Interactive Map to find information on other LUST sites within the vicinity of the subject LUST site. These files can provide information on soil types, depth to groundwater, and groundwater flow direction. This information can be used to determine the type of drilling rig to use and how deep monitor wells must be installed.

- Review Utah Division of Water Rights (DWR) records. These records can provide information on the presence of municipal, domestic, irrigation, and other types of water wells in the area. In some cases, geologic borehole logs and well construction information are available online as well.

- Review historical aerial photographs. This information can be used to determine past uses of the site and surrounding area. For example, aerial photographs can be used to determine if other USTs are/were located on the site.

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6.3 SITE RECONNAISSANCE

Prior to performing a subsurface investigation, a reconnaissance of the site and surrounding area should be conducted. Information to be obtained includes:

- The locations of all USTs, product piping, and pump islands.
- The locations of all other potential sources of environmental contamination, such as septic tanks, leach fields, and floor drains.
- The locations of all wells on site or in the vicinity of the site. Verify the presence and use of all wells identified by the DWR records search.
- The locations of overhead and underground utilities for drilling safety purposes and potential contaminant transport. "Blue Stakes" can be called to mark out the site prior to your site visit (Chapter 9).
- The locations and addresses of businesses and property owners in the vicinity for access agreements and potential environmental concerns.
- Photographs of the site and vicinity.

Using the information collected during the site reconnaissance, prepare scaled site and vicinity maps.

6.4 SUBSURFACE INVESTIGATION

The following sections describe several types of techniques used for traditional and expedited subsurface investigations.

6.5 SOIL AND GROUNDWATER SAMPLING

The following section describes the various types and locations of soil and groundwater samples collected at UST sites in Utah.

6.5.1 Sample Types

Utah UST regulations require that the following types of samples be collected at UST closure:

- Environmental samples: Soil and groundwater samples collected for laboratory analysis for petroleum hydrocarbon compounds by a Utah-certified analytical laboratory. Soil and water samples must be discrete, not composites.

- Unified Soil Classification System (USCS) samples: Soil samples analyzed for soil type. USCS samples may be described by a qualified geologist in the field or analyzed by a Utah-certified analytical laboratory or a geotechnical laboratory. Information on field soil classification is included in the section below on Soil Classification.

- Environmental confirmation samples are collected during an UST closure if overexcavation has removed additional soil past the location of the closure samples. USCS samples are not required during this and later phases, if USCS samples were collected during UST closure. However, detailed descriptions of subsurface lithology are required during the subsurface investigation phase in order to determine contaminant migration potential and select a remediation methodology.

Requirements for sampling of soil and groundwater at UST closures are detailed in Utah Underground Storage Tank Rule R311-205-2(b). The UST Rules are referenced in Chapter 1.

6.5.2 Subsurface Investigation Sampling

Soil boreholes and monitoring wells are installed as part of a subsurface investigation at a LUST site to delineate the lateral and vertical extent of contamination. Decisions regarding the number and locations of soil boreholes and monitoring wells should be made in consultation with the DERR Project Manager. For example, at some sites three or four soil boreholes may be enough to delineate the extent of contamination. At other sites a dozen or more soil boreholes may be needed. A minimum of one soil sample should be analyzed from each soil borehole, regardless of the depth of the borehole.

Several soil samples should be analyzed from deep soil boreholes. A sufficient number of soil samples from each soil borehole should be analyzed to determine the vertical extent of contamination in the borehole and document the lithology. It may be necessary to collect soil samples below the water table to fully delineate the vertical extent of contamination.

Instruments with photoionization and flame-ionization detectors (PID/FID) are commonly used in the field to monitor ambient air for the protection of worker health and qualitatively determine relative volatile petroleum hydrocarbon vapor concentrations in soil samples. These instruments are used to screen soil samples to determine which samples to analyze in an off-site Utah-certified analytical laboratory.

Groundwater monitoring wells are required at sites where groundwater is encountered. A minimum of three groundwater monitoring wells are necessary to determine the groundwater flow direction and gradient. In practice, more than three wells are typically necessary so that at least one monitoring well is located directly downgradient of the source of the contamination. A downgradient monitoring well is required to determine if contamination has migrated off site. Conversely, an upgradient well is useful to determine if contamination is migrating onto the site from an off-site source.

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6.5.3 Corrective Action Confirmation Samples

Corrective action confirmation samples are environmental samples that are collected to demonstrate that cleanup goals have been achieved after corrective action at site is complete. The number and locations of samples should be determined in consultation with the DERR Project Manager.

For example:

- Soil samples should be collected and analyzed from each sidewall and the bottom of an excavation pit after overexcavation of contaminated soil is complete.

- Groundwater samples should be collected from each monitoring well at a site after groundwater remediation is complete.

- Post remedial soil confirmation samples must indicate that contaminant concentrations in soil meet cleanup goals following in-situ remediation as well. These soil samples should be collected from each location where cleanup standards were exceeded during site investigation.

6.5.4 Soil Classification

In general, soil classification systems are used to describe soil particle-size distribution, or texture that affects hydrologic, engineering, and contaminant transport characteristics of the soil. The most common classification system utilized in classifying soils using their engineering properties is the USCS. Other classification systems not described in this manual may be better suited to interpret depositional environments and hydrologic and contaminant transport properties.

The American Society for Testing and Materials (ASTM) has developed a Standard Practice for Description and Identification of Soil (Visual-Manual Procedure) D2488-93, which describes the description of soils for engineering purposes using the USCS. Relative proportions of grain size are estimated either in the laboratory or field. The USCS also incorporates other soil properties such as plasticity, liquid limit, clod strength, dilatancy, toughness, and stickiness for classification.

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6.6 DRILLING AND SOIL SAMPLING METHODS

6.6.1 Drilling

Most subsurface investigations require the drilling of boreholes for one or more purposes: 1) collection of solids samples or cores for stratigraphic logging and laboratory testing, 2) stratigraphic and hydrogeologic characterization using borehole geophysical logging, and 3) installation of piezometers or monitoring wells. Drilling methods are selected based upon: 1) availability and cost, 2) suitability for the type of geologic materials at a site (unconsolidated or consolidated), and 3) potential effects on sample integrity (influence by drilling fluids and potential for cross contamination between aquifers).

A wide variety of drilling methods have been developed that could be suitable for one or more of the purposes described above. The hollow-stem auger is by far the most commonly used method for well installation in consolidated formations. Where cross contamination between aquifers is a concern, some kind of casing advancement method is required, with drill-through methods and dual-wall reverse circulation being the most commonly used.

This section that follows is a detailed description of direct push, not strictly a drilling method, excerpted from *Expedited Site Assessment Tools for Underground Storage Tank Sites* (EPA, 1997). This technology has been developed primarily in relation to geotechnical investigations, but is being used much more frequently for subsurface investigations at contaminated sites, especially in Utah.

6.7 DIRECT PUSH TECHNOLOGIES

Direct push (DP) technology (also known as “direct drive,” “drive point,” or “push” technology) refers to a growing family of tools used for performing subsurface investigations by driving, pushing, and/or vibrating small-diameter hollow steel rods into the ground. By attaching sampling tools to the end of the steel rods they can be used to collect soil, soil-gas, and groundwater samples. DP rods can also be equipped with probes that provide continuous *in situ* measurements of subsurface properties (*e.g.*, stratigraphy, contaminant distribution). DP equipment can be advanced with various methods ranging from 30 pound manual hammers to trucks weighing 60 tons.

DP technology has developed in response to a growing need to assess contaminated sites more completely and more quickly than is possible with conventional methods. As explained in Chapter 2, The Expedited Site Assessment Process, conventional assessments have relied heavily on traditional drilling methods, primarily hollow stem augers (HSA), to collect soil and groundwater samples and install permanent monitoring wells. Because installing permanent monitoring wells with HSA is a relatively slow process that provides a limited number of samples for analysis, the most economical use for the equipment is to perform site assessments in phases with rigid work plans and offsite analysis of samples.

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With the development of DP technologies, large, permanent monitoring wells are no longer the only method for collecting groundwater samples or characterizing a site. Multiple soil, soil-gas, and groundwater samples can now be collected rapidly, allowing high data quality analytical methods to be used on-site, economically. As a result, DP technologies have played a major role in the development of expedited site assessments (ESAs).

DP technologies are most applicable in unconsolidated sediments, typically to depths less than 100 feet. In addition to being used to collect samples from various media, they can also be used to install small-diameter (*i.e.*, less than 2 inches) temporary or permanent monitoring wells and small-diameter piezometers (used for measuring groundwater gradients). They have also been used in the installation of remediation equipment such as soil vapor extraction wells and air sparging injection points. Penetration is limited in semiconsolidated sediments and is generally not possible in consolidated formations, although highly weathered bedrock (*i.e.*, saprolite) is an exception for some equipment. DP equipment may also be limited in unconsolidated sediments with high percentages of gravels and cobbles. As a result, other drilling methods are necessary in site assessment and remediation activities where geological conditions are unfavorable for DP technologies or where larger diameter (*i.e.*, greater than 2 inches) wells are needed.

An additional benefit of DP technologies is that they produce a minimal amount of waste material because very little soil is removed as the probe rods advance and retract. Although this feature may result in some soil compaction that could reduce the hydraulic conductivity of silts and clays, methods exist for minimizing resulting problems.

In contrast, although most other drilling methods remove soil from the hole, resulting in less compaction, conventional drilling methods create a significant amount of contaminated cuttings and they also smear clay and silt across more permeable formations which can obscure their true nature. Moreover, these other drilling methods have the potential of causing a redistribution of contamination as residual and free product are brought to the surface.

Choosing a DP method (or combination of DP methods) appropriate for a specific site requires a clear understanding of data collection goals because many tools are designed for only one specific purpose (*e.g.*, collection of groundwater samples). This chapter contains descriptions of the operation of specific DP systems and tools, highlighting their main advantages and limitations; its purpose is to assist regulators in evaluating the appropriateness of these systems and tools.

This chapter does not contain discussions of specific tools manufactured by specific companies because equipment is evolving rapidly. Not only are unique tools being invented, but existing equipment is being used in creative ways to meet the needs of specific site conditions. As a result, the distinctions between types of DP equipment is becoming blurred and it is necessary to focus on component groups rather than entire DP systems. The four component groups discussed in this chapter include:

- Rod systems;
- Sampling tools;
- *In situ* measurements using specialized probes; and
- Equipment for advancing DP rods.

The chapter also includes a discussion of methods for sealing DP holes because of their importance in preventing the spread of contaminants and, therefore, in the selection of DP equipment. The cost of various DP equipment is not discussed in this chapter because cost estimates become quickly outdated due to rapid changes in the industry. An overview of the advantages and limitations of DP equipment and systems discussed in this chapter are presented in Exhibit V-1.

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Exhibit V-1
Overview of Direct Push Technologies

Direct Push Component	Example	Advantages	Limitations
Probing Systems	Single-rod or cases	Minimizes the waste disposal or treatment	Compaction of sediments may decrease hydraulic conductivity
Soil, Soil-gas and groundwater sampling	Piston samplers, expendable tip samplers	Relatively rapid	Permanent monitoring wells are limited to 2 inch diameter or less
In situ measurement of subsurface conditions	Conductivity probes, laser induced fluorescence	Can be used to rapidly log site	Correlation with boring logs is necessary
Methods for advancing probe rods	Percussion hammers, hydraulic presses	Some methods are extremely portable	Very dense, consolidated formations are generally impenetrable
Sealing Methods	Re-entry grouting, retraction grouting	Holes can be sealed so that contaminants cannot preferentially migrate through them	Appropriate sealing methods may limit sampling equipment options

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6.8 DIRECT PUSH ROD SYSTEMS

DP systems use hollow steel rods to advance a probe or sampling tool. The rods are typically 3-feet long and have male threads on one end and female threads on the other. As the DP rods are pushed, hammered, and/or vibrated into the ground, new sections are added until the target depth has been reached, or until the equipment is unable to advance (*i.e*., refusal). There are two types of rod systems, single-rod and cased. Both systems allow for the collection of soil, soilgas, and groundwater samples. Exhibit V-2 presents a schematic drawing of single-rod and cased DP rod systems.

6.8.1 Single-Rod Systems

Single-rod systems are the most common types of rods used in DP equipment. They use only a single string (*i.e.*, sequence) of rods to connect the probe or sampling tool to the rig. Once a sample has been collected, the entire string of rods must usually be removed from the probe hole. Collection of samples at greater depths may require re-entering the probe hole with an empty sampler and repeating the process. The diameter of the rods is typically around 1 inch, but it can range from 0.5 to 2.125 inches.

6.8.2 Cased Systems

Cased systems, which are also called dual-tube systems, advance two sections--an outer tube, or casing, and a separate inner sampling rod. The outer casing can be advanced simultaneously with, or immediately after, the inner rods. Samples can, therefore, be collected without removing the entire string of rods from the ground. Because two tubes are advanced, outer tube diameters are relatively large, typically 2.4 inches, but they can range between 1.25 and 4.2 inches.

6.9 DISCUSSION AND RECOMMENDATIONS

Single-rod and cased systems have overlapping applications; they can be used in many of the same environments. However, when compared with cased systems, single-rod systems are easier to use and are capable of collecting soil, soil-gas, or groundwater samples more rapidly when only one sample is retrieved. They are particularly useful at sites where the stratigraphy is either relatively homogeneous or well delineated.

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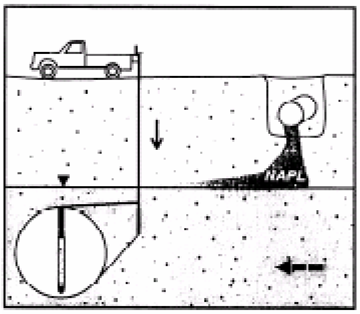
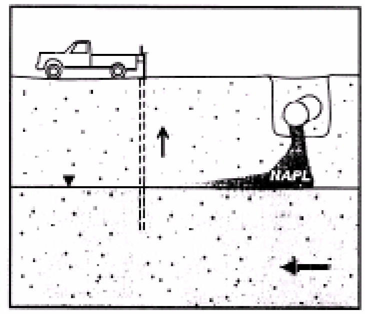
Exhibit V-2
Schematic Drawing of Single And Cased Direct Push Rod Systems

Single Rod Direct Push System

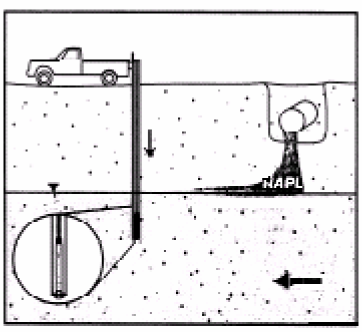


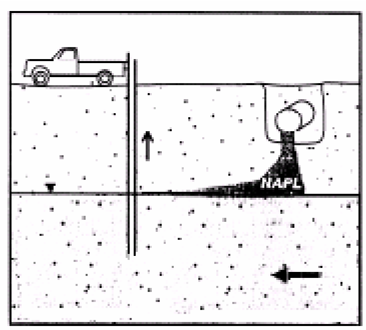


1) DP sampling tool is advanced on the end of a single sequence of rods.

2) Once the sampling tool is full, tool and rods are withdrawn from the ground. To collect another sample, the tool must be re-inserted and pushed to the next sampling depth.

Cased Direct Push System





1) DP sampling tool is attached to inner rods. Sampling tool, inner rods, and outer drive casing are advanced simultaneously.

2) To collect the sample, only the sampling tool and inner rods are removed. The outer drive casing remains in the ground to prevent sloughing or hole collapse. To collect a deeper sample, the tool and inner rods are re-inserted to the bottom of probe hole and advance along with the outer drive casing. The outer casing is removed only after the last sample has been collected.

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The primary advantage of cased DP systems is that the outer casing prevents the probe hole from collapsing and sloughing during sampling. This feature allows for the collection of continuous soil samples that do not contain any slough, thereby preventing sample contamination. Because only the inner sample barrel is removed, and not the entire rod string, cased systems are faster than single-rod systems for continuous sampling at depths below 10 feet. The collection of continuous samples is especially important at geologically heterogeneous sites where direct visual observation of lithology is necessary to ensure that small-scale features such as sand stringers in aquitards or thin zones of non-aqueous-phase liquids (NAPLs) are not missed.

Another advantage of cased systems is that they allow sampling of groundwater after the zone of saturation has been identified. This feature allows investigators to identify soils with relatively high hydraulic conductivities from which to take groundwater samples. If only soils with low hydraulic conductivity are present, investigators may choose to take a soil sample and/or install a monitoring well. With most single-rod systems, groundwater samples must be taken without prior knowledge of the type of soil present. (Some exposed-screen samplers used with single-rod systems as described in the *Groundwater Sampling Tools* section are an exception.)

A major drawback of single-rod systems is that they can be slow when multiple entries into the probe hole are necessary, such as when collecting continuous soil samples. In addition, in non-cohesive formations (*i.e.*, loose sands), sections of the probe hole may collapse, particularly in the zone of saturation, enabling contaminated soil present to reach depths that may be otherwise uncontaminated. Sloughing soils may, therefore, contaminate the sample. This contamination can be minimized through the use of sealed soil sampling tools (*i.e.*, piston samplers, which are discussed in more detail in the *Soil Sampling Tools* section that follows).

Multiple entries made with single-rod systems into the same hole should be avoided when NAPLs are present because contaminants could flow through the open hole after the probe rods have been removed; particularly if dense-nonaqueous phase liquids (DNAPLs) are present. In addition, multiple entries into the probe hole may result in the ineffective sealing of holes. (These issues are discussed in more detail in *Methods For Sealing Direct Push Holes* at the end of the chapter.) If samples need to be taken at different depths in zones of significant NAPL contamination, single-rod systems can be used, but new entries into soil should be made next to previous holes.

The major drawback of cased systems is that they are more complex and difficult to use than single-rod systems. In addition, because they require larger diameter probe rods, cased systems require heavier DP rigs, larger percussion hammers, and/or vibratory systems for advancing the probe rod. Furthermore, even with the additional equipment, penetration depths are often not as great as are possible with single-rod systems and sampling rates are slower when single, discrete samples are collected. Exhibit V-3 summarizes the comparison of single and cased systems.

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Exhibit V-3

Comparison Of Single-Rod And Cased Systems

	Single-Rod	**Cased**
Allows collection of a single soil, soil-gas, or groundwater sample	✓ (faster)	✓
Allows collection of continuous soil samples	✓[1]	✓[2] (faster)
Allows collection of groundwater sampling after determining ideal sampling zone[3]		✓
Lighter carrier vehicles can be used to advance rods	✓	
Greater penetration depths	✓	
Multiple soil samples can be collected when NAPLs are present		✓

[1]Sloughed soil may also be collected.
[2]Faster at depths below approximately 10 feet.
[3]Some exposed-screen samplers, discussed in the groundwater sampling section, also have this ability.

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6.10 DIRECT PUSH SAMPLING TOOLS

A large number of DP tools have been developed for sampling soil, soil-gas, and groundwater. Each of these tools were designed to meet a specific purpose; however, many of these tools also have overlapping capabilities. This section describes the commonly used tools currently available and clarifies their applications. All of the tools described in this section can be advanced by rigs designed specifically for DP. In addition, many of these tools can also be used with conventional drilling rigs.

6.11 SOIL SAMPLING TOOLS

There are two types of soil samplers: Nonsealed and sealed. Nonsealed soil sampling tools remain open as they are pushed to the target depth; sealed soil samplers remain closed until they reach the sampling depth.

6.11.1 Nonsealed Soil Samplers

The three most commonly used nonsealed soil samplers are barrel, split-barrel, and thin-walled tube samplers. All three are modified from soil samplers used with conventional drilling rigs (*e.g.*, HSA). The primary difference is that DP soil samplers have smaller diameters. Nonsealed soil samplers should only be used in combination with single-rod systems when sampling in uncontaminated fine-grained, cohesive formations because multiple entries into the probe hole are required. When sloughing soils and cross-contamination are a significant concern, nonsealed soil samplers may be used with cased DP systems or more conventional sampling methods (*e.g.*, HSA). In addition, nonsealed samplers necessitate continuous soil coring because there is no other way to remove soil from the hole. All three types of nonsealed soil sampling tools are presented in Exhibit V-4.

6.11.2 Barrel Samplers

Barrel samplers, also referred to as solid-barrel or open-barrel samplers, consist of a head assembly, a barrel, and a drive shoe (Exhibit V-4a). The sampler is attached to the DP rods at the head assembly. A check valve, which allows air or water to escape as the barrel fills with soil, is located within the head assembly. The check valve improves the amount of soil recovered in each sample by allowing air to escape. With the use of liners, samples can be easily removed for volatile organic compound (VOC) analysis or for observation of soil structure.

Without the use of liners, soil cores must be physically extruded using a hydraulic ram which may damage fragile structures (*e.g.*, root holes, desiccation cracks).

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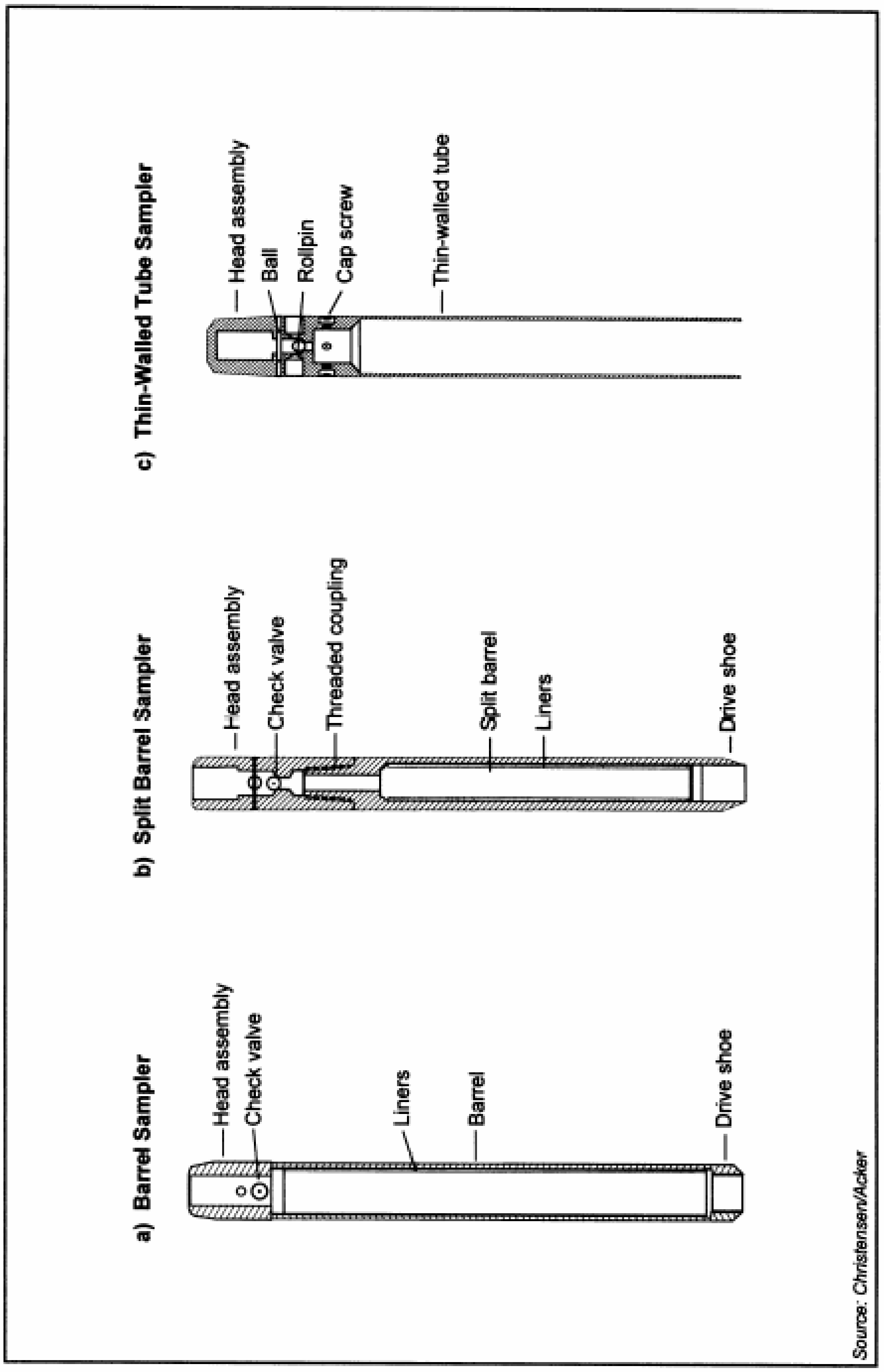
Exhibit V-4
Types of Nonsealed Direct Push SamplingTools

Exhibit V-4
Types Of Nonsealed Direct Push Soil Sampling Tools



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6.11.3 Split-Barrel Samplers

Split-barrel samplers, also referred to as "split-spoon" samplers, are similar to barrel samplers except that the barrels are split longitudinally (Exhibit V-4b) so that the sampler can be easily opened. The primary advantage of split-barrel samplers is that they allow direct observation of soil cores without the use of liners and without physically extruding the soil core. As a result, split-barrel samplers are often used for geologic logging. Split-barrel samplers, however, may cause more soil compaction than barrel samplers because the tool wall thickness is often greater. In addition, although liners are not compatible with all split-barrel samplers, liners are necessary if samples are used for analysis of VOCs.

6.11.4 Thin-Wall Tube Samplers

Thin-wall tube samplers (larger diameter samplers are known as Shelby Tubes) are DP sampling tools used primarily for collecting undisturbed soil samples (Exhibit V-4c). The sampling tube is typically attached to the sampler head using recessed cap screws or rubber expanding bushings. The walls of the samplers are made of thin steel (*e.g.*, 1/16-inch thick). The thin walls of the sampler cause the least compaction of the soil, making it the DP tool of choice for geotechnical sample analysis (*e.g.*, laboratory measurement of hydraulic conductivity, moisture content, density, bearing strength).

Samples are typically preserved, inside the tube, for off-site geotechnical analysis. If the samples are intended for on-site chemical analysis, they can be extruded from the sampler using a hydraulic ram, or the tubes can be cut with a hacksaw or tubing cutter. Because of their fragile construction, thin-wall tube samplers can be used only in soft, fine-grained sediments. In addition, the sampler is usually pushed at a constant rate rather than driven with impact hammers. If samples are needed for off-site VOC analysis, the tube is used as the sample container which can be capped and preserved.

6.11.5 Sealed Soil (Piston) Samplers

Piston samplers are the only type of sealed soil sampler currently available. They are similar to barrel samplers, except that the opening of the sampler is sealed with a piston. Thus, while the sampler is re-inserted into an open probe hole, contaminated soil and water can be prevented from entering the sampler. The probe displaces the soil as it is advanced. When the sampler has been pushed to the desired sampling depth, the piston is unlocked by releasing a retaining device, and subsequent pushing or driving forces soil into the sampler (Exhibit V-5). Several types of piston samplers are currently available. Most use a rigid, pointed piston that displaces soil as it is advanced. Piston samplers are typically air-and water-tight; however, if o-ring seals are not maintained, leakage may occur. Piston samplers also have the advantage of increasing the recovery of unconsolidated sediments as a result of the relative vacuum that is created by the movement of the piston.

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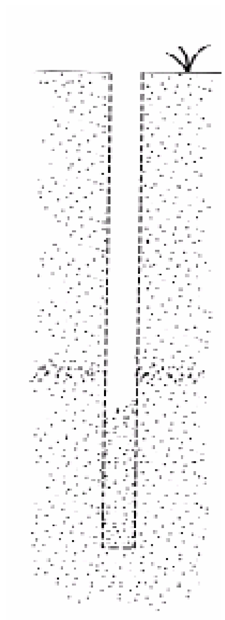
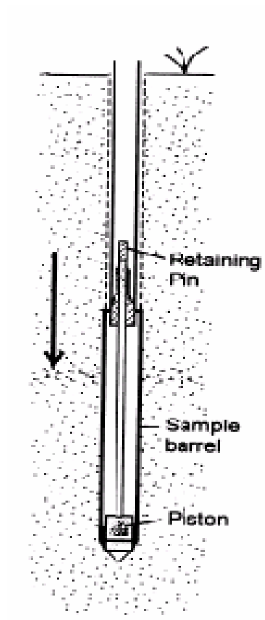
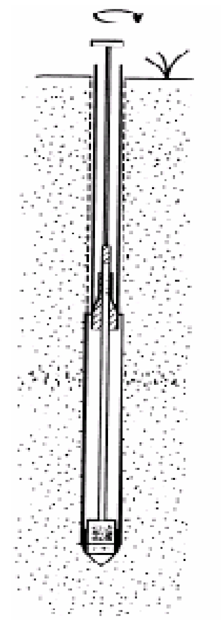
Exhibit V-5
Using the Sealed Direct Push Soil Sampler (Piston Sampler)



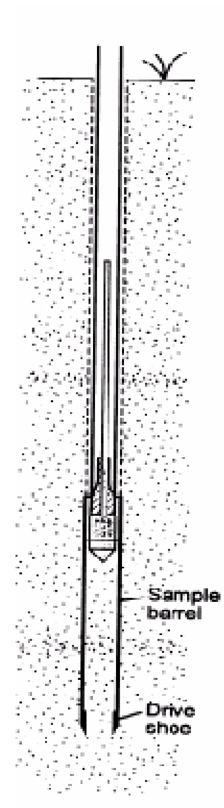
1) Previously cored hole. Lower portion of hole collapsed.



2) Sealed piston sampler is driven to beginning of next sampling interval. Piston is locked in place to prevent soil and water from entering sample barrel .



3) Unlocking (releasing) internal piston by removing retaining pin.



4) Sampler driven to collect next soil core. Piston remains stationary while sample barrel is advanced. Soil core is retrieved by removing entire assembly hole.

Source: Geoprobe © Systems

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6.12 DISCUSSION AND RECOMMENDATIONS

Issues affecting the selection of soil samplers include the ability of the sampler to provide samples for lithological description, geotechnical characterization, or chemical analysis. In addition, the potential of a sample contamination with a specific sampler must be considered.

6.12.1 Lithologic Description/Geotechnical Characterization

All soil samplers can be used to some extent for lithologic description and geotechnical characterization; but because the disturbance to the sample varies between tools, the preferred tool will vary depending on the application. Split-barrel samplers or barrel samplers used with split-liners are the best DP sampling methods for lithological description because they allow the investigator to directly inspect the soil without further disturbing the sample. Thin-walled tube samplers are best for collecting undisturbed samples needed for geotechnical analysis; barrel and piston samplers are the next best option. With single-rod systems, piston samplers are the only tools that can reliably be used for these same objectives because they produce discrete soil samples.

6.12.2 Chemical Analysis

All sealed or nonsealed soil samplers can be used for the collection of samples for VOC analysis. If samples are analyzed on-site, liners of various materials (*e.g.*, brass, stainless steel, clear acrylic, polyvinylchloride [PVC]) can be used as long as the soil is immediately subsampled and preserved. Soil samples intended for off-site analysis should be collected directly into brass or stainless steel liners within the DP soil sampling tool. Once the tool has been retrieved, the liners can be immediately capped, minimizing the loss of VOCs. Unfortunately, without extruding the soil core from the metal liners, detailed logging of the soil core is not possible. Short liners (4 to 6 inches long) may be useful for providing a minimal amount of lithological information. The soil lithology can be roughly discerned by inspecting the ends of the soil-filled liners; specific liners can then be sealed and submitted for chemical analysis. Extruding soil cores directly into glass jars for chemical analysis should be avoided since up to 90 percent of the VOCs may be lost from the sample (Siegrist, 1990).

6.12.3 Sample Contamination

The potential for sample contamination will depend on both the type of soil sampler and the type of DP rod system. The major concern with nonsealed samplers is that the open bottom may, when used with single-rod systems, allow them to collect soil that has sloughed from an upper section of the probe hole; they, therefore, may collect samples that are not representative of the sampling zone. If the sloughed soil contains contaminants, an incorrect conclusion could be made regarding the presence of contaminants at the target interval. Alternatively, if the overlying soil is less contaminated than the soil in the targeted interval, erroneously low

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concentrations could be indicated. As a result, nonsealed samplers should not be used with single-rod DP systems where contaminated soils are present. In such cases, piston samplers are the only appropriate soil samplers.

Nonsealed samplers can be safely used with cased DP systems above the water table. When sampling below the water table, particularly through geological formations with a high hydraulic conductivity, nonsealed samplers should not be used because contaminated water can enter the drive casing. In this situation, water-tight piston samplers must be used in combination with cased DP systems. In many low permeability formations, water does not immediately enter the outer drive casing of cased DP systems, even when the casing is driven to depths well below the water table. In these settings the potential for sample contamination is greatly reduced, and nonsealed soil samplers can be lowered through the outer casing. A summary of sealed and nonsealed soil samplers is presented in Exhibit V-6.

Exhibit V-6
Summary Of Sealed And Nonsealed Soil Sampler Applications

		Single-Rod System		**Cased System**	
		Nonsealed	Sealed	Nonsealed	Sealed
Sampling Above Watertable	NAPLs Not Present	✓[1]	✓	✓	✓
	LNAPLs Present		✓	✓	✓
Sampling Below Watertable	NAPLs Not Present	✓[1]	✓	✓	✓
	LNAPLs Present		✓	✓[2]	✓

[1] Fine-grained (cohesive) formations where probe hole does not collapse.
[2] In low permeability soil where groundwater does not enter drive casing.

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6.13 GROUNDWATER SAMPLING TOOLS

DP technologies can be used in various ways to collect groundwater samples. Groundwater can be collected during a one-time sampling event in which the sampling tool is withdrawn and the probe hole grouted after a single sample is collected. Groundwater sampling tools can be left in the ground for extended periods of time (*e.g.*, days, weeks) to collect multiple samples; or, DP technologies can be used to construct monitoring wells that can be used to collect samples over months or even years.

In general, when the hydraulic conductivity of a formation reaches 10^{-4} cm/second (typical for silts), collection of groundwater samples through onetime sampling events is rarely economical. Instead, collection of groundwater samples requires the installation of monitoring devices that can be left in the ground for days, weeks, or months. In general, however, it is difficult to get an accurate groundwater sample in low permeability formations with any method (whether DP or rotary drilling) because the slow infiltration of groundwater into the sampling zone may cause a significant loss of VOCs. As a result, DP groundwater sampling is most appropriate for sampling in fine sands or coarser sediments.

As with soil-gas sampling, probe tips for one-time groundwater sampling events should not be larger than DP rods because they can create an open annulus that could allow for contaminant migration. When installing long-term monitoring points, large tips can be used in conjunction with sealing methods that do not allow contaminant migration (*e.g.*, grouting to the surface).

Although most DP groundwater sampling equipment can also be used for determining groundwater gradients, using piezometers (*i.e.*, non-pumping, narrow, short-screened wells used to measure potentiometric pressures, such as the water table elevation) early in a site assessment is typically the best method. Piezometers are quick to install; they are inexpensive to purchase, and, because of their narrow diameter, they are quick to reach equilibrium. DP-installed monitoring wells may also be used for this purpose; however, they are more appropriate for determining groundwater contaminant concentrations once groundwater gradients and site geology have been characterized. Undertaking these activities first greatly simplifies the task of determining contaminant location, depth, and flow direction.

Methods now exist for installing permanent monitoring wells with both single-rod and cased DP systems (Exhibit V-9). These methods allow for the installation of annular seals that isolate the sampling zone. In addition, some methods allow for the installation of fine-grained sand filter packs that can provide samples with low turbidity (although the need for filter packs is an issue of debate among researchers). When samples are turbid, they should not be filtered prior to the constituent extraction process because organic constituents can sorb onto sediment particles. As a result, filtering samples prior to extraction may result in an analytical negative bias. For further information on the need for sediment filtration, refer to Nielsen, 1991.

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The following text focuses on the tools used for single-event sampling. These tools can be divided into two groups--exposed-screen samplers and sealed-screen samplers. Exhibit V-10 presents examples of these two groups of groundwater samplers. Exhibit V-10a is a simple exposed-screen sampler; Exhibit V-10b is a common sealed-screen sampler; and Exhibit V-10c is a sealed-screen, sampling method used with cased systems. Because new tools are continually being invented, and because of the great variety of equipment currently available, this *Guide* can not provide a detailed description and analysis of all available groundwater sampling tools. Instead, the advantages and limitations of general categories of samplers are discussed.

6.14 EXPOSED-SCREEN SAMPLERS

Exposed-screen samplers are water sampling tools that have a short (*e.g.*, 6 inches to 3 feet) interval of exposed fine mesh screens, narrow slots, or small holes at the terminal end of the tool. The advantage of the exposed screen is that it allows multi-level sampling in a single DP hole, without withdrawing the DP rods. The exposed screen, however, also causes some problems that should be recognized and resolved when sampling contaminants. These problems may include:

- Dragging down of NAPLs, contaminated soil, and/or contaminated groundwater in the screen;
- Clogging of exposed screen (by silts and clays) as it passes through sediments;
- The need for significant purging of sampler and/or the sampling zone because of drag down and clogging concerns; and
- Fragility of sampler because of the perforated open area.

There are several varieties of exposed-screen samplers. The simplest exposed-screen sampler is often referred to as a well point (Exhibit V-10a). As groundwater seeps into the well point, samples can be collected with bailers, check-valve pumps (Exhibit V-11), or peristaltic pumps. (Narrow-diameter bladder pumps may also soon be available for use with DP equipment.) Because well points are the simplest exposed-screen sampler, they are affected by all of the above mentioned limitations. As a result, they are more commonly used for water supply systems than groundwater sampling. They should not be used below NAPL or significant soil contamination.

The drive-point profiler is an innovative type of exposed-screen sampler that resolves many of the limitations of well points by pumping deionized water through exposed ports as the probe advances. This feature minimizes clogging of the sampling ports and drag down of contaminants and allows for collection of multiple level, depth-discrete groundwater samples. Once the desired sampling depth is reached, the flow of the pump is reversed, and groundwater samples are extracted. Purging of the system prior to sample collection is important because a small quantity of water is added to the formation. Purging is complete when the electrical conductivity of the extracted groundwater has stabilized. The data provided by these samples can then be used to form a vertical profile of contaminant distributions. Exhibit V-12 provides a schematic drawing of a drivepoint profiler.

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Exhibit V-9
Permanent Monitoring Well Installed
With Pre-packed Well Screens

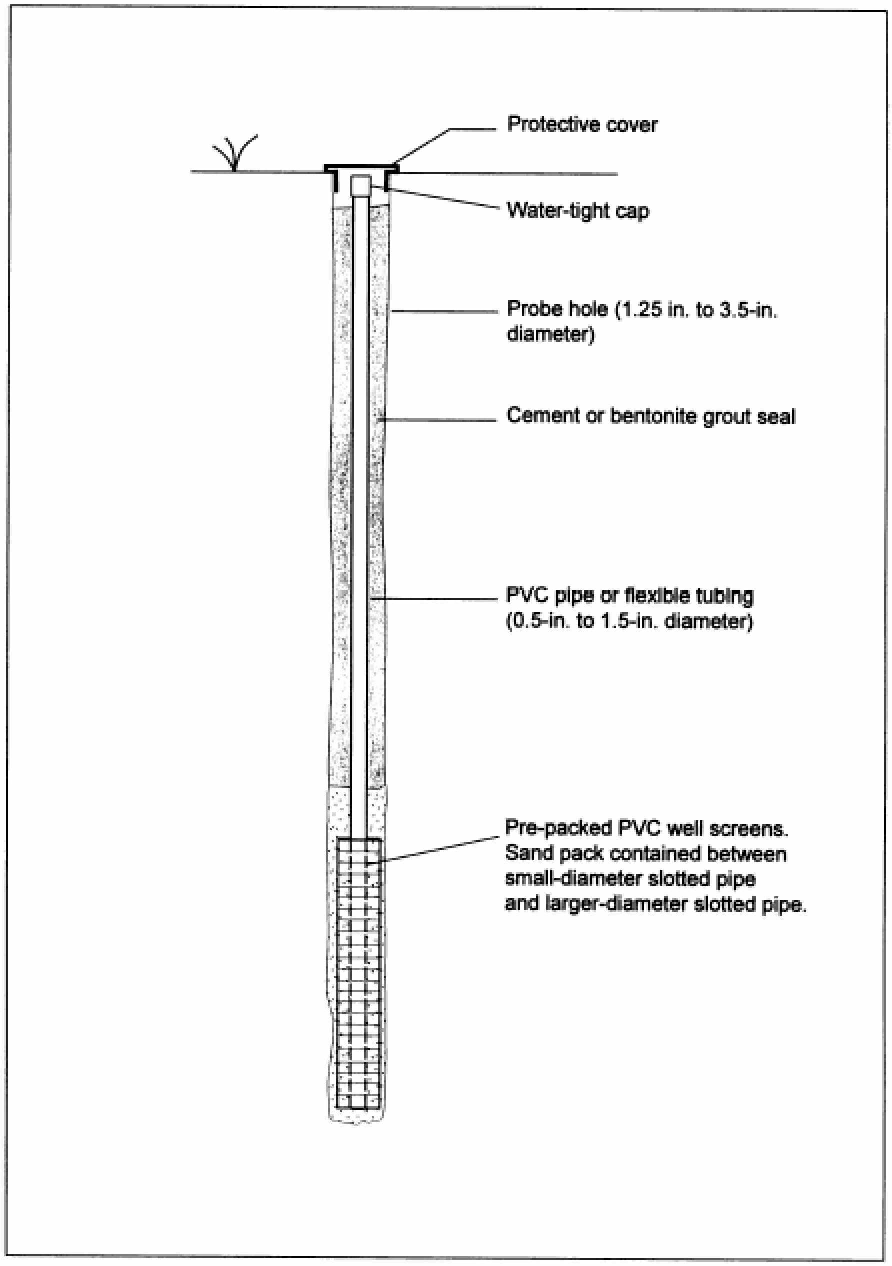

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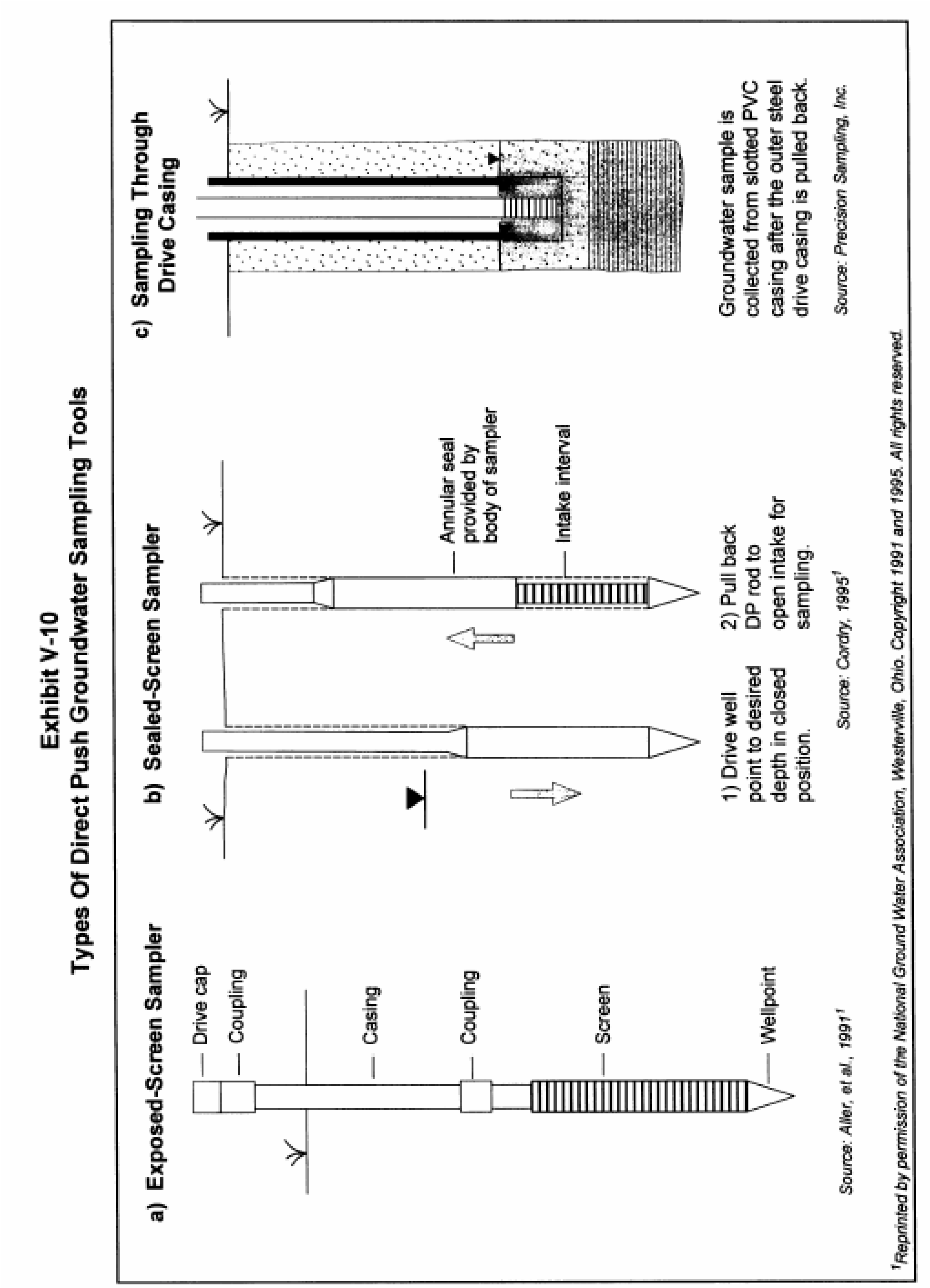
Exhibit V-10
Types of Direct Push Groundwater Sampling Tools



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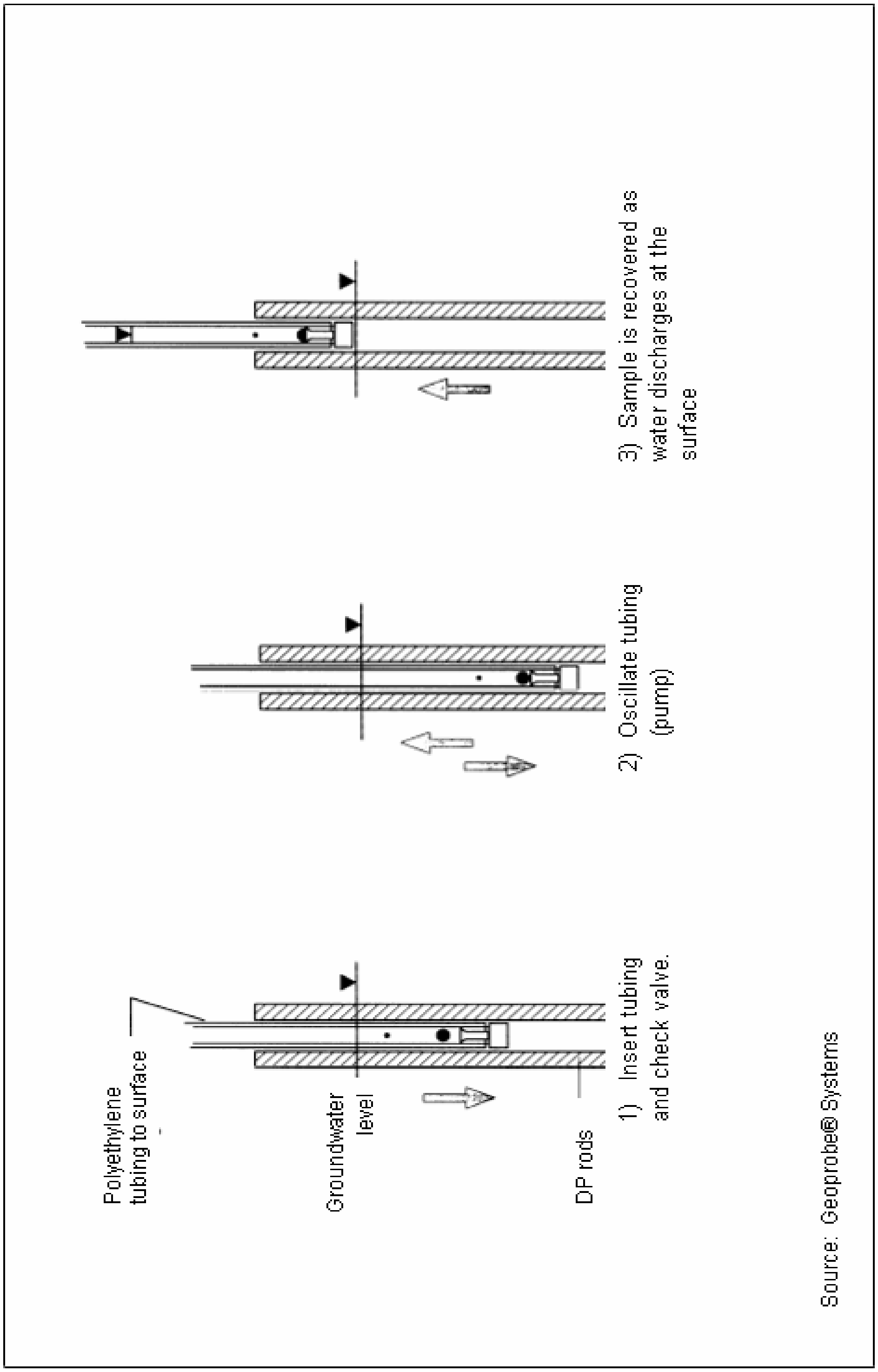
V-11
Using the Check Valve Tubing Pump

Exhibit V-11
Using The Check Valve Tubing Pump



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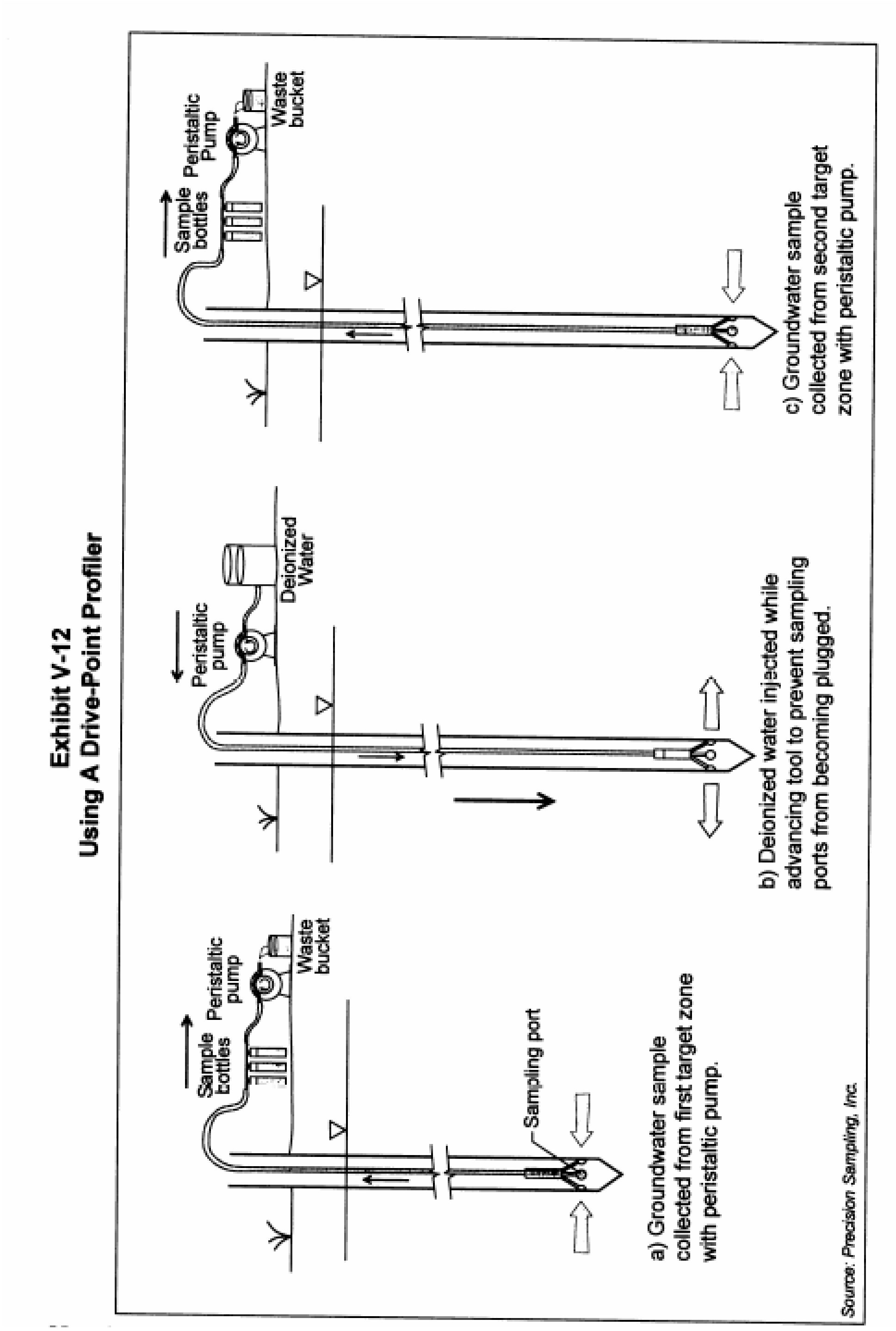
V-12
Using A Drive-Point Profiler



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6.14.1 Sealed-Screen Samplers

Sealed-screened samplers are groundwater samplers that contain a well screen nested inside a water-tight sealed body. The screen is exposed by retracting the probe rods once the desired sampling depth has been reached. They can be used for collecting accurate, depth-discrete samples. A very common type of sealed-screen sampler is presented in Exhibit V-10b.

The design of sealed-screen samplers is extremely variable. Many are similar to expendable or retractable tip samplers used for soil gas sampling. Some samplers are designed only for a single sampling event; others are designed to be left in the ground for an extended period of time (many weeks or even beyond one year) so that changes in concentrations can be monitored.

The main advantage of this type of sampler is that the well screen is not exposed to soil while the tool is being pushed to the target depth. Thus, the screen cannot become plugged or damaged, and the potential for sample contamination is greatly reduced. O-rings are used to make the sampler water-tight while it is being pushed to the sampling depth. (In order to ensure a water-tight seal, o-rings should be replaced frequently; water tightness can be checked by placing the sealed sampler in a bucket of water.) Sealed-screen samplers are appropriate for the collection of depth-discrete groundwater samples beneath areas with soil contamination in the vadose zone. Because there is no drag-down of contaminants or clogging of the sampling screens, sealed-screen samplers do not require purging.

Some sealed-screen samplers allow sample collection with bailers, check-valve pumps, or peristaltic pumps. (Bladder pumps can also be used with wide-diameter cased DP systems.) The quantity of groundwater provided by these samplers is limited only by the hydraulic conductivity of the formation. Other samplers collect groundwater in sealed chambers, *in situ*, which are then are raised to the surface. Depending on their design, these samplers may be extremely limited in the quantity of groundwater that they can collect (*e.g.*, 250 ml per sampling event), and they may not collect free product above the water table. If the storage chamber is located above the screen intake, groundwater samples must be collected sufficiently below the water table to create enough hydrostatic pressure to fill the chamber. Only sampling chambers located below the screen intake are, therefore, useful for collecting groundwater or LNAPL samples at or above the water table.

Cased DP systems can also be used as sealed-screen groundwater samplers. After the target zone has been penetrated and the inner rods have been removed, well screen can be lowered through the outer casing to the bottom of the probe hole. The drive casing is then retracted (a few inches to a few feet) exposing the well screen (Exhibit V-10c). This method allows for the collection of deeper samples by attaching a sealed-screen sampling tool that is pushed into the formation ahead of the tip of the drive casing.

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6.15 DISCUSSION AND RECOMMENDATIONS

Exposed-screen samplers are most appropriate for multi-level sampling in coarse-grained formations (*i.e.*, sediments of fine-grained sands and coarser material). They are typically used in a single sampling event. The major concern with using exposed-screen samplers is that they can cause cross contamination if precautions are not taken (*e.g.*, pumping deionized water through sample collection ports). As a result of these concerns, significant purging of the sampling zone is required.

Sealed-screen samplers are most appropriate for single-depth samples. When they are used in a single sampling event, they are appropriate in formations of fine-grained sands or coarser material because these soils typically allow rapid collection of groundwater. When they are used as either temporary or long-term monitoring wells, they can also be used in formations composed of silts. In addition, because sealed-screen groundwater samplers do not require purging of groundwater, they allow more rapid sampling from a single depth than exposed-screen samplers. Multi-level sampling with sealed-screened samplers is possible with cased and single-rod systems; however, with single-rod systems, the entire rod string must be withdrawn after samples are collected from a given depth. This practice with single-rod systems may create some cross contamination concerns in permeable, contaminated aquifers because the hole remains open between sampling events, allowing migration.

In addition, DP groundwater sampling tools have several advantages over traditional monitoring wells. DP tools allow groundwater samples to be collected more rapidly, at a lower cost, and at depth-discrete intervals. As a result, many more samples can be collected in a short period of time, providing a detailed 3-dimensional characterization of a site. Exhibit V-13 provides a summary of DP sampling tool applications.

6.16 GENERAL ISSUES CONCERNING GROUNDWATER SAMPLING

There are several issues concerning the collection, analysis and interpretation of groundwater samples that affect both DP equipment and more conventional monitoring wells. Two major issues are the loss of VOCs and the stratification of contaminants.

6.16.1 Loss Of VOCs

The ability of DP groundwater sampling methods to collect samples equivalent to traditional monitoring wells is a topic of continued debate and research. Loss of VOCs is the most significant groundwater sampling issue. All groundwater sampling methods--including methods used with traditional monitoring wells--can affect VOC concentrations to some degree. The key to preventing the loss of VOCs is to minimize the disturbance of samples and exposure to the atmosphere. Several studies that have compared VOC concentrations of samples collected with DP methods with samples collected by traditional monitoring wells have shown that DP methods compare favorably (Smolley *et al.*, 1991; Zemo, *et al.*, 1994).

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Exhibit V-13

Summary Of Groundwater Sampling Tool Applications

	Exposed-Screen	**Sealed-Screen**
Multi-level sampling	✓[1]	✓[2]
Samples can be collected immediately, little or no purging required		✓[3]
Used to install long-term monitoring point	✓[4]	✓
Can be used in formations composed of silts		✓[5]
Appropriate below contaminated soil		✓

[1] Cross contamination may be an issue of concern, and purging is required.
[2] Multi-level sampling without withdrawing all DP rods is only possible with cased DP systems.
[3] Collection of a single sample is more rapid with this method.
[4] One type of exposed-screen sampler (*i.e.*, well points) has been used to install monitoring points, but this method is generally not recommended in zones of NAPL contamination. It may be appropriate at the leading edge of a contaminant groundwater plume.
[5] Sampling in silts is generally only appropriate when temporary monitoring wells are installed. Significant VOC loss may occur if water flows into sampling point over days, weeks, or months.

6.16.2 Stratification Of Contaminants

Being able to take multiple, depth-discrete groundwater samples with DP equipment is both an advantage and a necessity. At least one recent study has shown that the concentration of organic compounds dissolved in groundwater can vary by several orders of magnitude over vertical distances of just a few centimeters (Cherry, 1994). Because DP sampling tools collect samples from very small intervals (*e.g.*, 6 inches to 3 feet), they may sometimes fail to detect dissolved contamination if the tool is advanced to the wrong depth. Therefore, multiple depths should be sampled to minimize the chances of missing contaminants. At sites with heterogeneous geology, contamination may be particularly stratified. Because the distribution of the contaminants is controlled by the site geology and groundwater flow system, the hydrogeology of the site must be adequately defined before collecting groundwater samples for chemical analysis.

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The stratification of contaminants may also result in artificially low analytical results from traditional monitoring wells. These wells are typically screened over many feet (*e.g.*, 5 to 15 feet), while high concentrations of contaminants may be limited to only a few inches (in the case of LNAPLs, typically the top of the aquifer). The process of sampling groundwater, however, may cause the water in the well to be mixed, resulting in a sample that represents an average for the entire screen length (*i.e.*, very high concentrations from a specific zone may be diluted). DP methods avoid this problem by collecting depth-discrete samples.

6.16.3 Conclusion

The practice of collecting groundwater samples both with DP systems and with traditional monitoring wells is a subject of continued research and debate. Both methods can provide high quality groundwater samples for regulatory decisions. Both methods may also provide misleading information if appropriate procedures are not followed and/or if the hydrogeology of a site is not well characterized. Investigators and regulators must be aware of the issues that affect groundwater sample quality and interpretation in order to make appropriate site assessment and corrective action decisions.

6.17 SOIL SAMPLING

Soil sampling methods can be broadly classified as hand-held and power-driven. Criteria for selection of hand-held equipment includes: 1) if an undisturbed core is required, 2) soil conditions at the site (cohesion, stones, moisture), 3) the sample size and depth desired, and 4) the number of required operators.

Power-driven samplers are usually operated in conjunction with drill rigs, although thin-wall tube samplers attached to hydraulic rigs for near-surface sampling can be attached to pickup trucks. Collection of soil cores is the preferred method for sampling solids because much more accurate stratigraphic logging is possible than with cuttings from drill methods that do not obtain cores as part of the drilling process, such as diamond drilling. The most common method for collection of disturbed cores is the split-barrel sampler.

Thin-wall open tube samples are the most common method for collecting undisturbed cores. In consolidated geologic material, rotating core samplers are used. This-wall piston samplers are usually used where poor cohesion prevents good recovery with conventional thin-wall samplers. Specially designed thin-wall samplers might be required for gravelly and very stiff or cemented unconsolidated deposits.

The following sections excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describe hand-auger sampling, hollow-stem auger drilling, direct air-rotary drilling, casing advancement drilling, solid-flight and bucket auger drilling, and directional drilling methods, uses, considerations, and frequency of use. Most relevant references from the original text have been included in this document. For complete references and additional drilling method information, please review Chapter 2 of *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b), which can be found online at **http://nepis.epa.gov/**.

6.18 HAND-HELD SAMPLING DEVICES

6.18.1 Other Names Used To Describe Method

Screw auger, helical auger, closed spiral auger, open spiral auger, worm auger, bucket auger, barrel auger (standard, sand, mud/clay, dutch, in situ soil recovery, stony soil, planer, poet-hole/Iwan-type, silage), spiral auger, ram's horn auger.

6.18.2 Uses At Contaminated Sites

Collecting disturbed soil samples; used in combination with tube samplers for collecting undisturbed soil samples.

6.18.3 Method Description

Hand-held augers consist of an auger bit, a solid or tubular drill rod, and a “T” handle Figure 2.3.2a). When the drill rod is threaded, extensions can be added or auger bits interchanged. The auger tip bites into the soil as the handle is rotated, and soil retained on the auger tip is brought to the surface and used as the soil sample. Alternatively, augers can be used to bore to the desired sampling depth, and a tube sampler replaced for collection of the actual sample. Many types of auger bits are available: Screw-type (Figure 23.2a), bucket-type (Figure 23.2b), and spiral-type (Figure 23.2c). Table 2.3.2 describes the applications and special limitations of ten types of augers. Hand-held power screw augers, requiring one or two people to operate, can also be used. ASTM (1980) provides descriptions of about a dozen types of hand-held and machine-operated augers.

6.18.4 Method Selection Considerations

General Advantages: (1) Relatively inexpensive, readily available, and most types can be easily operated by one person; and (2) depending on the type, larger volumes of soil can be obtained compared to hand-held tube samplers (Section 2.3.3). **General Disadvantages**: (1) Difficult to know the exact depth from which sample comes; (2) cross-contamination of samples from lower depths by cave-in or sloughing of borehole walls is common (can be reduced by use of in situ soil recovery auger); (3) samples are disturbed, so measurements requiring undisturbed soil cannot be taken, and accurate soil profile description is difficult; (4) disturbance of exposure of soil to air makes most types unsuitable for sampling volatile contaminants; (5) sampling depth is usually limited to 1 or 2 meters, but up to 3 meters is possible under favorable conditions using extensions. **Screw Auger Advantages**: (1) Hand-held types usually penetrate more rapidly than bucket augers in moist soil; (2) power-driven hand held screw augers allow deep and rapid penetration in cohesive, soft, or hard soils; (3) open thread provides easy access to sample; and (4) fairly easy to decontaminate. **Screw Auger**

Disadvantages: (1) Will not retain dry, loose, or granular material; and (2) only suitable for obtaining composite samples. Truck-driven solid flight augers (Section 2.1.9) yield samples similar to screw augers and have the same advantages and disadvantages.

Bucket Auger Advantages: Variety of types allows selection of auger head for much wider variety of soil conditions than screw auger and tube sampler. **Bucket Auger Disadvantages**: (1) Extraction of sample from closed bucket-types cumbersome; and (2) more difficult to decontaminate than screw augers.

6.18.5 Frequency of Use

Commonly used for collection of composite near surface samples, and in combination with tube samplers to collect undisturbed samples.

6.18.6 Standard Methods/Guidelines

ASTM (1980), Boulding (1991), Ford et al. (1984), U.S. EPA (1986b-also covers sampling from solid flight augers).

Sources for Additional Information: See Table 2-5.

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Figure 2.3.2
Hand Held Augers

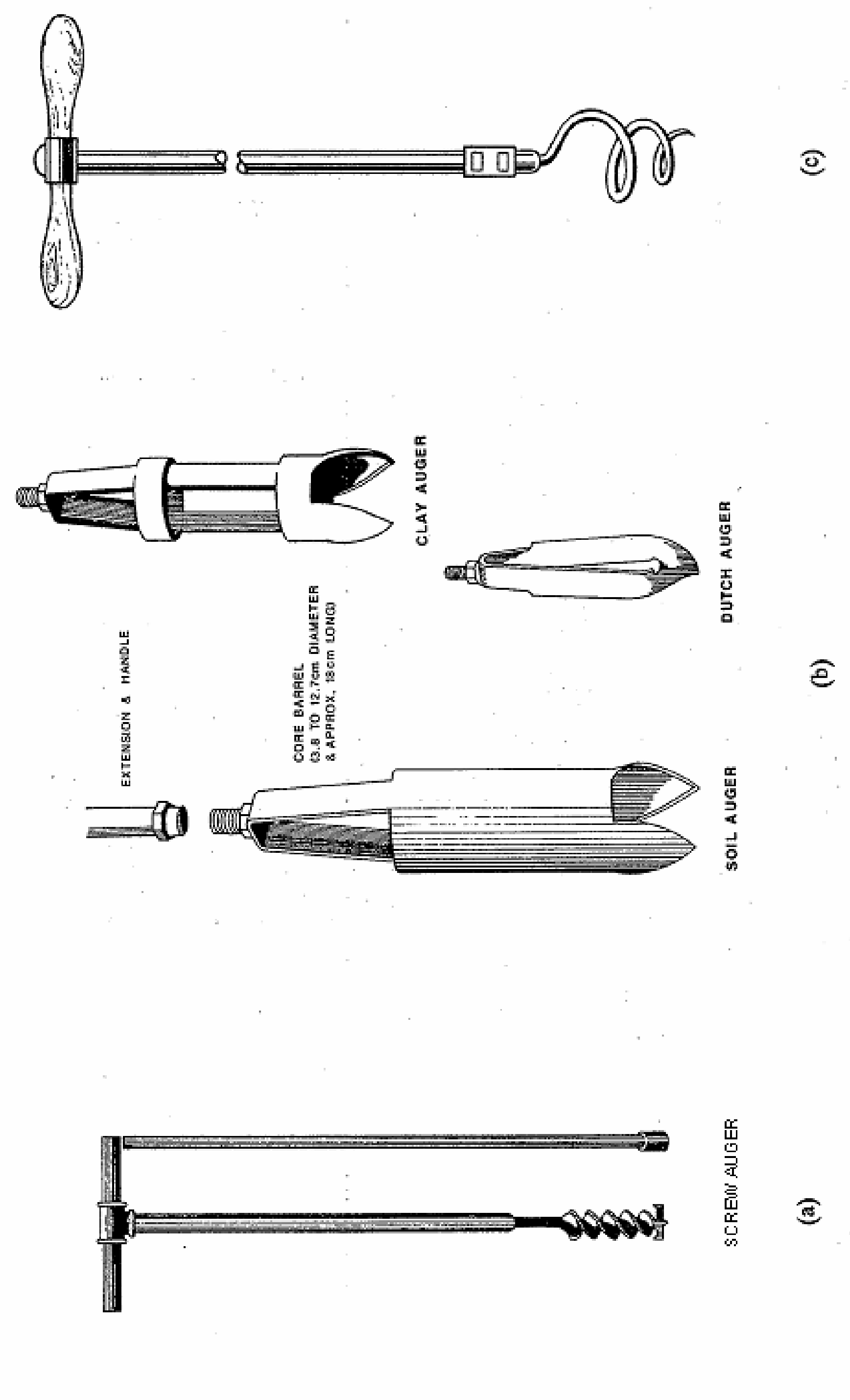

Figure 2.3.2 Hand-held augers: (a) Screw auger (Rehm et al., 1985, Copyright © 1985, Electric Power Research Institute, EPRI EA-4301, *Field Measurement Methods for Hydrogeologic Investigations: A Critical Review of the Literature*, reprinted with permission); (b) Examples of bucket augers (Rehm et al., 1985, Copyright © 1985, Electric Power Research Institute, EPRI EA-4301, *Field Measurement Methods for Hydrogeologic Investigations: A Critical Review of the Literature*, reprinted with permission); (c) Spiral or ram's horn auger (U.S. Army, 1981).

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6.19 HOLLOW STEM AUGER

6.19.1 Other Names Used To Describe Method Helical Auger.

6.19.2 Uses at Contaminated Sites

Drilling for solids sampling and installation of ground-water monitoring wells in unconsolidated materials; drilling vadose monitoring wells (lysimeters); and identifying depth to bedrock.

6.19.3 Method Description

A hollow-stem auger column (Figure 2.1.1) simultaneously rotates and axially advances using a mechanically or hydraulically powered drill rig. The hollow stem of the auger allows use of various methods for continuous (see Figure 14.3b) or intermittent sampling of soil material (see Figure 2.4.4b). Casing and screens for monitoring wells can be placed in the hollow stem when the desired depth has been reached, and gravel pack and grouting emplaced as the auger is gradually withdrawn from the hole. Use of different diameter augers allows use of casings to isolate near-surface contamination, and continuation of drilling with a smaller diameter auger. Special screened auger sections allow ground-water sampling at different depths as drilling progresses (see Figure *5.2.7a).*

6.19.4 Method Selection Considerations

Usually the favored method with moderately cohesive unconsolidated materials. **Advantages:** (1) Set-up time and drilling is fast and causes minimal damage to aquifer because no drilling fluids or lubricants are required; (2) high mobility rigs can reach most sites and equipment is generally readily available throughout the United States; (3) the hollow stem allows flexible choice of soil core sampling methods and use of natural gamma ray logging equipment; (4) depth to water table can usually be determined during drilling and formation waters can be sampled during drilling by using a screened lead auger or advancing a well point ahead of the augers; (5) auger flights act as temporary casing. Stabilizing the hole for construction of small-diameter monitoring wells; and (6) usually less expensive than rotary or cable drilling. **Disadvantages:** (1) Cannot be used in consolidated deposits and might have to be abandoned if boulders are encountered; (2) heaving sands present problems, requiring special procedures to counteract; (3) generally limited to wells less than 150 feet in depth and works best to depths around 75 feet; (4) vertical mixing of formation water and geologic materials can occur; and (5) hollow sterns might not be suitable for running a complete suite of geophysical logs. Aller et al. (1991) give hollow-stem augers top ratings compared to other drilling methods for Up to 4-inch monitoring wells in unsaturated, unconsolidated material to 150 feet up to .4-inch shallow monitoring wells (<15 feet) in saturated conditions; and for small (<2 inch) monitoring wells in saturated unconsolidated material to 150 feet (see Table 2.L1).

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6.19.5 Frequency of Use

The large majority of monitoring wells installed in unconsolidated materials in North America are constructed using hollow stem augers.

6.19.6 Standard Methods/Guidelines ASTM (1993a), Appendix A in Aller et al. (1991).

6.19.7 Sources for Additonal Information Aller et al. (1991), Shuter andTeasdale (1980). See also, Table 2-4.

Figure 2.1.1
Hollow-Stem Auger

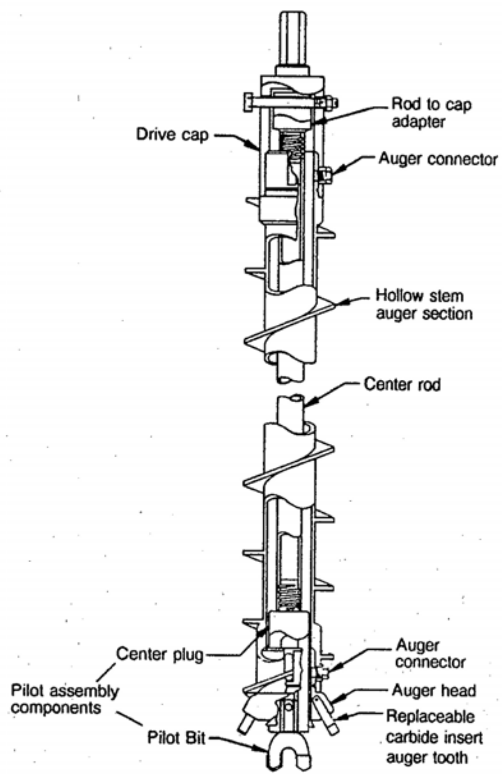

Figure 2.1.1 Typical components of a hollow-stem auger (Aller et al., 1991).

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6.20 DIRECT AIR ROTARY WITH ROTARY BIT/ DOWNHOLE HAMMER

6.20.1 Other Names Used to Describe Method

Air rotary bit with roller-cone (tri-cone) bit, down-the-hole hammer, air- percussion rotary.

6.20.2 Uses at Contaminated Sites:

Air rotary bit: Monitoring well installation in deeper, stable unconsolidated material, and sedimentary rocks. Downhole hammer: Monitoring well installation in very hard to hard geologic formations.

6.20.3 Method Description

Air rotary bit: The basic rig setup for air rotary with a tri-cone or roller-cone bit is similar to direct mud rotary (see Figure 2.1.3 in next section), except the circulation medium is air instead of water or drilling mud. Figure 2.1.2a illustrates the main components of a drill string using a tri-cone bit. Compressed air is circulated down through the drill rods to cool the bit, and carries cuttings up the open hole to the surface. A cyclone separator slows the air velocity and allows the cuttings to fall into a container. A roller cone drill bit is used for unconsolidated and hard to soft consolidated rock. In dry formations the cuttings are very fine-grained and a small amount of water and/or foaming surfactant can be added to increase the size of fragments discharged to the surface, allowing good characterization of the formation. **Downhole hammer**: A down-the-hole hammer, which operates with a pounding action as it rotates, replaces the roller-cone bit (Figure 2.1.2b). Other operational features are similar to those described for the rotary bit, except that small amounts of water or surfactants are needed for dust and bit temperature control.

6.20.4 Method Selection Considerations

Air rotary is often the method of choice for monitoring well installation in consolidated material, and deeper unconsolidated materials that form a stable hole. **Air Rotary Bit Advantages**: (1) Drilling is fast and can be used in both consolidated and unconsolidated formations, but is best suited for consolidated rock; (2) no drilling fluid is used, minimizing contamination of formation water (3) depth is limited only by the capacity of the air compressor to deliver enough air downhole to maintain circulation; (4) cuttings can be recovered rapidly and are not contaminated by drilling mud (recovery is best in hard, dry formations); *(5)* major water-bearing zones can be identified when formation water is blown out of the hole along with cuttings and yields of strong water-producing zones can be estimated with a relatively short interruption of drilling; (6) well suited for highly fractured or cavernous rock because loss of drilling fluids is not a problem; (7) field analysis of water blown from the hole can provide information on changes in some basic water-quality parameters such as chlorides; and (8) drill rigs are readily available throughout most of the United States. **Air Rotary Bit Disadvantages:** (1) Oil contamination might result from the air compressor if air filters are not operating properly; (2) surfactant foams, if used, might react with formation water and affect

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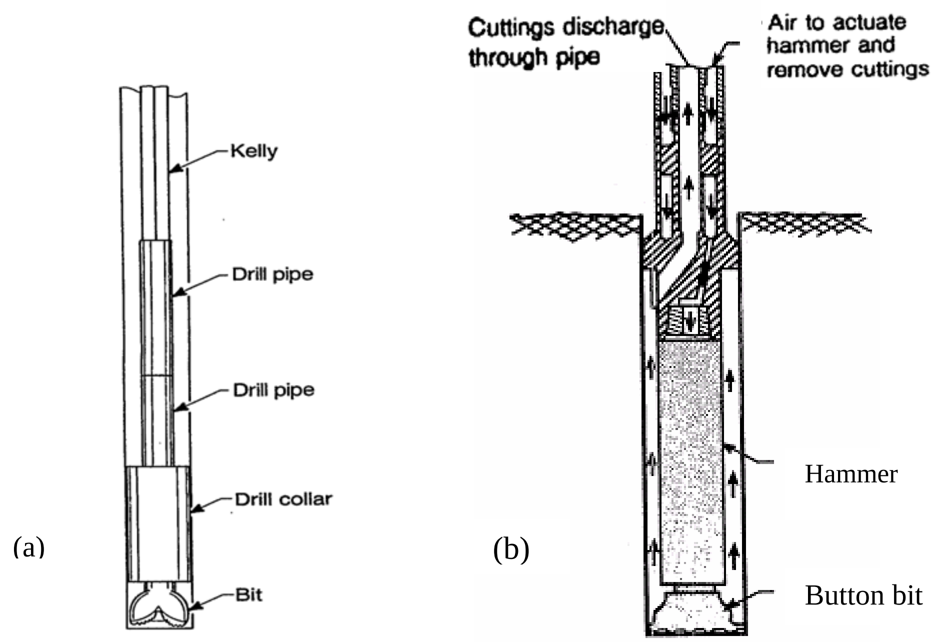
representativeness of ground-water samples; (3) the drying effect of air can make lower yield water producing zones difficult to observe (4) the air can modify chemical and biological conditions in an aquifer, with recovery time uncertain; (5) casing is required to keep the hole open when drilling in soft, caving formations below water table; (6) if hydrostatic pressures of water bearing zones are different, cross-contamination might occur between the time drilling is completed and the well casing is placed and grouted; (7) relatively expensive, might not be economical for small jobs; (8) requires a minimum 6-inch diameter hole; (9) cuttings and water blown from the hole can pose a hazard to crew and surrounding environment if toxic compounds are encountered; and (10) not suitable for soft, caving formations. Aller et al. (1991) give air rotary top ratings for all situations involving consolidated rock, and top ratings compared to other drilling methods for large diameter wells (4 to 8 inches) deeper than 15 feet in unsaturated, unconsolidated material where invasion of drilling fluid is not allowed (see Table 2.1.2). **Downhole Hammer Advantages**: (1) Downhole hammer provides better penetration in very hard geologic formations such as igneous and metamorphic rocks and very fast penetration in other formations; and (2) longer bit life, less drill collar wear, and easier to control deviation, while maintaining penetration rates compared to rotary bit. **Downhole Hammer Disadvantages**: (1) Oil is required in the air stream to lubricate the actuating device for the hammer, creating the possibility of hydrocarbon contamination of the monitoring well; (2) limited to systems using compressible circulating fluids (air, foam); and (3) use of surfactants might alter ground-water chemistry.

Figure 2.1.2
Air Rotary Drilling Methods



(Figure 2.1.2 Air rotary drilling methods: (a) Drill string for a direct rotary rig with tri-cone bit (Driscoll, 1986, by permission); (b) Diagram of direct air rotary with downhole hammer (Aller et al., 1991).

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6.21 CASING ADVANCEMENT (ODEX, TUBEX)

6.21.1 Other Names Used to Describe Method

Down-the-hole hammer drill with underreaming capability, downhole hammer with eccentric bit.

6.21.2 Uses at Contaminated Sites

Monitoring well installation in bouldery glacial tile or hard or fractured bedrock, and where prevention of cross contamination of aquifers is important.

6.21.3 Method Description

Downhole casing advancers are similar to drill-through casing drivers using downhole air hammer (see Section 2.1.5), except that eccentric (off-centered) bits drill a hole larger than the casing, Figure 2.1.7 illustrates major elements of the ODEX drilling assembly and method of operation. The weight of the casing, plus blows from the hammer (which are directed onto a drive shoe welded to the leading edge of the casing) are enough to advance the casing through hard formations. When the desired depth has been reached, the eccentric bit is rotated briefly in the reverse direction, causing it to become smaller than the casing, so that it can be removed. Monitoring well installation procedures are similar to hollow-stem auger, but casing removal is a little more difficult

6.21.4 Method Selection Considerations

Advantages: (1) Compared to open hole methods, holes are straighter and better geologic samples are collected because uphold erosion and contamination is eliminated; (2) mast methods can advance through difficult formations such as cobbles, boulders, caliche, heaving sands, weathered bedrock, and clay; and (3) air requirements also are reduced for air total)' and percussion methods. **Disadvantages:** (1) Relatively expensive due to slower drilling and materials; and (2) casing removal after well installation might be difficult.

6.21.5 Frequency of Use

In unconsolidated material, generally only used in situations where hollow-stem augers have problems (coarse gravels, cobbles, boulders, and heaving sands) or where prevention of cross-contamination between aquifers is critical. Casing advancement methods in consolidated rock are being used with increasing frequency as a means of insuring integrity of well installation.

6.21.6 Standard Methods/Guidelines --

6.21.7 Sources for Additional Information
Aller et al. (1991), Baker et al. (1987.ODEX), Hix (1991), Murphy (1991- ODEX/rUBEX).

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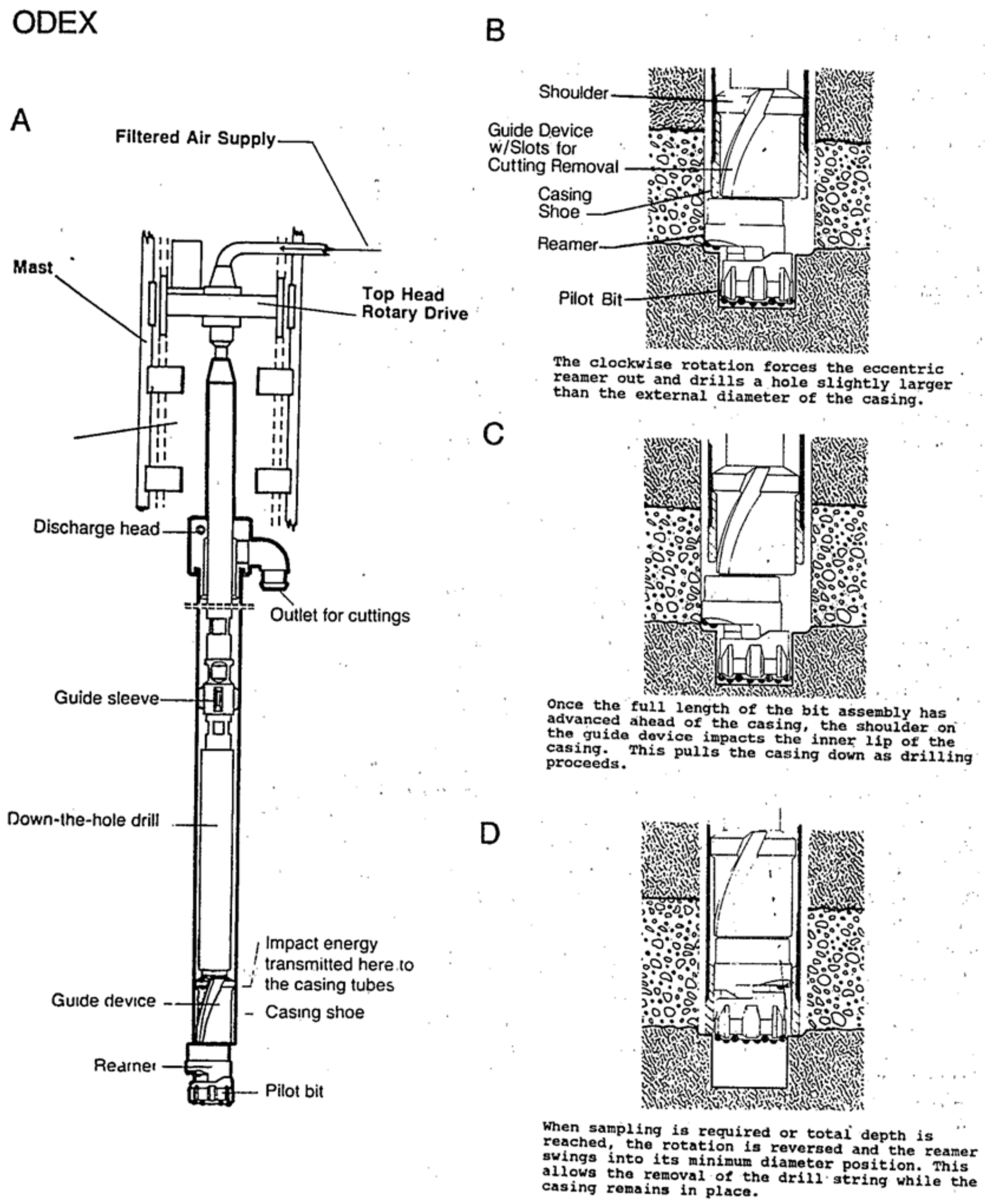
Figure 2.1.7
Diagram of ODEX Downhole Casing Advancer Drilling Assembly and Operations



(Murphy, 1991, by permission)

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6.22 SOLID FLIGHT AND BUCKET AUGERS

6.22.1 Other Names Used to Describe Method

Solid-stem auger, solid-core auger, continuous flight auger, he1ical/worm-type auger, disk auger, rotary bucket drilling.

6.22.2 Uses at Contaminated Sites

Investigating shallow soil and vadose monitoring wells (lysimeters); monitoring wells in saturated, stable soils; identifying depth to bedrock.

6.22.3 Method Description

Solid flight augers: Auger sections with a solid stem and fighting (the curve corkscrew-like blades) are connected in a continuous string to the lowermost section with a cutting head that is approximately 2 inches larger in diameter than the fighting (Figure 2.L9a). Cuttings are rotated upward to the surface by moving along the continuous fighting as the cutting head advances into the earth (Figure 2.L9b), making it difficult to obtain reliable depth-specific soil samples from the cuttings that are brought to the surface. In stable soils, rotation can be stopped at the desired depth, the augers removed from the borehole, and samples taken from the bottom flight. Use of different diameter augers allows placement of casing to isolate near-surface contamination, and continuation of drilling with a smaller-diameter auger. Recovery of samples from the saturated zone is difficult, the only way to collect undisturbed samples is to remove the auger string, attach a split-spoon or thin-wall sampler to the end of the drill rod and put the entire string back into the borehole. A **disk auger** is similar to a solid flight auger except that it has a larger diameter and the fighting only goes around the stem once. **Bucket augers** (8-inch minimum diameter and typically 2 feet long) have a cutting edge on the bottom that is slowly rotated by a square telescoping Kelley of drill stem. When the bucket fills with cuttings, it is brought to the surface to be emptied. Figure I1.9c illustrates several types of bucket augers. Other variants include the spoon auger and the Vicksburg hinged auger.

6.22.4 Method Selection Considerations

Solid Stem Auger Advantages: (1) In unconsolidated material, drilling rigs are fast and mobile and (2) minimal damage to aquifer and no drilling fluids or lubricants required. **Solid Stem Auger Disadvantages**: (1) Soil samples are unreliable unless split-spoon or thin-wall samples are taken, slowing drilling speed, and those can only be taken where stable soils exist; (2) generally unsuitable for monitoring-well installation in the saturated zone because of borehole caving upon auger removal; (3) depth generally restricted to 30 meters or less; (4) because auger must be removed before well can be set, vertical mixing can occur between water-bearing zones; (5) can only be used in unconsolidated materials; (6) depth to water table might be difficult to determining accurately in deep borings; and (7) drilling through a contaminated soil zone might result in downward transport of contaminants. Aller et al. (1991) give consistently low ratings compared to other drilling methods in unconsolidated saturated material, and the methods usually rate second highest, after hollow- stem auger, for most unsaturated conditions (see Table 2.1.9**)**. **Bucket Auger Advantages**: (1) Good for construction wells just into the water table in unconsolidated formations that form stable borehole walls, such a clayey sediments walls; (2) after hole has been drilled, the setting of casing with screen and grouting outside to casing is relatively easy; (3) soil samples taken with a bucket auger arc disturbed, but representative, unless caving of the borehole has occurred; and (4) depth specific sampling and detailed in situ soil descriptions might be possible if the diameter of the boring is large enough to let a person work in the hole. **Bucket Auger Disadvantages**: (1) Large diameter holes create a large annular space when small-diameter casing is used, necessitating a large volume of grout, and special care in grout placement and backfilling; (2) in caving formations below the water table, water must be added continuously to prevent caving; (3) restricted to depths less than about 50 feet; and (4) rigs might not be readily available.

6.22.5 Frequency of Use

Solid stem auger: Most commonly used for geotechnical investigations in unconsolidated material. Less commonly used for monitoring well installation because most installations need to be completed into the saturated zone. **Bucket auger**: Most commonly used for large-diameter borings associated with foundations and building structures.

6.22.6 Standard Methods/Guidelines --

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Figure 2.1.9
Power Driven Augers

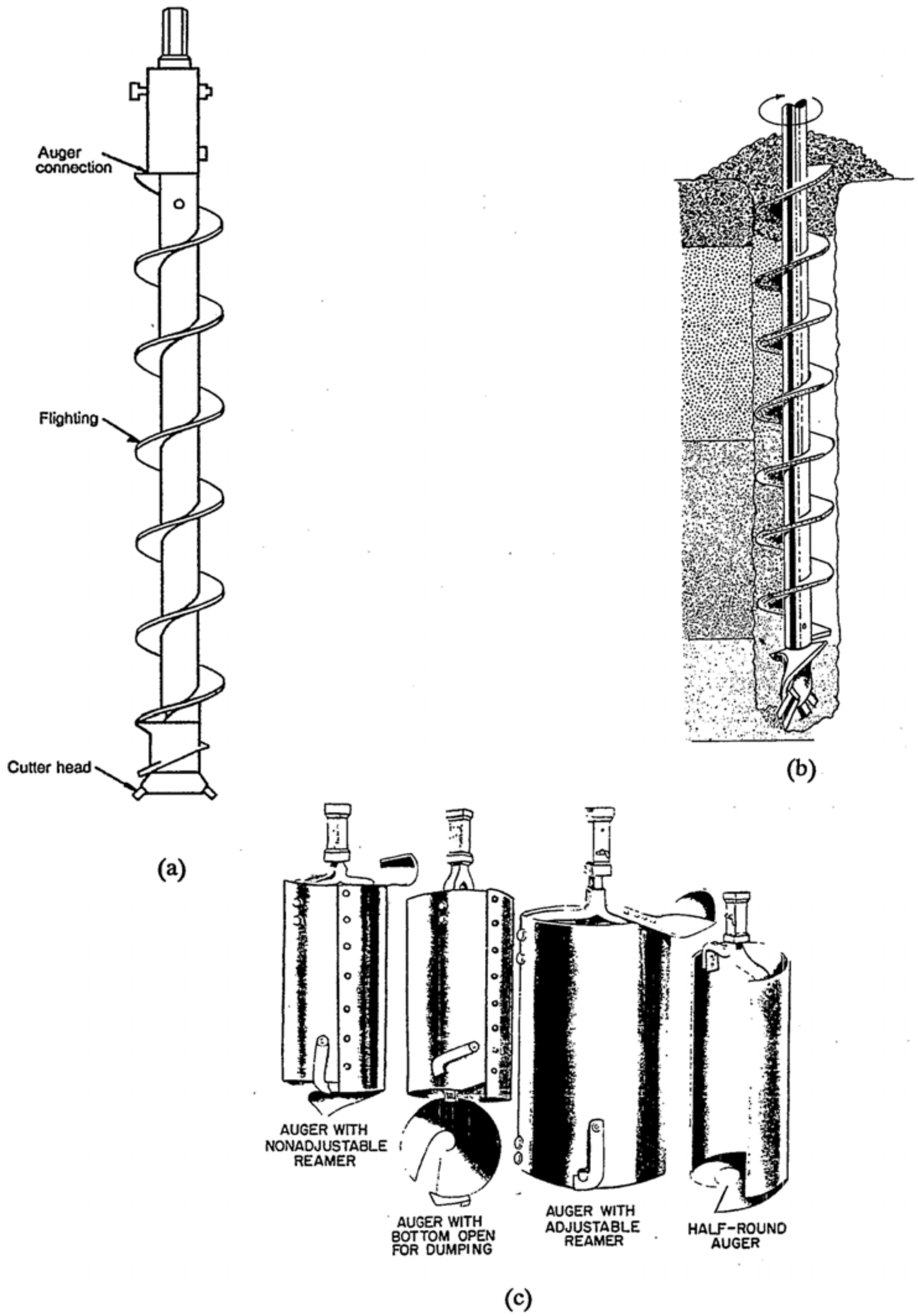

Figure 2.1.9 Power-driven augers: (a) Diagram of solid-flight auger (Aller et al., 1991); (b) Relationship of surface cuttings and subsurface (Scalf et al., 1981); (c) Bits for power bucket augers (U.S. Army, 1981).

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6.23 DIRECTIONAL DRILLING

6.23.1 Other Names Used to Describe Method

Radial/horizontal drilling, conical jet drilling, slant rig drilling.

6.23.2 Uses at Contaminated Sites

Installing horizontal or slanting wells for geophysical measurement or vadose zone monitoring conducting soil and ground-water remediation (pump-and-treat, grouting, soil gas vacuum extraction, bioventing, in situ remediation, and soil flushing).

6.23.3 Method Description

Directional drilling involves use of drilling equipment located at the ground surface to drill slanting or horizontal holes in the subsurface. All directional drilling systems require: (1) A steerable drill stem, and (2) the capability to detect the location of the drill head or trajectory of the borehole. Directional drilling equipment with potential for applications at contaminated sites range in size from scaled-down rigs developed for the oil industry to relatively compact, simple equipment used to install utilities. Eastnian-Qnistensen (BC) has developed a custom-equipped drill rig with a slanting rig mast capable of being oriented from the vertical, to 60 degrees from vertical, which can drill horizontally on a 100-foot radius (Figure 2.Ll.la). The drilling assembly consists of a dual-wall drill string and an expandable bit, which drills a hole large enough to permit casing to be advanced during drilling. The drill bit is guided using measurement from a tool face indicator, which records the indication of the drilling assembly. When the well is drilled to the desired length, the inner drilling assembly is withdrawn and the well screen installed. A horizontal section of screen greater than 500 feet in length can be accurately placed at target depths from around 10 feet to greater than 300 feet. Several radial drilling systems have been developed. In these systems a relatively large diameter vertical hole is first drilled and cased. Specific systems vary somewhat, but have the common elements of a vertical drilling string or assembly with a nonrotating orientation assembly or whipstock at the depth of interest that guides a flexible drive pipe from the vertical to horizontal direction (Figure 2.1.llb). Two types of drilling methods have been reported for radial drill holes: (1) A mud rotary system with a top-drive hydraulic rotary rig (Kaback et aL, 1989), and (2) Petrolphysics conical jet drilling system, which uses a nwzie designed to produce a conical shell of high velocity water that also serves to advance the drill pipe. With the jet drilling system, multiple laterals (as many as 12) up to 200 feet or more can be placed at several levels using the same vertical well (Figure 21.llb). Utility rigs use an initially indined borehole and develop a trajectory that is similar to the BC rig described above, except that the equipment is smaller and less sophisticated. Boring methods include jet-assisted rotary, above-ground hydraulic percussion, water jet, down-hole pneumatic percussion, or down-hole pneumatic motor. Drill head location is monitored using a radio transmitter in the drill head and a receiver at the surface over the drill head. Boring lengths greater than 500 feet at depths of 3 to 20 feet are possible. Greater depths require specialized monitoring equipment. Equipment can be mobilized behind a pickup truck.

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6.23.4 Method Selection Considerations

Advantages: (1) Alloy borehole access to subsurface areas such as beneath buildings, tanks, landfills, and impoundments where vertical drill rigs cannot go; (2) reduces potential for cross-contamination between aquifers; (3) excellent for remediation techniques that require maximum horizontal access to contaminated zone or contaminant plumes that are not vertically dispersed; (4) production from horizontal wells generally is higher than from vertical wells due to greater possible screen length; (5*)* Petrolphysics radial jet drilling is very rapid in bedrock (112 foot per minute in granite, more than 1 foot per minute in sedimentary rock); and (6) cost of drilling with utility rigs is similar to vertical drilling with an auger rig. **Disadvantages**: (1) There has been relatively little actual experience using directional drilling methods at contaminated sites, arid value for site characterization and monitoring (as opposed to remediation) has yet to be demonstrated; (2) drilling costs are high for petroleum industry-related equipment (100 to several hundred dollars a foot); (3) utility rigs, although less expensive than petroleum rigs, have more limited depth capabilities (around 20 feet compared to 300 feet for BC slant rig); (4) equipment that uses water or other fluids to advance the well bore might affect quality of samples; (5) sampling capabilities are currently limited.

6.23.5 Frequency of Use

Small-scale equipment is widely used to install underground utilities. Use of large scale drilling ís well established in the petroleum industry. At contaminated sites, test applications have focused on remedial activities, but good potential exists for use with geophysical and other vadose monitoring methods.

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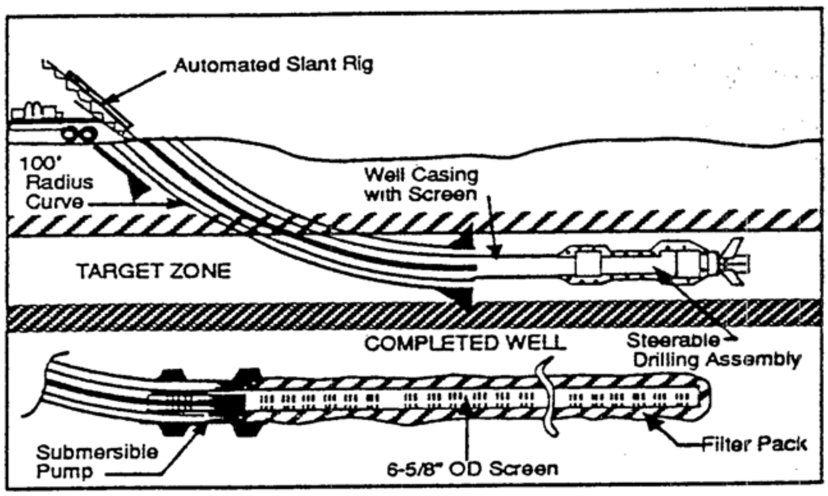
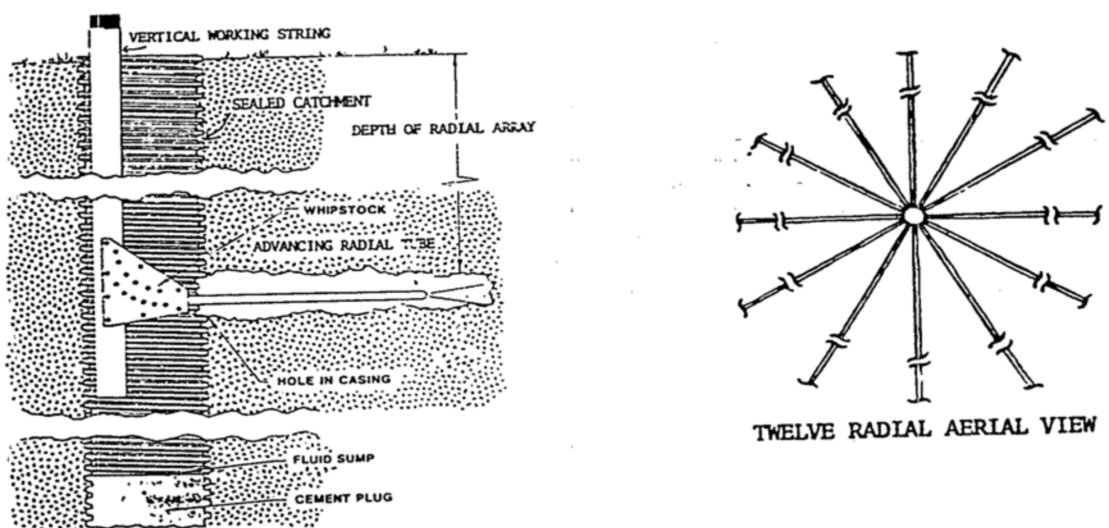
Figure 2.1.11
Directional Drilling Methods



(a)



(b)

Figure 2.1.11 Directional drilling methods: (a) Eastman-Christensen slant rig (Metcalf and Eddy, 1991); (b) Petrolphysics rig with a shallow radial system (U.S. EPA, 1992).

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6.24 DESIGN AND CONSTRUCTION OF MONITORING WELLS

The following section excerpted *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describes groundwater well construction including single-riser/limited interval wells, nested wells/single borehole, nested wells/multiple boreholes, well materials, well development, and well abandonment.

6.24.1 Design And Construction Of Monitoring Wells

This appendix provides an overview of basic elements of the design and construction of permanent ground-water monitoring wells in which portable sampling devices can be used. Section 2 covers well drilling methods and Section 5.4 should be referred to for a discussion of basic types of monitoring well installations. ASTM (1992c) and US. EPA (1992) identifies the minimum set of data elements necessary for documenting the location and construction of monitoring wells.

Figures A-la and A-lb show the basic design components of properly and constructed single- and multi-cased monitoring wells. Nielsen and Schalla (1991) have identified six common monitoring well design flaws and installation problems that should be avoided:

1. Use of well casing or well screen materials that are not compatible with the hydrogeologic environment, known or suspected contaminants, or the requirements of the ground-water sampling program. The result is chemical alteration of samples or failure of the well. See Section A.l.

2. Incorrect screen slot-sizing practices or use of nonstandard types of well screen, such as field-slotted, drilled, or perforated casing, the result is well sedimentation and turbid samples throughout the monitoring program. See Section A.2.

3. Improper length and placement of well screens so that discrete zones of the aquifer are missed or cannot be differentiated. In this situation, water level measurements and water quality samples might provide misleading results. See Section 5.4.

4. Improper selection and placement of filter pack materials. Consequences can include well sedimentation, well screen plugging, ground-water sample alteration, or potential well failure. See Section A.3.

5. Improper selection and placement of annular seal materials. The results can include alteration of chemistry of water samples, plugging of the filter pack and/or well screen, and cross-contamination between water-bearing units that have not be adequately isolated. See Section A.4.

6. Inadequate surface protection measures, such as surface seals that are susceptible to frost heave. The results can include surface water entering the well, chemical alteration of water quality samples, and well damage to destruction. See Section A.4.

Another common installation problem that can be added to this list occurs after installation has been completed:

7. Use of improper well development techniques. The results can include continuing turbidity in water quality samples due to failure to remove fines for the well screen and filter pack, chemical alteration of water quality samples due to the introduction of air or foreign water into the aquifer, and possible damage to the well screen by stresses caused by excessive surging. See Section A.5.

Once a well has been installed, ongoing maintenance is required to ensure proper functioning and rehabilitation might be required if routine maintenance is not able to prevent impairment of well efficiency or if modifications are required for a change in purpose of the well (see Section A.6). Finally, when a well is no longer required for its original or modified purpose, it must be properly abandoned (see Section A.7).

Table A-1, located at the beginning of the reference section, provides an index of general references which cover monitoring well design and installation, as well as references that cover more specific topics.

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Figure A-1
Monitoring Well Design and Construction

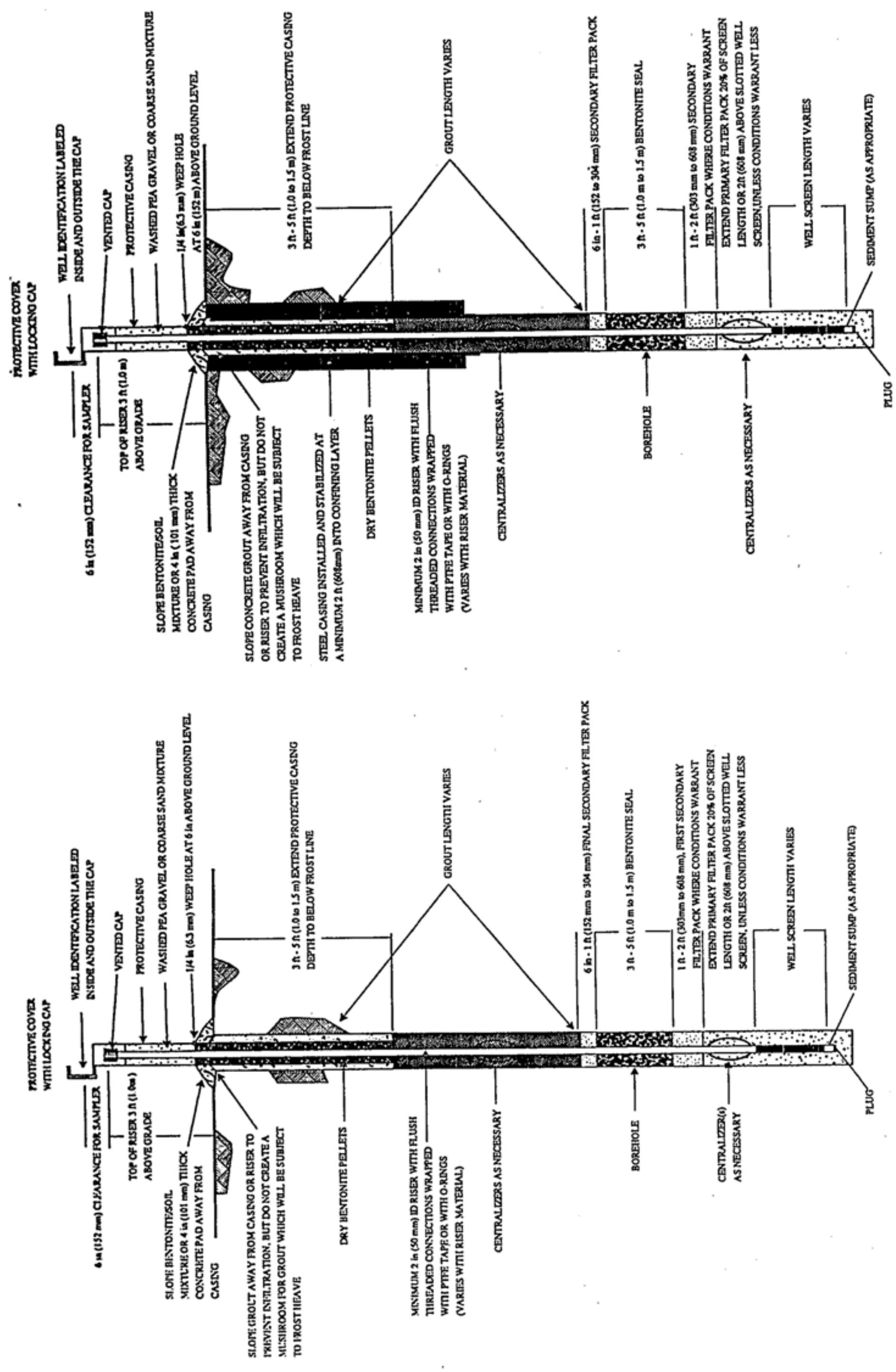

Figure A-1 Monitoring well design and construction: (a) Single-cased monitoring well design (b) Multi-cased monitoring well design (ASTM, 1990a, Copyright ASTM, reprinted with permission).

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6.25 SINGLE RISER/ LIMITED INTERVAL WELLS

6.25.1 Other Names Used to Describe Method

Single-level or short-screened installations/well completions/piezometers.

6.25.2 Uses at Contaminated Sites

Providing access for ground-water sampling of specific subsurface intervals.

6.25.3 Method Description

A borehole is drilled to the desired depth in an aquifer and a short to moderate length screen (usually 3 to 10 feet) is installed (Figure *5.4.1).* See Appendix B for additional information on well installation, and Figure B.la for a more detailed schematic of elements of a monitoring well

6.25.4 Method Selection Considerations: **Advantages:** (1) Simple and suitable for any type of formation; (2) easier to install, pack, and seal than multilevel installations; (3) no potential for vertical cross-contamination between sampling points due to leaky seals; *(4)* maximum flexibility in selection of well diameter (up to diameter of borehole); and *(5)* most common well diameters (2 to 4 inches) do not restrict the choice of sample collection methods. **Disadvantages:** (1) Provide no information on the vertical distribution of contaminants; (2) high cost per sampling point compared to multilevel installations, especially at great depth; and (3) contaminant plume might bypass wells with short screened intervals.

6.25.5 Frequency of Use Common.

6.25.6 Standard Methods/Guidelines —

6.25.7 Sources for Additional Information Aller at al. (1991), Gillham et al. (1983), Morrison (1983), Scalf et al. (1981).

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Figure 5.4.1
Typical Monitoring Well Screened Over A Single Vertical Interval

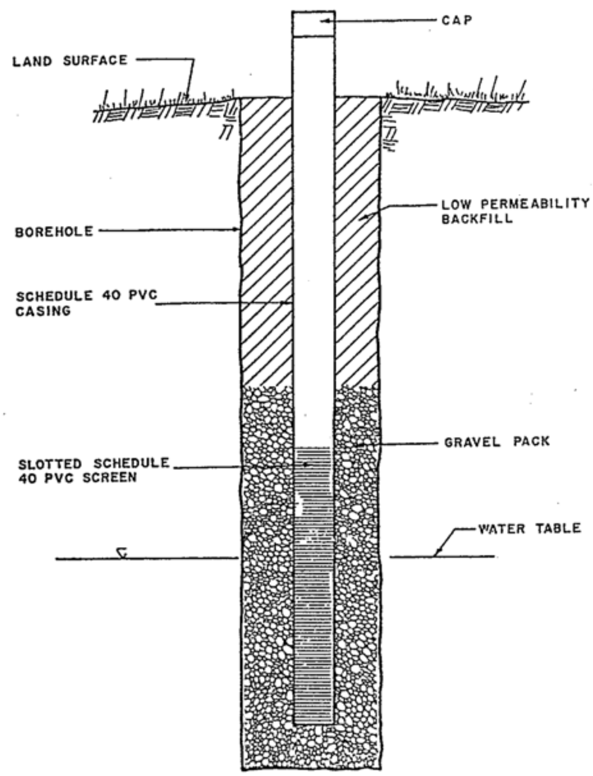

Figure 5.4.1 Typical monitoring well screened over a single vertical interval (Gillham et al., 1983, after Fenn et al., 1977, by permission).

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6.26 NESTED WELLS/SINGLE BOREHOLE

6.26.1 Other Names Used to Describe Method

Multiple wells/single borehole installation, multiple well-single borehole installation/completion, well dusters, hybrid.

6.26.2 Uses at Contaminated Sites

Delineating contaminant plumes; detection monitoring

6.26.3 Method Description

A cluster of single-riser/limited interval wells is installed at different depths in a single borehole (Figure *5.4.3a).* Each screened interval is separated by a grout seal. In cohesionless deposits, bund pyrometers can be installed, which consist of a bundle of narrow-diameter standpipe pyrometers, each a different length. At the bottom of each pipe is a short (6-8 inch) slotted interval wrapped with fine screen. A duster of nine piezometers can be placed down a hollow-stem auger, and the formation is allowed to cave in around the bundles as the auger is withdrawn from the hole (Figure *5.4.3b).* Well casings can be eliminated by installing in situ samplers (well screens with submersible pumps) or individual gas-direction-lift samples (Section *5.6.1)* at different levels in a single borehole. **Hybrid** well installations can involve a variety *old* combinations of permanently placed in situ vadose zone and ground-water monitoring devices and/or small diameter monitoring wells (Figure *5.4.3c).*

6.26.4 Method Selection Considerations

Advantages: (1) Allow sampling for vertical distribution of ground-water constituents; (2) lower cost per sampling point than separate single-riser wells; and (3) the generally smaller diameters of individual wells in a nest compared to single-riser installations means that smaller volumes of water must be removed for purging. **Disadvantages**: (1) Installation, packing, and sealing is more difficult than for single-level installations and increases greatly as the number of wells in the boreholes increases; *(2)* the shod- screened intervals must be separated by a grout seal with the possibility that small zones of contaminated water might be missed in heterogeneous materials (reconnaissance methods such as destructive sampling [see Sections *5.7.1* and *5.7.2]* can reduce the this likelihood); (3) cross-contamination of sampling points might occur as a result of leaky seals (this can be checked using tracer tests); (4) number of sampling points per borehole is restricted by the diameter of the borehole and the diameter of the individual piezometer; (5) bundle piezometers are suitable only where cohesion less sands will collapse around the tips (6) the small diameter of individual piezometers might restrict choice of sampling methods; and (7) in fine-grained material with low hydraulic conductivity the small storage volume of individual piezometers might make it difficult to collect samples of sufficient volume.

6.26.5 Frequency of Use Relatively uncommon.

6.26.6 Standard Methods/Guidelines —

6.26.7 Sources for Additional Information

Aller et al. (1991), Fenn et al. (1977), Gillham et al. (1983), Morrison: 1983), Scalf at al. (1981). See also, Table 54.

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Figure 5.4.3
Multiple Wells in a Single Borehole

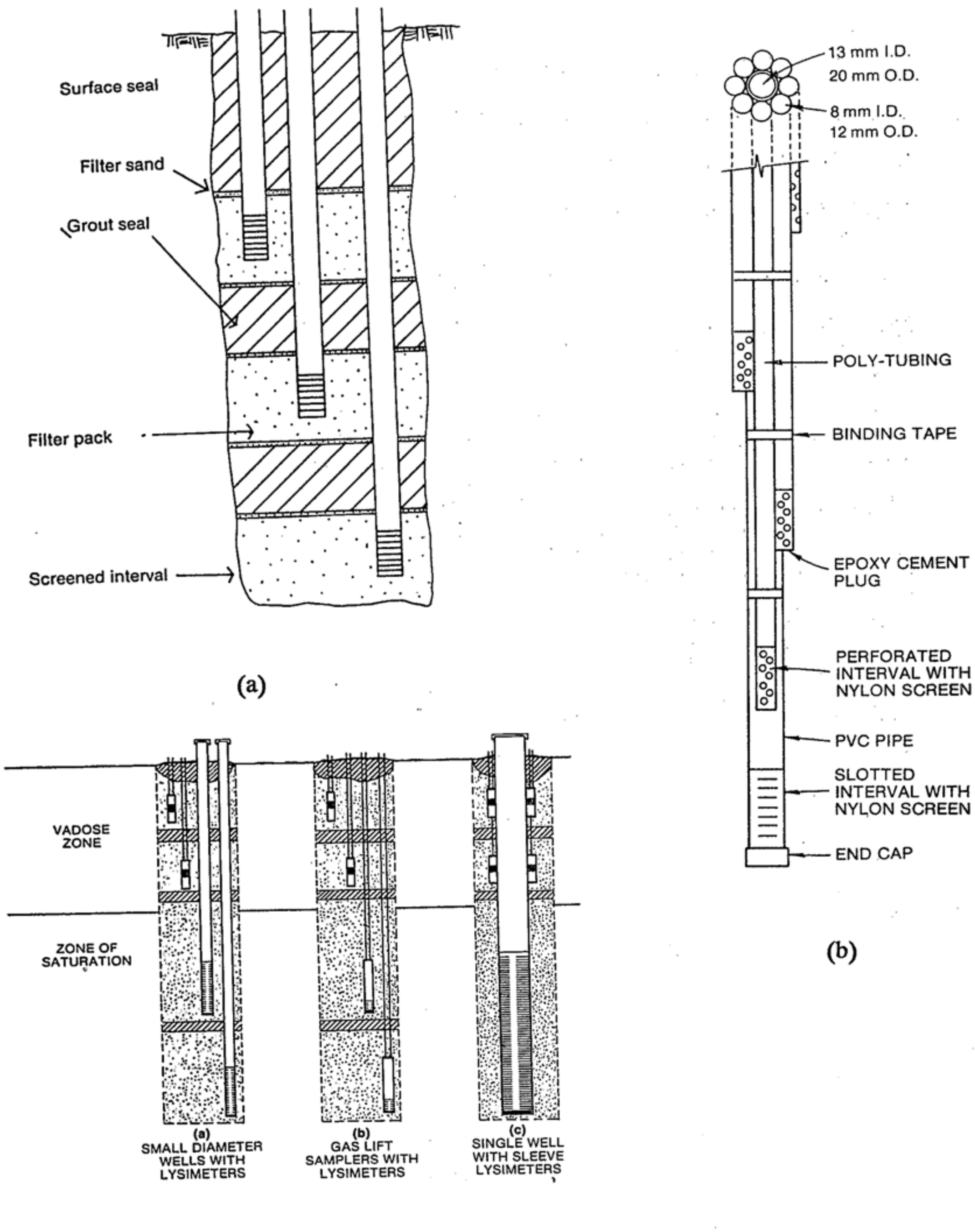

Figure 5.4.3 **Multiple wells in a single borehole: (a) Conventional completion (Aller et al., 1991, after Johnson, 1983); (b) Bundle piezometers (Morrison, 1983, by permission); (c) Hybrid well systems (Morrison, 1983, by permission).**

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6.27 NESTED WELLS/ MULTIPLE BOREHOLES

6.27.1 Other Names Used to Describe Method

Multi-level wells/multiple borehole installation, multi-level wells/multiple borehole completion.

6.27.2 Uses at Contaminated Sites

Delineating contaminant plumes detection monitoring

6.27.3 Method Description

A series of single-riser/limited interval wells is installed at different depths in an aquifer in separate, but closely spaced or clustered boreholes (Figure *5.4.4).* See Appendix B for additional information on well installation.

6.27.4 Method Selection Considerations

Advantages: (1) Allow sampling for vertical distribution of ground-water constituents; (2) somewhat lower cost per sampling point than widely spaced single-riser wells; (3) simple design and operation; *(4)* potential for cross-contamination between different levels in the aquifer is eliminated (5) only the drilling method limits well diameter and (6) if desired, screened intervals can be placed to provide complete vertical coverage of the aquifer. **Disadvantages:** (1) More expensive than nested wells in a single borehole; and (2) small zones of contaminated water might be missed in heterogeneous materials if the screened intervals do not provide complete vertical coverage of the aquifer (reconnaissance methods such as distinctive sampling [see Sections 5.7.1 and 5.7.2] can reduce the this likelihood).

6.27.5 Frequency of Use Common.

6.27.6 Standard Methods/Guidelines —

6.27.7 Sources for Additional Information

Aller et al. (1991), Gillham et al. (1983), Reynolds (1991).
Figure 5.4.4 Nested wells with multiple boreholes (Aller et al, 1991, after Johnson, 1983).

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Figure 5.4.4
Nested Wells with Multiple Boreholes

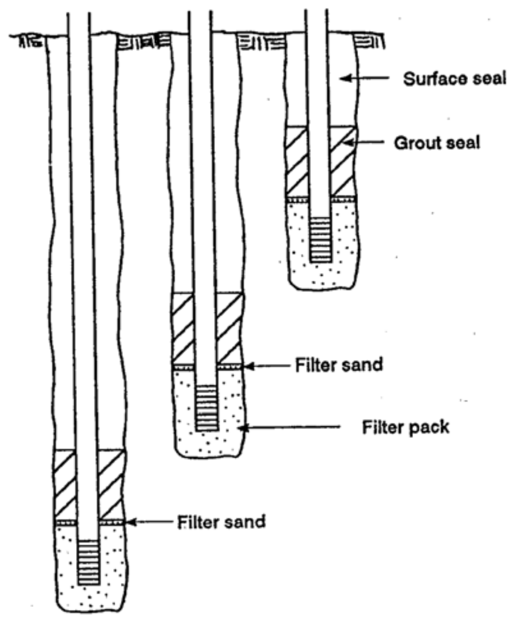

Figure 5.4.4 **Nested wells with multiple boreholes (Aller et al., 1991, after Johnson, 1983).**

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6.28 WELL CASING MATERIAL SELECTION

6.28.1 Other Names Used to Describe Materials

Thermoplastics: Polyvinyl chloride (PVC), aciylonitrile butadienestyrene (ABS).Fluoropolymers: Polytetrafluomethyiene/tetrafluoroethylene (PTFEITFE, Teflon, Halon, Fluon, Hostaflon, Polyflon, Algoflon, Soriflon), fluorinated ethylene propylene (PEP, Neflon, Teflon), perfluomalkoxy (PFA, Neoflon, Teflon), pdyvinylidine fluoride (PVDF, Kynar), chlorotrifluoroethylene (CThI, Kcl-F, Diaflon). Metallic: Cast iron, mild joft steel, carbon steel, low carbon steel, galvanized steel, and stainless steel (particularly types 304 and 316). Fiber-glass reinforced: Fiberglass-reinforced epoxy (FRE), fiberglass-reinforced plastic (PRP),

6.28.2 Uses at Contaminated Sites

6.28.3 Casing Materials For Monitoring Wells

6.28.4 Materials Description

Thermoplastics include varying formulations of plastics, which are molded or extruded to form rigid well casing (PVC and ABS) or tubing (polyethylene and polypropylene). Fluoropolymers are plastics with high chemical resistance consisting of different formulations of fluoromonomers, which can be either molded by powder metallurgy methods or extruded with heat. Metals: Various types of steel tubing Fiberglass reinforced plastic or epoxy forms casing of higher strength than thermoplastic or fluoropolymer materials.

6.28.5 Materials Selection Considerations

Plastic Casing Advantages: (1) is lightweight; (2) PVC is inexpensive; and (3) generally good to excellent chemical resistance (fluompolymers have the best chemical resistance, except for fluorinated solvents; PVC has poor resistance to high concentrations of aromatic hydrocarbons [toluene, xylene, trichlorethylene] esters, and ketones). **Plastic Casing Disadvantages:** (1) Weaker, less rigid, and more temperature sensitive than metallic materials (PTFWIFE is especially low, PVDF s stronger, ABS has low strength and less heat resistance compared to *PVC);* (2) *PVC* might adsorb some constituents from ground water, (3) PVC might react with and leach some constituents into ground water and PTFE is prone to sorption of selected organic compounds (proper purging and sampling procedures can minimize these problems); (4) fluoropolymers are expensive (PVDF is less expensive than PTFE,'rFE); (5) some materials are not commonly available (ABS, PVDF); (6) tensile strength of wear resistance of PTFWFE is low compared to other plastics, and screen slot opening might decrease in size overtime; and (7) antistick properties of fluoropolymer materials make it difficult to achieve an annular seal with neat cement grout, creating potential for alteration of groundwater chemistry by percolating surface water (see Figure A.4a). **Metallic Casing Advantages:** (1) Stainless steel has least adsorption of halogenated and aromatic hydrocarbons; (2) all steel casings have high strength and generally are not temperature sensitive; (3) stainless steel has excellent resistance to corrosion and oxidation; (4) stainless steel is readily available in all diameters and screen slot sizes; and (5) mild steel is readily available and less expensive than stainless steel for casing. **Metallic Casing Disadvantages**: (1) Heavier than plastics; (2) stainless steel might corrode and leach some chromium in highly acidic water, and might act as a catalyst in some organic reactions; (3) stainless steel screens are more expensive than plastic screens; (4) mild steel might react with and leach some constituents into ground water and is not as chemically resistant as stainless steel; (5) under saturated conditions carbon and low carbon steel rust easily, providing highly sorptive surface for many metals, and they deteriorate in corrosive environments; and (6) zinc might leach from galvanized steel, and if the coating is scratched, will rust, providing a highly sorptive surface for metals. **Fiberglass Reinforced Advantages**: (1) High- strength (almost as strong as stainless steel); (2) light (weighs about the same as PVC); and (3) limited available data indicate that it is relatively inert in most monitoring well environments. **Fiberglass Reinforced Disadvantages:** (1) Some adsorption of volatile organics (can be overcome by proper purging and sampling procedures; and (2) not readily available and little data available on its performance in the field.

6.28.6 Frequency of Use

PVC in the most commonly used casing material, followed by stainless steel. PTFE is uncommon due to expense and low strength (best application where concentrations of organic solvents are high [parts-per-thousand levels] and highly corrosive conditions preclude use of metallic casing).

6.28.7 Standard Guidelines ASTM (1990a, b).

6.28.8 Sources for Additional information

Aller et al. (1991), Devinny et al. (1990), Driscoll (1986), Nielsen and Schalla (1991).See also, Table A-L

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6.29 WELL SCREEN SELECTION

6.29.1 Other Names Used to Describe Method

Monitoring wells: Wire-wound (plastic) continuous-slot, vertical or horizontal machine slotted casing, factory slotted perforated pipe, bridge-slot, shutter-type (louvre-type). Other well screens: Field slotted pipe (torch cut or perforated), wire-wound perforated pipe (pipe-based screen).

6.29.2 Uses at Contaminated Sites Allowing ground water to enter monitoring wells for sampling.

6.29.3 Method Description

Well screens of the appropriate length and slot size are attached to solid casing and placed at the depth in the aquifer where sampling is desired. This method usually is used in unconsolidated formations in combination with filter pack (see Section A.3) to minimize entry of fine particles from the aquifer into the well during development (Section A.5), purging (Section B.2), and sampling (Section B3). The slot size is selected to: (1) Maximize open area for water to flow through, and (2) minimize entry of fines into the well during pumping. The major types of well intake screens are: (1) Factory slotted (Figure A.2a), (2) continuous slot (Figure A.2b), (3) bridge slot (Figure A.2c), and (4) shutter type (Figure A.2d). Other types include field- slotted pipe, in which slots are manually cut, and wire-wound perforated pipe.

6.29.4 Method Selection Considerations

Factory Slotted Casing Advantages: (1) Has good slot control; (2) is readily available; and (3) is inexpensive. **Factory Slotted Casing Disadvantages**: (1) Low amount of open area makes development difficult; (2) rough, jagged edges might be present, forming surface for sorption of chemicals, (3) lighter stock metal screens (less than 8 gage) not strong enough for depths greater than 100 to 150 feet, and plastic screens much weaker (one-sixth to one-tenth as strong as stainless steel screens) are used. **Continuous Slot Advantages**: (1) Very good slot control is possible, allowing custom made slot sizes for specific aquifer gradations; (2) wide range of slot sizes arc available; (3) is the most efficient screen available because of high amount of open area, facilitating development and ensuring good *flow* for sampling. (4) wire-wound is made in both telescoping and pipe sizes; and (5) plastic is less expensive than wire-wound. **Continuous Slot Disadvantages**: (1) Wire-wound is more expensive than slotted pipe, but still moderately priced; and (2) plastic screens have much lower strength than metal screens. **Bridge and Shutter Type Advantages**: (1) Slots are accurately sized; (2) are wire-brushed to remove roughness and irregularities; (3) have reasonably high intake area (up to 20%); and (4) are relatively inexpensive. **Bridge and Shutter Type Disadvantages**: (1) a relatively easily, (2) have relatively low collapse strength; (3) have a minimum diameter of 6 inches. Field-Slotted pipe Is not recommended due to low amount of open area, poor slot control, and the development of rough jagged edges, which are vulnerable to corrosion (metal pipe). **Wire-wound perforated**

pipe screens have good tensile and collapse strength, but have relatively low open area and are easily dogged with fines.

6.29.5 Frequency of Use

Wire-wound continuous-slot (or continuous plastic slotted) screens and machine slotted casing are the most commonly used types of screens, because they are the most readily available for 2-inch monitoring wells.

6.29.6 Standard Methods/Guidelines ASTM (1990a).

6.29.7 Sources for Additional Information

Aller et al. (1991), Bureau of Reclamation (1981), Devinny et al. (1990).See also, TableA-I.

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Figure A.2
Major Types of Well Screens

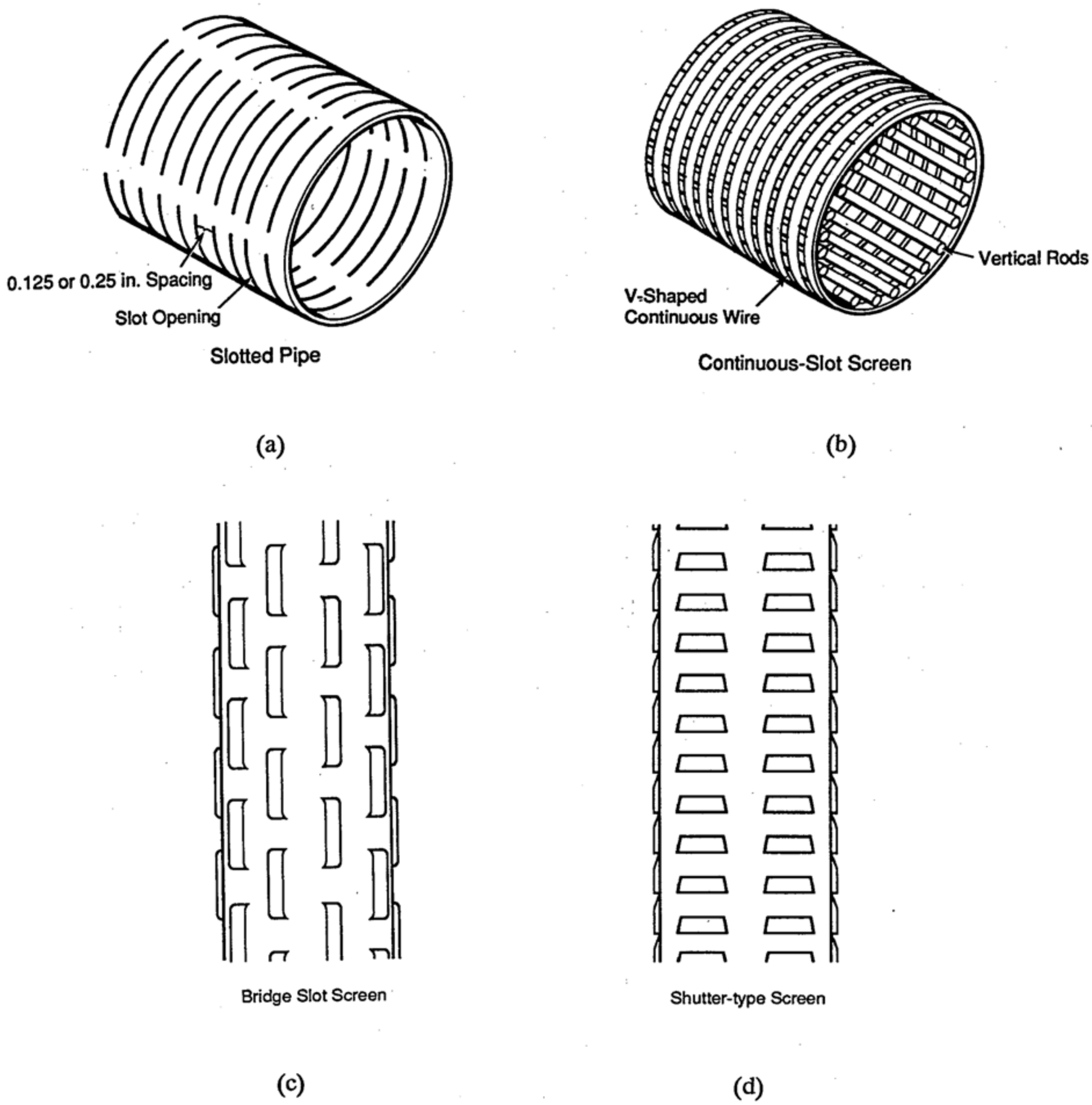

Figure A.2 Major types of well screens: (a) Slotted (Nielsen and Schalla, 1991, by permission); (b) Continuous slot (Nielsen and Schalla, 1991); (c) Bridge slot (Aller et al., 1991, by permission); (d) Shutter type (Aller et al., 1991).

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6.30 FILTER PACK SELECTION

6.30.1 Other Names Used to Describe Method Natural and artificial "gravel" pack/sand pack.

6.30.2 Uses at Contaminated Sites

Increasing hydraulic conductivity around the well screen and keeping fine partides from entering the well screen during ground-water sampling.

6.30.3 Method Description

An artificial filter pack *is* placed around the well screen. The filter pack must: (1) Be clean (to minimize loss of material during development and development time [Section A.5j), (2) have well-rounded grains (to increase hydraulic conductivity porosity yield, and effectiveness of well development), (3) have 90 to *95%* quartz grains (to minimize changes to ground-water chemistry and to eliminate loss of volume by dissolution of minerals), and (4) have a uniformity coefficient of 2.5 or less (to minimize separation during installation and lower head loss). Alternatively, well screen slot size is determined based on the particle-size distribution in the aquifer materials and the fines are removed during the development process. In relatively shallow wells, the filter pack can be placed by simply dumping sand down the annulus (provided the annular space is more than 2 inches). More typically, the filter pack is placed by pouring the sand into a tremie pipe a rigid or partially flexible tube of pipe that allows funneling of the material directly to the interval around the well screen (Figure A.3a). Other methods include the reverse circulation method, where a sand and water mixture is fed into the annulus around the well screen and the water entering the screen is pumped up to the surface (Figure A.3b), and backwashing, where water is pumped down the well and allowed to rise up around the annular area as filter- pack material filters down through the rising water (Figure A.3c).

6.30.4 Method Selection Considerations

Artificial Piker Pack Advantages: Characteristics of the filter-pack material can be selected for optimum efficiency of well operation. **Artificial Filter Pack Disadvantages**: (1) Procedure is relatively time consuming and expensive; (2) bridging might prevent complete filling around the well screen; (3) extension of filter pack above or below the screen area might allow contaminants to move to uncontaminated areas; (4) filter pack material might introduce contaminants into the aquifer (a leaching test can be used to determine whether this might be a problem); and (5) use of reverse circulation and backwashing emplacement methods might alter ground-water chemistry. **Natural Filter Pack Advantages**: (1) Simpler and can be less expensive (depending on time requirements for well development); and (2) potential for alteration of groundwater chemistry is minimized. **Natural Filter Pack Disadvantages**: (1) Well development is more difficult, and success is less assured; (2) selection of optimum screen slot size is more difficult.

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6.30.5 Frequency of Use

Filter packs are a standard feature of monitoring wells. Artificial filter packs are usually used in finer and very coarse grained material.

6.30.6 Standard Methods/Guidelines ASTM (1990a).

6.30.7 Sources for Additional Information

Ailer et al. (1991), Campbell and Lehr (1973), Driscoll (1986), U.S. EPA

6.31 GROUTS AND SEALS

6.31.1 Other Names Used to Describe Method Bentonite, cement, neat cement.

6.31.2 Uses at Contaminated Sites

Sealing the annular space between the well casing and the formation to prevent contaminants from moving upward or downward to uncontaminated areas (Figure A.4).

6.31.3 Method Description

After the filter pack is placed, grout (usually either bentonite or neat cement) is used to provide the optimum seal in the annual space between the casing and borehole walls. Bentonite can be placed either as unhydrated pellets or chips with water added later, or pumped down through a tremie pipe as a slurry. Neat cement (a mixture of *5* to 6 gallons of clean water per 1 cubic foot bag of Portland Cement, usually Type I) is mixed manually or with a mechanical mixture and pumped into the annulus. A variety of additives can be mixed with the cement slurry to change the properties of the cement (Table A.4). The more common additives include: (1) Bentonite (to improve workability, and to reduce weight and shrinkage), (2) calcium chloride (to accelerate setting time and create higher early strength, especially useful in cold climates), (3) gypsum (quick setting, expanding cement, but expensive), (4) aluminum powder (which produces a strong, quick-setting cement than expands on setting), (5) fly ash (to increase sulfate resistance and early compressive strength), (6) hydroxylated carbozylic acid (to retard setting time and improve workability without compromising set strength), and (7) diatomaceous earth (to reduce slurry density and thickening time, but increase water demand and reduce set strength). Table A.4 summarizes information on the effect of 15 additives commonly used with cement. Major surface sealing measures include: (1) Placement of a sturdy protective outer casing with cover and lock to a depth below the frost line and a drainage hole to prevent moisture buildup between the protective casing and the well casing, and (2) placement of a concrete pad sloping away from the casing to prevent infiltration of surface water and shaped so as to prevent frost heaving. See Figure A-la for typical surface protection measures.

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6.31.4 Method Selection Considerations

Bentonite Advantages: (1) is readily available; (2) is inexpensive; and (3) pellets or slurry can be used. **Bentonite Disadvantages** (1) Might cause constituent interference due to Ion exchange; (2) might not give complete seal and complete bond to casing cannot be assured; (3) pellets might bridge or wet and swell, sticking to the formation or casing before filling the annular space; and (4) pump might clog if shiny gets too dense. **Cement Advantages**: (1) Is readily available; (2)is inexpensive; (3)can use sand and/or gravel filler and (4) is possible to determine how well the cement has been placed by means of temperature logs (see Figure 2.6.a) or sonic bond logs (Section 3.6.2). **Cement Disadvantages** (1) Might cause constituent interferences (high pH with attendant change in ground-water chemistry); (2) mixer, pump, and trernie lines are required and more cleanup generally is required compared to bentonite; (3) can have problems getting the material to set up; (4) channeling between the casing and seal might develop because of temperature changes during the curing process, swelling and shrinkage of the grout while the mixture cures, and poor bonding between the grout and the casing surface; and (5) heat from setting can compromise structural integrity of some well casing materials (i.e., thermoplastic)

6.31.5 Frequency of Use Both bentonite and neat cement are used widely.

6.31.6 Standard Methods/Guidelines API (1990, 1991a), ASTM (1990a, 19921).

6.31.7 Sources for Additional Information Aller et al. (1991), Driscoll (1986). See also, Table A-I.

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Figure A.4

Potential Pathways for Fluid Movement in the Casing-Borehole Annulus

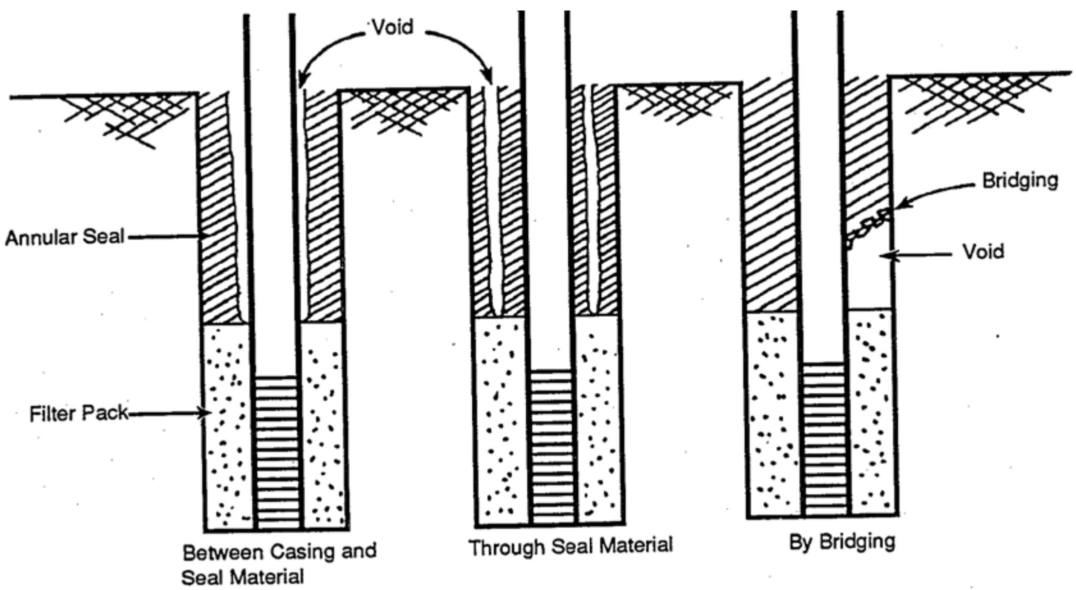

Figure A.4 Potential pathways for fluid movement in the casing-borehole annulus (Aller et al., 1991).

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6.32 WELL DEVELOPMENT

6.32.1 Other Names Used to Describe Method

Over-pumping, backwashing, surge-plunger, surge block, mechanical surging, bailer, compressed air, airlift pumping, air surging, high velocity (water/hydraulic) jetting, blasting, acidizig,

6.32.2 Uses at Contaminated Sites

Removing fines from filter pack around monitoring wells top hydraulic performance and eliminate or reduce collection of sediment in water quality samples; rectifying damage done during drilling to borehole wall and adjacent formation.

6.32.3 Method Description

In **overpumping,** the well is pumped at a rate that substantially exceeds the ability of the formation to deliver water. **Backwashing** often is used in conjunction with overpumping. If the pump does not have a backflow prevention valve, alternately starting and stopping the pump creates a surging effect where water is driven back into the formation during the off cycle. Alternatively, water can be added to the well (Figure A.5a). In **bailing,** a bailer (Section 53.1) is allowed to fall freely through the borehole until it strikes the surface of the water. The impact of the bailer produces an outward surge of water through the well screen and filter pack. As the bailer fills, the flow of water reverses and fines migrate into the well and are brought to the surface in the bailer. Sediment in the bottom of the well can be mobilized by short rapid strokes of the bailer near the bottom before retrieving the bailer. **Mechanical surging** forces water into and out of the well screen by operating a plunger, called a surge block, which is attached to a drill rod or a wire line (Figure A.5b). The surge block is lowered to the top of the well intake and operated in a pumping action with strokes typically around 3 feet and is gradually varied downward through the screened interval. At regular intervals, the surge block is removed and fines that have entered the well are removed by pumping or with a bailer. **Compressed air** can be used to alternately surge and air-lift pump a well to remove sediment. **In air surging**, injected air lifts the water column until it reaches the top of the casing and the air supply is shut oft causing an outward surging action in the well intake. Air lift pumping using compressed air (Figure A.5c) brings water to the surface as described in Section 5.2.4k. **High velocity jetting** uses a single- or multiple-nozzle device, which directs a horizontal stream of water against the well screen opening (Figure Aid). The jetting tool is placed near the bottom of the screen and slowly rotated while being pulled upward. Material that enters the screen in the backwash of the jet stream is removed by pumping or bailing. **Jetting/pumping**, which combines jetting with simultaneous pumping, provides for maximum development efficiency. Two development methods that are used for water wells but are not recommended for monitoring well development because they introduce contaminants into the aquifer are: (1) Blasting (used only in solid rock wells), and (2) acidizing (used only in limestone aquifers).

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6.32.4 Method Selection Considerations

Overpumping Advantages: (1) Is convenient for small wells or poor aquifers; (2) minimal Time and effort are required; (3) no new fluids are introduced; and *(4)* removes fluids introduced during drilling and fine sediments. **Overpumping Disadvantages**: (1) Not adequate for large wells; (2) will not develop maximum efficiency in a well because does not effectively remove fine-grained sediment; (3) tends to cause sand to bridge in the formations (can be reduced by alternating pump on and pump off) (4) requires the use of high capacity pumping equipment; (5) can result in a large volume of water to be contained and disposed; (6) can leave the lower portion of large screen intervals undeveloped; (7) excessive pumping rates can caused well collapse, especially in deep wells; and (8) equipment for effective overpumping might not fit in small diameter wells. **Backwashing Advantages**: (1) Effectively rearranges filter pack; (2) effective in breaking down bridging and (3) no new fluids introduced with on-off overpumping. **Backwashing Disadvantages**: (1) Fine sand, mud, silt, or clay can be washed into the well or filter pack from the formation; (2) not fully effective unless combined with surging, bailing, or pumping; (3) large quantities of water are required; (4) unless combined with pumping or bailing, does not remove drilling fluids; and (5) backwashing with added water introduces fluid into the well that might alter formation chemistry. **Bailing Advantages**: (1) No new fluids are introduced into the aquifer, (2) removes fluids introduced during drilling; (3) removes fines from well; and (4) bailers are easily obtained and can double as sampling devices. **Bailing Disadvantages**: (1) Is time-consuming and tiring If done manually, (2) not as effective as surge blocks; and (3) is not effective in unproductive wells. **Mechanical Surging Advantages**: (1) Is low cost; (2) effectively rearranges filter pack; (3) has greater suction action and surging than backwashing (4) breaks down bridging in filter pack *(5)* no new fluids are introduced; and (6) convenient to use for cable-tool rigs. **Mechanical Surging Disadvantages**: (1) Can produce unsatisfactory results when an aquifer contains clay because the casing or screen can collapse if it becomes plugged with fines; (2) tends to push fine-grained sediments into the filter pack; (3) unless combined with pumping or bailing, does not remove drilling fluids. (4) sometimes the well seal can be disturbed when surging; and (5) excessive sand can result in sand- locking of the surge block. **Compressed Air Advantages**: It is a rapid method. **Compressed Air Disadvantage**: Not recommended for monitoring wells because: (1) Air can become entrained in the filter pack and reduce permeability (2) where yield is very weak and drawdown rapid, or submergence is low, other methods will be more satisfactory, and (3) introduction of air into aquifer can alter chemistry. **Jetting Advantages**: (1) Simple to use; (2) effectively rearranges and breaks down bridging in filter pack; (3) effectively removes mud cake around screen; (4) jetting with simultaneous pumping is particularly successful for wells in unconsolidated sands and gravels; and (5) jetting/pumping removes sediment from the well before it can settle in the screen and jetting waters can be recirculated after sediment has been removed at the surface. **Jetting Disadvantages**: Generally not recommended because: (1) Foreign water and possible contaminants are introduced to the aquifer (2) air blockage can develop with air jetting; (3) air jetting can change water chemistry and biology (iron bacteria) near well; (4) unless combined with pumping or balling, does not remove drilling fluids; and (5) jetting with simultaneous pumping is not always practicable.

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6.32.5 Frequency of Use

Well development in some form should be performed on any monitoring well. Overpumping and backwashing are probably the most commonly used forms of well development. These methods or bailing combined with mechanical surging will be the most effective methods for most situations.

6.32.6 Standard Methods/Guidelines: Draft ASTM guide(AS1M,1993).

6.32.7 Sources for Additional Information

Aller et al. (1991), Barcelona et al. (1983), Barrett Ct al. (1980), Campbell and Lehr (1973), Driscoll (1986), GeoTrans (1989), Scalf et al. (1981), Unwin (1982),U.S.EPA(1986).Seealso,TableA-1.

6.33 WELL ABANDONMENT

Chapter 9 of this manual also includes the Division of Water Rights requirements for well abandonment specific to the State of Utah.

6.33.1 Other Names Used to Describe Method Decommissioning.

6.33.2 Uses at Contaminated Sites

Eliminating physical hazards preventing ground-water contamination; conserving aquifer yield and hydrostatic head; preventing intermixing of subsurface water.

6.33.3 Method Description

Well abandonment involves the combination of full or partial casing/screen removal and plugging. **Casing/screen removal techniques**: The two main casing removal techniques are: (1) **Pulling,** using hydraulic jacks or by pumping the casing with a rig, and (2) **over drilling**, in which a large-diameter hollow stem auger is used to drill around the casing. In shallow, sandy aquifers, casing can be removed by jetting (see Section 2.1.8). **Sandlocking** can be used' to remove telescoped well screens, where the diameter is smaller than the casing. A pulling pipe wrapped with burlap strips is lowered to penetrate about 2/3 of the length of the screen. Sand is added to create a locking effect and the screen is pulled to the surface. **Latch-type** tools can be used to remove telescoped well screens that are 2 to 6 inches in diameter. **Partial casing removal** involves cutting the casing off below ground level. **Plugging techniques**: The simplest technique for plugging an uncased borehole is to fill the entire hole with grout material, commonly a cement/bentonite mixture (Section A.4), which is chemically compatible with the formation. Where casing is left in place, the interval adjacent to water-bearing zones is ripped or perforated with casing tippers, gun-perforators, or jet perforators, and grouted under pressure to allow penetration outside the casing. **Partial grouting** requires the use of bridge plugs, which allow sealing of selected portions of a borehole. **A permanent bridge seal** is the most deeply located plug that forms a bridge upon which fill material can be placed and is used to prevent cross contamination between lower and upper aquifers. If more than two water-bearing zones are intersected by the wells. Intermediate seals are placed adjacent to intermediate zones and the remaining permeable zones are filled with clean disinfected sand, gravel, or other material. Uppermost aquifer seals keep out surface water and keep artesian aquifers from flowing to the surface. In artesian aquifers, special procedures might be required for plugging such as: (1) Pumping nearby wells to lower hydrostatic head, (2) placing fluids of high specific gravity in the borehole, or (3) elevating the casing high enough to stop the flow.

6.33.4 Method Selection Considerations

Casing Removal Advantages: Preferred method for abandonment because complete removal of casing provides greatest assurance that the hole is completely sealed. **Casing Removal Disadvantages:** (1) Pulling method generally is not feasible if casing has been sealed and grouted; (2) over drilling requires hollow stem at least 2 inches larger than the casing being removed, which might not be available; (3) over drilling will not work in consolidated formations and might be difficult if the well casing is not plumb, (4) sandlocking and latch-type tools can only be used when screen diameter is smaller than the inner diameter of casing and (5) unstable boreholes require placement of grout at the same time the casing is pulled. **Plugging Advantages**: (1) Full plugging provides the greatest assurance that there will be no contamination or cross contamination of aquifers; and (2) partial plugging is less expensive than full plugging. **Plugging Disadvantages**: (1) Pull plugging is more expensive than partial plugging, especially in deep boreholes; and (2) partial plugging procedures are more complex and do not provide as great assurance that the effective seals have been developed.

6.33.5 Frequency of Use

All wells should be properly abandoned when they are no longer needed for their original or a modified purpose.

6.33.6 Standard Methods/Guideline:

ASTM (1992c). Most states have well abandonment laws (see Kraemer et al., 1991 for summary of status of state well abandonment requirements). AWWA (1984), also reproduced as Appendix C in Met et al. (1991), provides general guidelines for well abandonment.

6.33.7 Sources for Additional Information

Aller et al. (1991), Campbell and Lehr (1973), Driscoll (1986), US. EPA (1975, 1986). See also, Table A-I.

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6.34 GROUNDWATER SAMPLING DEVICES

The following section is also excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) and describes the most commonly used groundwater sampling devices including bailers, bladder pumps, and suction-lift pumps. For information on other sampling devices please consult the full text of the EPA document.

6.35 BAILERS

6.35.1 Other Names Used to Describe Method Open bailer, point-source bailer.

6.35.2 Uses at Contaminated Sites Collecting ground-water samples.

6.35.3 Method Description

A bailer is a hollow tube with a check valve at the base (open bailer) or a double check valve (point-source bailer). The bailer is attached to a line (polypropylene or nylon rope, or stainless steel or Teflon-coated wire) and lowered into the water column, with the check valve allowing water to flow through the bailer. When the desired depth is reached, the bailer is pulled up, with the weight *of* the water dosing the check valve. At the surface, the sample in decanted into a sample container. Open bailers provide an integrated sample of the column of water through which it has descended (Figure *5.3.la).* Point-source bailers can use balls that serve as checks to prevent additional water from entering the bailer when I is pulled to the surface (Figure 5.3.lb), or can have valves that are opened and closed from a cable operated from the surface, allowing collection of a sample at a specific point. The first type allows water to flow through the bailer as it is being lowered, whereas the latter type allows water to enter only when the sampling depth has been reached. The check valves of depth-specific bailers can also be operated pneumatically (Section *53.2).*

6.35.4 Method Selection Considerations

See Table *5-2* for suitability ratings of open and point-source ballets for different ground-water parameters. **Advantages:** (1) Low cost can allow dedication of one bailer per well, avoiding potential for cross contamination; (2) simple to operate; (3) easily cleaned, although cleaning *of* ropes and/or cables can be more difficult (4) can be constructed of almost any rigid or flexible material, including those materials that are inert to chemical contaminants and can be made to fit any diameter well and to almost any length to obtain desired sample volume; (5) no limit to depth of sampling; (6) bailers made of flexible material can pass through nonplumb wells; (7) very portable and require no power source; and (8) good for sampling nonaqueous phase liquids at the water table surface. **Disadvantages**: (1) Time consuming and physically demanding (if device is lowered and raised by hand) when used for purging, especially in deep wells; (2) lines used with bailer can be difficult to decontaminate and cause cross contamination If not dedicated to a sample well; (3) can cause chemical alterations due to aeration, degassing, volatilization, turbulence, or atmospheric invasion while lowering the bailer through the water column and/or

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when transferring the sample to the storage container, (4) the person sampling might be exposed to contaminants in the sample; (5) does not supply a continuous flow of water to the surface; (6) with open bailers, it might be difficult to determine the point within the water column that the sample represents; (7) bailer check valves might not operate properly with high suspended solids content or freezing temperatures; and (8) the swabbing effect of tightly fitting bailers might cause fines to enter the well, especially if it has been poorly developed.

6.35.5 Frequency of Use

Bailers have been the most widely used sampling method because they are inexpensive, but other devices, such as the bladder pump, helical rotor, and gear-drive pump, provide better results when sensitive constituents, such as volatile organics, are present.

6.35.6 Standard Methods/Guidelines Berg (1982), deVera (198(1), Ford et al (1984).

3.35.7 Sources for Additional Information

Dunlap et al. (1977), Gillham et a]. (1983), Morrison (1983), Nielsen and Yeates (1985), Pohlmann and Hess (1.988), Rehm et al. (1985), Scaf et al. (1981). See also, Table *5-4*

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Figure 5.3.1

Bailers

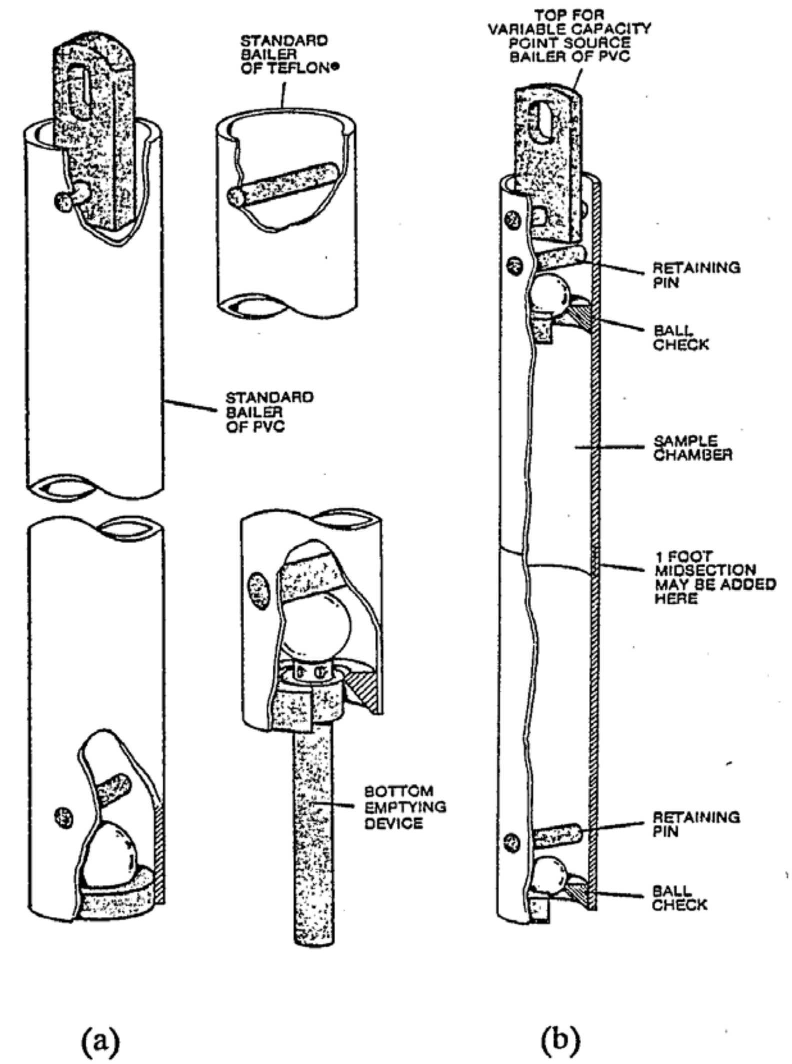

Figure 5.3.1 Bailers: (a) Standard type; (b) Point-source type (Gillham et al., 1983, by permission).

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6.36 BLADDER PUMPS

6.36.1 Other Names Used to Describe Method

Gas-operated bladder pump, gas-squeeze pump, diaphragm pump, Middelburg-type bladder pump, gas-operated squeeze pump.

6.36.2 Uses at Contaminated Sites Collecting ground-water samples.

6.36.3 Method Description

A flexible bladder within the device has check valves at each end (Figure 5.1.la). The pump mechanism is placed in the well. Gas from ground surface is cycled between the bladder and sampler wall, forcing the sample to enter the bladder and then be driven up the discharge line. Figure 5.1.lb shows an operational bladder pump unit.

6.36.4 Method Selection Considerations

See Table *5-2* for suitability ratings for different ground-water parameters using bladder pumps. **Advantages**: (1) Most bladder pumps have been designed specifically to sample for low levels of contaminants, so most are, or can be, made of inert or nearly inert materials; (2) the driving gas does not contact the sample directly, minimizing problems of aeration or gas stripping; (3) are portable, although accessory equipment can be cumbersome; (4) relatively high pumping rate in comparison to other sampling devices allows well purging and large sample volumes to be collected; (5) pumping rate of most models can be controlled easily to allow for both well purging at high flow rates and collection of volatile samples at low flow rates; (6) most models are capable of pumping lifts in excess of 200 feet; (7) are easy to disassemble for cleaning and repair; (8) most models are designed for use in small-diameter wells (1.5 to 2 inches), while large diameter pumps (3.25 inch outer diameter) are available for larger diameter wells; (9) are relatively durable, allowing dedication of pumps to individual wells to eliminate cross contamination and speed sample collection; and (10) In-line filtration is possible. **Disadvantages**: (1) Deep sampling requires large volumes of gas and longer cycles, increasing operating time and expense, and reducing portability (2) check valves in some pump models can fail in water with high suspended solids; (3) relatively expensive; (4) minimum rates of discharge for some models can be higher than ideal for sampling volatile compounds; (5) require large but portable power source (compressed gas); and (6) intermittent but adjustable flow.

6.36.5 Frequency of Use

Second most common sampling device and the most widely used device when samplers are dedicated to a single well. One of the best devices for sampling both trace inorganics and volatile organics.

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6.36.6 Standard Methods/Guidelines

6.36.7 Sources for Additional Information

Gillham et al. (1983), Morrison (1983), Nielsen and Yeates (1985), Pohlmann and Hess (1988), Rehm at al. (1985), Scaf et al. (1981). See also, Table *5-4.*

Figure 5.1.1
Bladder Pump

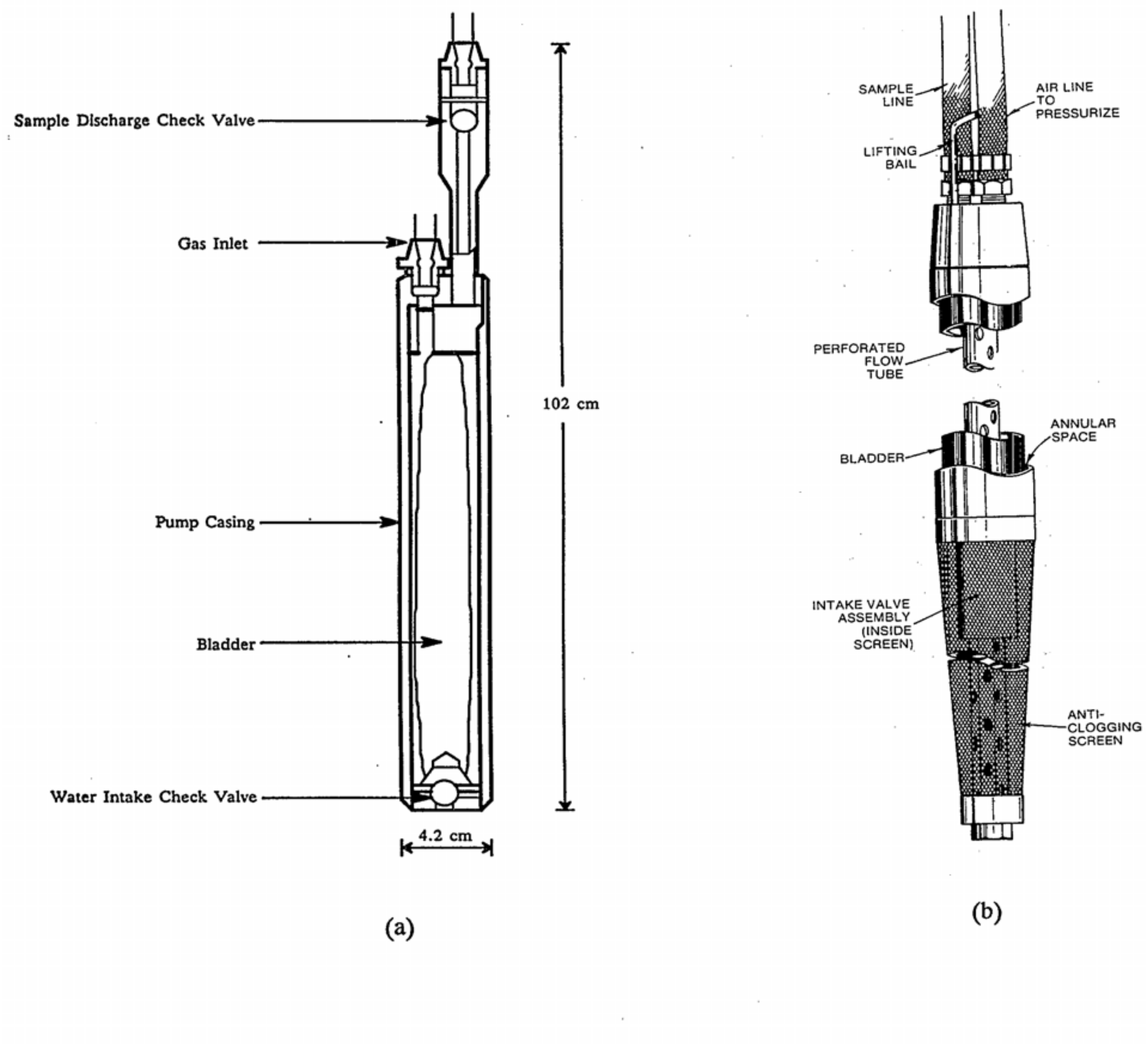

Figure 5.1.1 Bladder pump: (a) Schematic (Pohlmann et al., 1990); (b) Operational unit (Morrison, 1983, by permission).

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6.37 SUCTION LIFT PUMPS

6.37.1 Other Names Used to Describe Method

Peristaltic suction/tubing pump, direct line vacuum pump, surface centrifugal pump, manual diaphragm-type pump, pitcher pump, surface adsorption/thermal desorption (ATD) sampler, subsurface ATD sampler.

6.37.2 Uses at Contaminated Sites Collecting ground-water samples.

6.37.3 Method Description

A large variety of surface pumps that apply a vacuum to the well casing, or to tubing running from the pump to the desired sampling depth, can be used for ground-water sampling. The most commonly used is the peristaltic pump, which is a self priming manual or power operated vacuum pump (Figure *5.2.la).* Other types of manual vacuum or diaphragm-type pumps or portable gasoline-powered or electric surface centrifugal pumps can be attached to tubing for sample retrieval. Another device that can be used as a permanent sampling installation for ground-water sampling where sensitive parameters are not involved is the conventional manual pitcher pump, which is commonly used on shallow water supply wells (Figure *5.2.lb).* Ground-water samples containing volatile organic compounds require use of sample tubing and containers that can be used for gas headspace/vacuum extraction (Section 10.2.1) or purge and trap extraction (Section *10.22),* or adsorption/thermal desorption (ATD) samplers (Section 10.2.4). ADT samplers can be placed at the surface (Figure *5.2.lc)* or in the well (Figure *5.2.14)*

6.37.4 Method Selection Considerations

Sec Table *5-2* for suitability ratings for different ground-water parameters using a peristaltic pump. **Advantages:** (1) Most suction lift pumps are easily controlled to provide a continuous and variable flow rate; (2) simple, convenient to operate, highly portable, and readily available; (3) most are relatively inexpensive to purchase and operate, (4) sample does not come in contact with the pump, so only the tubing must be cleaned (peristaltic pump only); (5) can be used in wells of any diameter and can be used in nonplumb wells; (6) easily cleaned; (7) components can be made of inert materials; and (8) in-line filtration is possible. **Disadvantages**: (1) Sampling is limited to wells where the water level is less than 25 feet below the surface; (2) the drop in pressure caused by the suction causes degassing of the sample and loss of volatiles, especially if the sample is taken from an in-line vacuum flask; (3) the gasoline motor power source used for most centrifugal pumps creates potential for hydrocarbon contamination of samples; (4) pumping with centrifugal pumps causes aeration and turbulence, which might disturb sample integrity (5) centrifugal pumps might have to be primed, providing a possible source of sample contamination; (6) low pumping rates of peristaltic pumps make it difficult to purge the well in a reasonable amount of time; (7) can cause contamination if sample is allowed to touch pump components; and (8) where the sample comes in contact with the pump mechanism or tubing, the choice of appropriate materials for impellers (centrifugal pump) or flexible pump-head tubing (peristaltic pump) might be restrictive.

6.37.5 Frequency of Use

Surface centrifugal pump is commonly used for well development. Peristaltic pumps are commonly used for shallow ground-water sampling.

6.37.6 Standard Methods/Guidelines Peristaltic (purging and sampling): Ford et al. (1984).

6.37.7 Sources for Additional Information

Gillham et al. (1983), Morrison (1983), Nielsen and Yeates (1985), Pohlmann and Hess (1988), Rehm et al. (1985), Scalf et al. (1981), Unwin (1982). See also, Table *5-4.*

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Figure 5.2.1
Suction-Lift Pumps

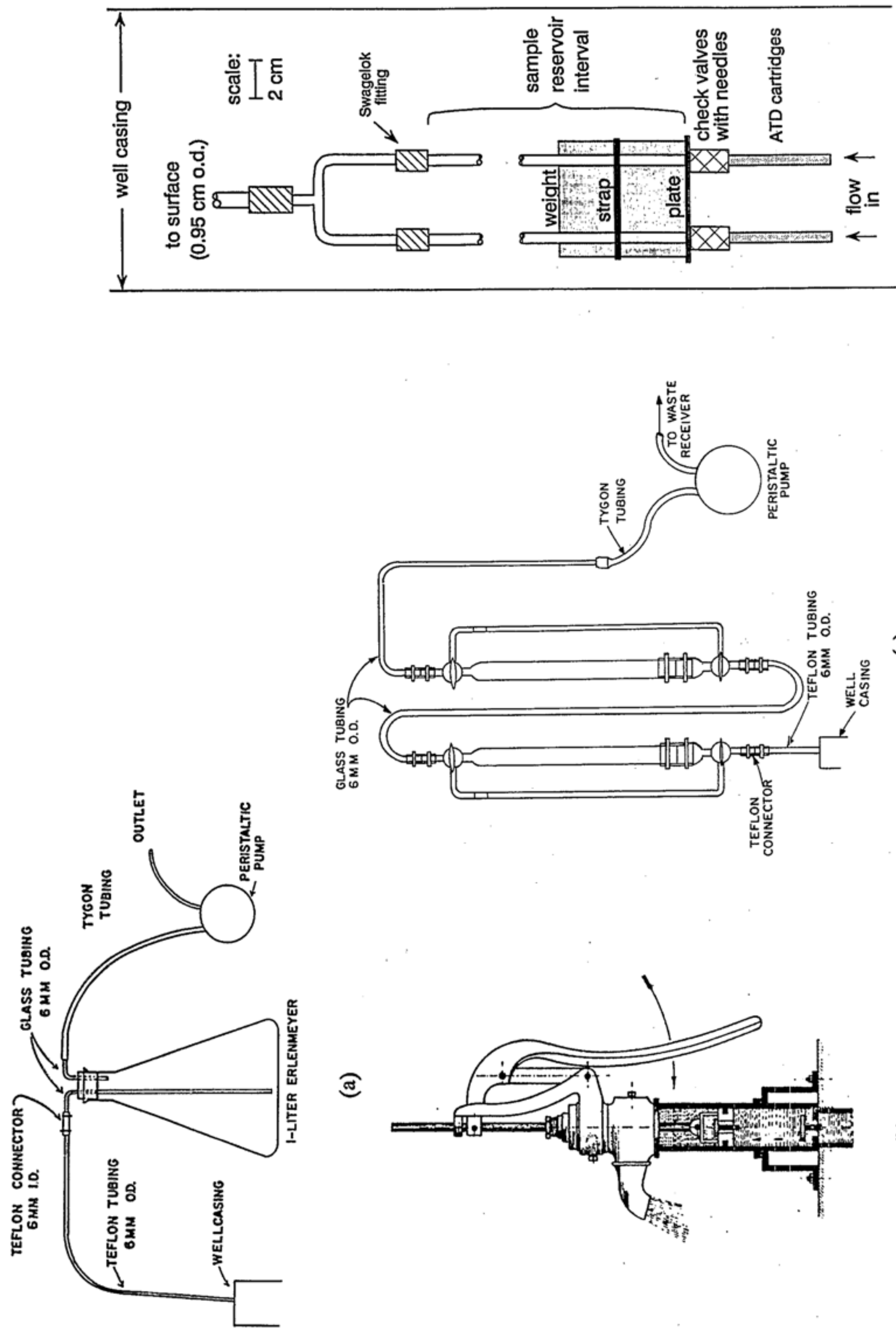

Figure 5.2.1 Suction-lift pumps: (a) Grab sampling with peristaltic pump (Scalf et al., 1981); (b) Pitcher pump (Unwin, 1982); (c) Organics adsorption column surface sampler with peristaltic pump (Scalf et al, 1981); (d) Downhole adsorption/thermal desorption (ATD) sampler (Rosen et al., 1992, by permission).

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6.38 GROUNDWATER SAMPLING AND HANDLING PROCEDURES

This section provides an overview of groundwater sampling and handling procedures, which generally are applicable to any groundwater monitoring program. This section is not intended to provide specific guidance on sampling for a specific situation, but provides information on the major activities that are required for sample collection and handling.

The starting point for any groundwater sampling program is the quality assurance/quality control (QA/QC) plan. Groundwater sampling protocols appropriate to the data quality objectives and the site conditions will define the specific procedures that will be followed for individual sampling events. Well purging typically has been an important element of sampling procedures, the specific procedures of which will vary with site conditions. Specific sample handling and preservation procedures are likely to vary somewhat, depending on the analyte of interest at a site, as will decontamination procedures.

6.39 LUST SITE GROUNDWATER MONITORING WELL PURGING

Prior to collecting groundwater samples from a monitoring well, stagnant water must be removed from the well. This is called “well purging.” A minimum of three well volumes of water should be removed to ensure that all stagnant water has been replaced by representative formation water.

If free product is detected during water level measurements, an interface probe or hydrocarbon-sensitive paste should be used to measure the apparent thickness of the LNAPL.

The following section excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describes well purging methods, considerations, and frequency of use.

6.40 LUST SITE GROUNDWATER SAMPLING

Following purging, groundwater samples are typically collected from monitoring wells with a bailer. The bailer should be lowered into the water slowly, allowing only the top portion of the water nearest the air-water interface to be sampled. For volatile petroleum hydrocarbon compounds, such as TPH, BTEX, and MTBE, the groundwater sample should be poured from the bailer into volatile organic analysis (VOA) vials. After filling, no air bubbles (no headspace) should be present in the VOA vials.

Groundwater may also be collected with a low-flow pump to minimize aeration of the sample.

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6.41 WELL PURGING

6.41.1 Other Names Used to Describe Method Well flushing.

6.41.2 Uses at Contaminated Sites Removing stagnant water from a well before sample collection.

6.41.3 Method Description

Well purging involves the pumping of stagnant water from a well before sample collection. A monitoring well is pumped (generally at a rate from 1 to *5* gallons per minute) until a certain number of well volumes have been removed and until water quality indicators, such as pH, conductance and/or temperature, have stabilized, indicating that fresh formation water fills the well. Sampling takes place after purging is completed. Recent research (Kearl et al, 1992) has suggested that purging is not desirable because it can mobilize colloidal particles upon which contaminants are sorbed. The alternative to purging is to use a dedicated sampling device set at the level of the well screen capable of low pumping rates (around 100 mI./minute), which will not increase colloid density in the ground-water sample compared to natural colloidal flow through the well.

6.41.4 Method Selection Considerations

Recommended rules of thumb, such as purging three to five volumes (Fenn et al., 1977) should be treated only as a starting point. Accurate estimation of purge volume requires knowing: (1) Well yield, determined from a slug or pumping test, and (2) the stagnant volumes of both the well casing and the sand pack. Figure B.2a shows the volume of water stored per foot of well casing at different diameters. In slowly recovering wells, extra care is required when purging to ensure that water levels do not drop below the level of the well screen because aeration might allow loss of volatile or redox sensitive contaminants. After stagnant water has been removed or isolated, chemical indicators (pH, conductance, and temperature) should continue to be monitored until they reach a consistent end point (no upward or downward trend). Another important consideration in purging is that the pumping rate should not exceed levels that will cause turbulent flow. Turbulent flow in the well might cause pressure changes, which could result in loss of carbon dioxide and other volatile gases, subsequently changing pH and dissolved solids content (Meredith and Brine, 1992). The maximum discharge rate during pumping that avoids turbulent flow is a function of hydraulic conductivity, the length of the well screen, width of the screen openings, and the total open area of the screen. Figure B.2b shows the optimum screen entrance velocity related to the hydraulic conductivity of an aquifer. Table B2 provides guidelines for maximum purging rate based on screen type, diameter, slot size, open area, and entrance velocity (from Figure B.2b).

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6.41.5 Frequency of Use

Has been a standard procedure for all ground-water sampling. Although, as noted above, the practice has been called into question.

6.41.6 Standard Methods/Guidelines Barcelona et al. (1985) provide a detailed procedure for estimating well purging volume.

6.41.7 Sources for Additional Information

All standard guides on ground-water sampling discuss purging (see general texts/reports and additional references listed under "purging" in Table B-I). Herzog et al. (1991) provide a good review of the literature on well purging.

6.42 QUALITY ASSURANCE/QUALITY CONTROL

The following section excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describes QA/QC protocols, considerations, and frequency of use.

The following section excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describes QAJQC protocols, considerations, and frequency of use.

6.42.1 Other Names Used to Describe Method QA/QC, sampling protocol.

6.42.2 Uses at Contaminated Sites

Minimizing the sources of error in ground-water (and soil) sampling results.

6.42.3 Method Description

A QA/QC plan involves the establishment of a sampling protocol, which is designed to minimize sources of error in each stage of the sampling process, from sample collection to analysis and reporting of analytical data. Key elements include: (1) Development of a statistically sound sampling plan for spatial and temporal characterization of ground water (U.S. EPA, 1989b); (2) installation of a vertical and horizontal sampling network, which allows collection of samples that are representative of the subsurface; (3) use of sampling devices that minimize disturbance of the chemistry of the formation water (4) use of decontamination procedures for all sampling equipment to minimize cross-contamination between sampling points (see Section B.4); (5) collection of QA/QC samples (see Table B.1 for types of samples); and (6) bottling, preservation, and transport of samples to maximize the integrity of the samples (Section B3). Additional QA/QC procedures must be followed in the laboratory. Figure B.1 shows a generalized flow diagram for ground-water soil sampling protocol.

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6.42.4 Method Selection Considerations

As requirements for precision and accuracy increase, the type and number of QA/QC samples will increase. Field rinsate blanks should be collected any time there is a possibility of cross-contamination from sampling equipment.

6.42.5 Frequency of Use Required standard procedure for all ground-water sampling.

6.42.6 Standard Methods/Guidelines

6.42.7 Sources for Additional Information See Table B-L

6.43 LABORATORY ANALYTICAL REQUIREMENTS, SAMPLE HOLDING TIMES, AND DOCUMENTATION

6.43.1 Sample Containers and Preservation

The type and number of sample containers and the sample preservation method depends on the analysis required, the media sampled (soil or water), and the laboratory used. Check with the Utah-certified analytical laboratory that you will be using for specific information on sample containers and preservation.

6.43.2 Sample Holding Times

Check with the Utah-certified analytical laboratory in advance of sampling to determine if they can perform the analyses within the specified sample holding time. For example, the holding time for analysis of volatile petroleum hydrocarbon compounds (TPH, BTEX, and MTBE) is 14 calendar days (groundwater samples must be acidified with HCl for the 14-day holding time, otherwise the holding time is 7 days). For TRPH and Oil & Grease analyses, the holding times are 28 calendar days.

6.43.3 Sample Documentation

Sample documentation materials include chain-of-custody forms and sample labels. The chain-of-custody form is used to track the possession of a sample from the time the sample is collected until the time the sample is analyzed. Samples must remain in the control of the individual in custody of the samples at all times (or in a secured location) until the sample is released to the next chain-of-custody recipient or to the analytical laboratory. The chain-of-custody form must include the sample identification number, date/time of collection, place of collection (borehole/well number), type of material (soil or water), sample container type (VOA vial, 1-liter bottle, etc.), preservation method (acidified, cooled, etc.), signature/printed name and company of the sample collector, and signatures/printed names and dates/times of persons involved in the transportation and handling of the sample. An example chain-of-custody form is included at the end of this chapter.

Each sample container should be labeled with a permanent label that includes the sample identification number, date and time of collection, place of collection, and name of person/company collecting the sample. The sample number on the sample container should be the same as the sample number on the chain-of-custody form and the laboratory report.

6.43.4 Utah Certified Laboratories

The Utah Department of Health has a program that establishes and enforces standards for laboratories that provide test results for compliance purposes to the Utah Department of Environmental Quality. A laboratory requesting certification is required to complete an application, participate in a proficiency testing program, and meet state laboratory standards. The certification process requires an on-site survey of the laboratory by state certification officers to assess the laboratory's compliance with state standards. All analytical test results submitted to the DERR for an UST site in Utah must be performed by a Utah Certified laboratory. A list of Utah Certified laboratories is located at:
http://health.utah.gov/lab/labimp/labcert/LabsCertified_RCRA.xls.

6.43.5 Approved Analytical Methods

Specific analytical methods must be used when sampling for petroleum constituents at UST sites in Utah. Refer to the following table in this section for the correct analytical methods: *Analytical Methods for Environmental Sampling at Underground Storage Tank Sites in Utah (July 2004)***.**

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Analytical Methods for Environmental Sampling at Underground Storage Tank Sites in Utah (July 2004)

Substance or Product Type	Contaminant Compounds to be Analyzed for Each Substance or Product Type	ANALYTICAL METHODS[1] Soil, Groundwater or Surface Water
Gasoline	Total Petroleum Hydrocarbons (purgeable TPH as gasoline range organics C_6 - C_{10})	EPA 8015B or EPA 8260B
	Benzene, Toluene, Ethyl benzene, Xylenes, Naphthalene, (BTEXN) and MTBE	EPA 8021B or EPA 8260B
Diesel	Total Petroleum Hydrocarbons (extractable TPH as diesel range organics $C_{10} – C_{28}$)	EPA 8015B
	Benzene, Toluene, Ethyl benzene, Xylenes, and Naphthalene (BTEXN)	EPA 8021B or EPA 8260B
Used Oil	Oil and Grease (O&G) or Total Recoverable Petroleum Hydrocarbons (TRPH)	EPA 1664A or EPA 1664A (SGT*)
	Benzene, Toluene, Ethyl benzene, Xylenes, Naphthalene (BTEXN) & MTBE; and Halogenated Volatile Organic Compounds (VOX)	EPA 8021B or EPA 8260B
New Oil	Oil and Grease (O&G) or Total Recoverable Petroleum Hydrocarbons (TRPH)	EPA 1664A or EPA 1664A (SGT*)
Other	Type of analyses will be based upon the substance or product stored, and as approved by the Executive Secretary (UST)	Method will be based upon the substance or product type
Unknown	Total Petroleum Hydrocarbons (purgeable TPH as gasoline range organics $C_6 – C_{10}$)	EPA 8015B or EPA 8260B
	Total Petroleum Hydrocarbons (extractable TPH as diesel range organics $C_{10} – C_{28}$)	EPA 8015B
	Oil and Grease (O&G) or Total Recoverable Petroleum Hydrocarbons (TRPH)	EPA 1664A or EPA 1664A **(SGT*)**
	Benzene, Toluene, Ethyl benzene, Xylenes, and Naphthalene (BTEXN) and MTBE; and Halogenated Volatile Organic Compounds (VOX)	EPA 8021B or EPA 8260B

.[1] The following modifications to these certified methods are considered acceptable by the Executive Secretary (UST):

- Dual column confirmation may not be required for TPH and BTEXN/MTBE analysis.
- A micro-extraction or scale-down technique may be used for aqueous samples, but only for the determination of extractable TPH as diesel range organics ($C_{10} – C_{28}$).
- Hexane may be used as an extraction solvent.

*Silica Gel Treatment (SGT) may be used in the determination of Total Recoverable Petroleum Hydrocarbons

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6.44 AQUIFER TEST METHODS

The following section excerpted from *Subsurface Characterization and Monitoring Techniques* (EPA, 1993b) describes common aquifer testing methods including slug tests and pumping tests, considerations, and frequency of use.

When ground water is contaminated, the needs for aquifer characterization can be boiled down to four basic questions. How deep is it? What direction is it flowing? How much is flowing through the system? How fast is it flowing? Remedial actions requiring hydrodynamic controls to contain a contaminant plume or requiring pump-and-treat activities also require an understanding of the storage properties of the aquifer in order to evaluate bow flow patterns will respond to pumping from or injection into the aquifer.

6.45 BASIC CHARACTERISTICS OF GROUND WATER

Water state in the subsurface is measured in terms of **hydraulic head** in the saturated zone, and **negative pressure potential or suction** in the vadose zone (covered in Section 6.1). The term ground water usually is applied to subsurface water occurring in a saturated zone, where water fills the pore space and moves as a result of differences in hydraulic head. The hydraulic head at a particular location is the elevation to which water rises. In an open borehole (or the elevation to which a flowing well would rise if the casing were extended above the ground surface). The hydraulic gradient is measured as the change in water level per unit of distance along the direction of maximum head decrease. The gradient can be determined from a water-table map of an unconfined aquifer, or a piezometric (pressure) surface map showing the elevation to which water would rise in a well tapping a confined or artesian aquifer. Either type of map is called a potentiometric map. Table 4-1 summarizes information on seven techniques for measuring water levels in open or cased boreholes and three methods for measuring pressure head in flowing (artesian) wells. The steel-tape and electric probe methods are used most commonly for routine measurement of water levels. Transducers are used most commonly in aquifer tests where accurate measurement of changes in multiple wells is required in relatively short time periods. Pressure potential in the saturated zone also can be measured by burying In-situ piezometers that sense pore pressure (Section 4.1.10). Table *5-3* in Section *5* provides information on possible sources for commercially available ground-water level measuring devices.

The hydraulic conductivity (K, often expressed in terms of centimeters or meters per second) is a basic aquifer parameter used to calculate the amount of ground-water flow using Darcy's Law (Q = -KiA, where Q = discharge, i = the hydraulic gradient, and A = the area through which the ground-water is flowing). Ground water flux (q) is the flow of water through a specified area (q = Q/A = Ki). The average flow velocity (v) can also be calculated if K, I, and the effective porosity (n) is known: v =qn = Ki. Transmissivity (F), or transmissibility, is a measure of the amount of water moving through an entire aquifer and is calculated by multiplying the thickness of the aquifer (b) by K (F = Kb). Storage properties of aquifers are measured in terms of the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head (specific storage S.). Storativity (or storage coefficient) (S) is the specific storage

or yield multiplied by the aquifer thickness (S = Sb). Characterization of aquifer heterogeneity (K varies depending on the location within the aquifer) and anisotropy (K varies at a given point in an aquifer depending on the direction of measurement) is essential for accurate prediction of ground-water flow direction. Ground-water flow in porous media, such as unconsolidated deposits and sandstone, has very different characteristics than flow in which fractures (typically igneous and metamorphic rocks) and conduits (karst limestone) are present. Dispersion (the net effect of a variety of microscopic, macroscopic, and regional conditions that influence the spread of a solute concentration front through an aquifer) is another important aquifer parameter that requires some evaluation. Dispersion allows contaminants to remove more rapidly through an aquifer than would be predicted by the average hydraulic conductivity as measured by a pumping test, for example.

This section classifies aquifer characterization methods into four categories: (1) Shallow water table tests, (2) well tests, (3) tracer tests, and (4) other methods. Table 4-2 summarizes information on the types of aquifer parameters that can be measured using specific techniques.

6.46 WELL TEST METHODS

6.46.1 Slug Tests

6.46.2 Other Names Used to Describe Method

Instantaneous head change test, Bailer test, rising/falling head test. Slug tests vary somewhat in procedures and formulas used for calculations. Different methods are usually identified by the names of the developers: Hvorslev, Ferris-Knowles, Cooper-Bredehoeft.Papadopulos, Bouwer-Rice, and Nguyen-Pinder methods.

6.46.3 Uses at Contaminated Sites

Measuring hydraulic conductivity (all methods), storativity and transmissivity (some methods).

6.46.4 Method Description

Slug testing involves measuring the rate at which water in a well returns to its initial level after (1) A sudden injection or withdrawal of a known volume of water from a well, or (2) instantaneous displacement by a weight or change in pressure. Changes in water level over time are recorded and formulas used to calculate hydraulic conductivity are plotted and matched against type curves. Rising-head (withdrawal) and falling-head (injection) methods often yield different results and the best estimate might be an average of the two values. Figure 4.3.la shows an apparatus for a water Injection test and Figure 4.3.lb Illustrates an equipment setup for a pneumatic rising head test.

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6.46.5 Method Selection Considerations

Advantages: (1) Can be used in hydrogeologic units with a wide range of permeabilities and (2) relatively inexpensive in terms of manpower, equipment, and site set-up, allowing multiple tests for characterization of aquifer heterogeneity. **Disadvantages**: (1) Very high or very low permeabilities might require sophisticated electronic monitoring equipment, such as transducers and data loggers, and with high hydraulic conductivity even transducers might not work very well; (2) permeability values are only applicable to a small volume of the aquifer, (3) most tests do not provide information on aquifer storage properties(4) injection-type tests should not be done in wells from which water quality samples will be collected; and (5) mechanical slug tests might not displace enough water for meaningful results. Different methods are applicable to different well and hydrologic conditions. Hvorslev method can be used for both unconfined and confined aquifers with gully or partially penetrating wells below the water table. The Bouwer-Rice method applies to unconfined aquifers. The Cooper-Bredeboeft-Papadopulos method is for confined conditions with fully penetrating wells. The Nygun-Pinder method can be used for partially penetrating wells in confined aquifers.

6.46.6 Frequency of Use Common.

6.46.7 Standard Method /Guidelines ASTM (1991b, 1991c).

6.46.8 Sources for Additional Information See Table 4-5.

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Figure 4.3.1

Slugs Tests

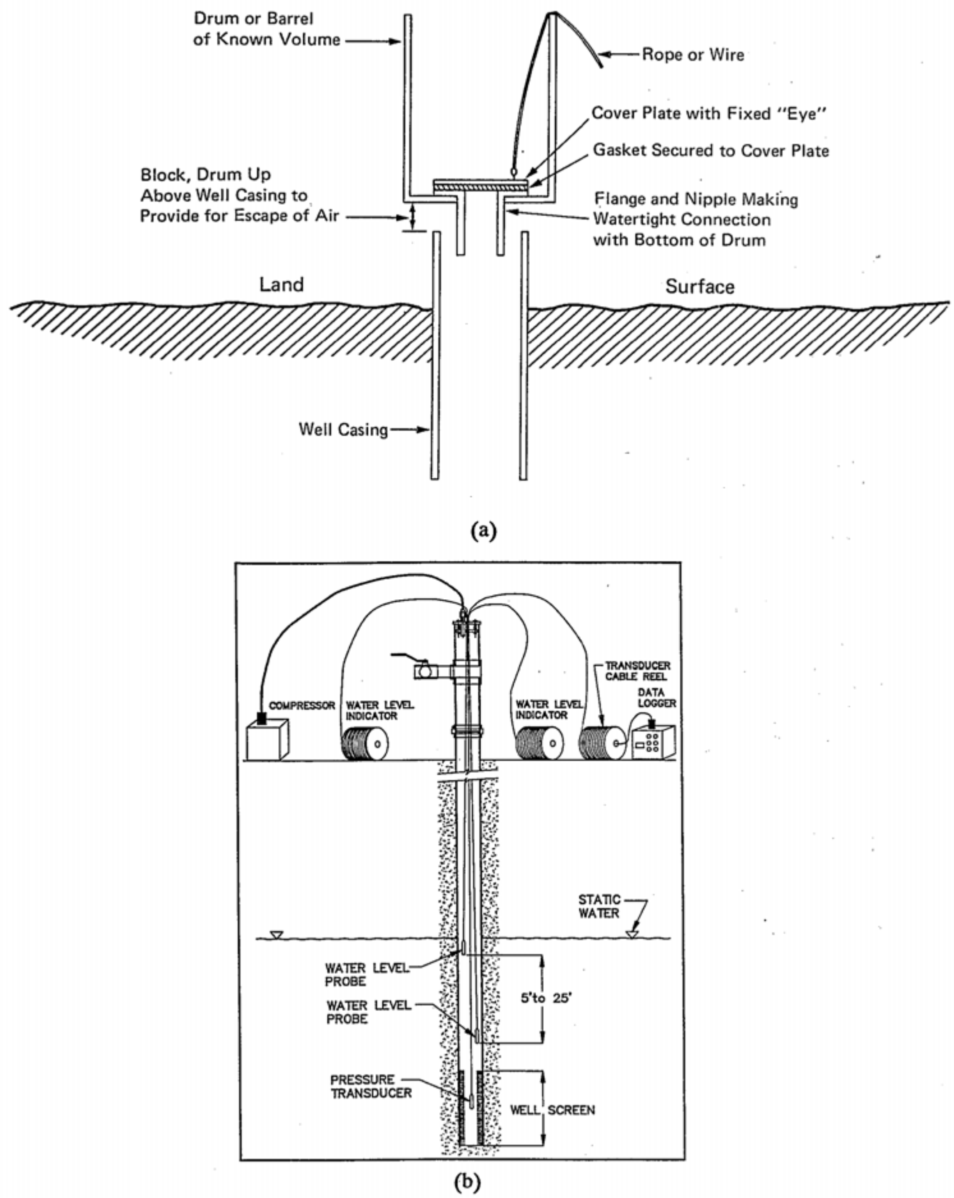

Figure 4.3.1 Slugs tests: (a) Apparatus for performing water injection slug test (Brakensiek et al., 1979); (b) Equipment setup for conducting a pneumatic rising head slug test (McLane et al., 1990, by permission).

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6.47 PUMPING TESTS

6.47.1 Other Names Used to Describe Method

6.47.2 Uses at Contaminated Site:

Measuring aquifer hydraulic conductivity transmissivity, and storage properties (specific storage, specific yield, storativity). Properly designed multiple-well tests also can measure anisotropy.

6.47.3 Method Description

Single-well pumping tests (Figure 4.3.2a) differ from withdrawal slug tests in that water is removed at a constant rate over a period of time from hours to days. Thirty minutes to four hours a common length for domestic wells. **Multiple-well** pumping tests usually involve placing observation wells at different distances from a pumping well (Figure 4.3.2b) or in a circle around the pumping well. Pumping rates can be measured volumetrically, commonly using an orifice weir (see Section 1042), or using a commercial water meter. Water levels in the pumping and observation wells are measured at specified intervals, closely spaced at the beginning of the test and more widely spaced as time goes on. The use of pressure transducers and automatic dataloggers facilitates data collection and analysis. Numerous analytical methods are available for analyzing pump test data, which usually are presented as a series of types curves against which the time-drawdown test data plots are matched to obtain transmissivity and storage parameters. The Thiem equilibrium equation and the Theis nonequilibrium equation are two of the most commonly used basic analytical solutions for pump tests. A variety of solutions to the Theis nonequllibrium equation have been derived for special aquifer and pumping conditions. Important considerations in selection of an analytical solution for a pump test includes: (1) type of aquifer (confined, leaky, or unconfined), (2) how much of the aquifer is intersected by the well(s) (fully or partially penetrating), and (3) the degree of heterogeneity and anisotropy in the aquifer.

6.47.4 Method Selection Considerations

Advantages: (1) Analytical solutions are available for almost any aquifer and well-type; (2) average hydraulic properties are measured for a relatively large volume of the aquifer; (3) can be used over a wide range of permeabilities; and (4) test wells also can be used for water quality sampling after completion of the test. **Disadvantages**: (1) Expensive due to manpower and equipment requirements and length of test (several days is not uncommon); (2) large volumes of pumped water require appropriate handling and disposal; and (3) are inaccurate in rock with fractures or high secondary porosity (karst limestone). Multiple well configurations generally provide better results than single-well tests because they (1) Are more accurate for measuring storage values; (2) pumping well measurements are more affected by construction methods than measurements from observation wells; (3) observation wells allow detection and characterization of aquifer heterogeneity and anisotropy and (4) observation wells are less affected by changes in pumping rate, which might occur in longer tests.

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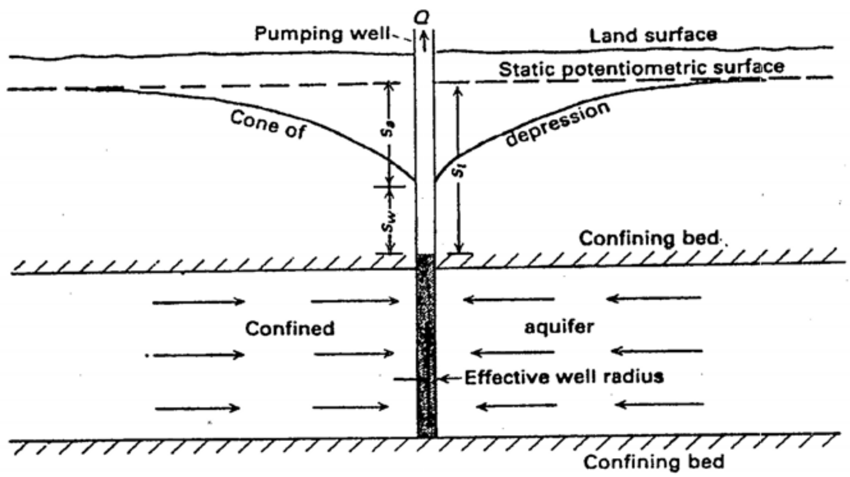
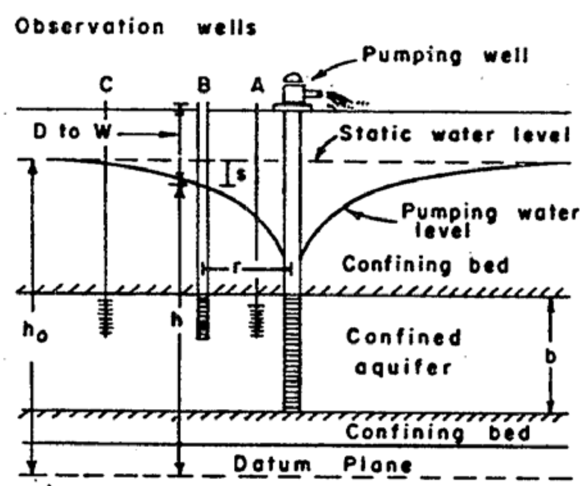
6.47.5 Frequency of Use Common.

6.47.6 Standard Methods/Guidelines ASTM (19914, 1991e, 1991f 1992a, 1992b).

6.47.7 Sources for Additional Information See Table *4-5.*

Figure 4.3.2
Pumping Tests





(b)

Figure 4.3.2 Pumping tests: (a) Single-well test; (b) Multiple-well test (U.S. EPA, 1991).

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6.48 WASTE DISPOSAL

Wastes generated at LUST sites include free-phase petroleum product (LNAPL), tank bottom sludges, USTs and associated piping, contaminated soil (drill cuttings or excavated soil) and water (well purge or development water), and materials or sampling equipment used.

Proper disposal or treatment of wastes depends upon the waste classification and the type of facility accepting the waste. The treatment/disposal facility must be consulted to determine testing and acceptance requirements. The waste must be accepted by the facility prior to transporting it off the site. Depending on the type of contaminants contained in the waste, and the process that generated the waste, wastes generated at LUST sites may be classified as RCRA hazardous wastes or non-hazardous wastes.

For example, a waste (sludge, soil, or water) containing chlorinated solvents generated from a waste oil UST would probably be classified as a RCRA hazardous waste. RCRA hazardous waste can only be transported to a RCRA-permitted treatment/disposal facility. Soil and groundwater contaminated with gasoline or diesel fuel generated at a LUST site would most likely not be classified as a RCRA hazardous waste. The UST owner/operator is responsible for properly classifying the waste and for ensuring that the waste is properly treated or disposed in accordance with the classification and appropriate regulations.

6.49 USTs AND ASSOCIATED PIPING

Rules regarding the proper handling and disposal of USTs and associated piping are presented in *Utah Underground Storage Tank Rules* R311-204-3 (Chapter 1). Documentation of proper disposal should be kept by the owner/operator and included with the UST Closure Notice.

6.50 Residual Product and LNAPL

Residual petroleum product is removed from USTs prior to UST removal. After the residual product is removed, a licensed waste hauler/recycler cleans the UST and pumps out the rinsate. The residual petroleum product and rinsate is typically disposed of at the waste recycler's facility. The waste recycler may also accept contaminated groundwater from the UST excavation if the water is classified as non-hazardous. Documentation of proper disposal should be kept by the owner/operator and included in reports to regulatory agencies.

LNAPL removed from wells and stored on site must be safely stored in accordance with local fire code regulations. The owner/operator must determine whether the LNAPL is classified as hazardous waste. A waste recycler can assist with this determination and may require specific testing of the free product prior to acceptance if it is suspected that the product may be classified as a hazardous waste.

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6.51 CONTAMINATED SOIL

Contaminated soil from an UST closure or LUST cleanup can be disposed or treated at solid waste landfills, permitted waste disposal facilities, landfarming operations, or asphalt batch plants. The type of treatment/disposal facility depends on the types and concentrations of petroleum hydrocarbon compounds in the soil. Generally, the analyses required for disposal of petroleum hydrocarbon contaminated soil from LUST sites are TPH, BTEXN, MTBE, and lead, however, these requirements are specific to each facility. The maximum concentrations of contaminants in soil that are acceptable are also specific to each facility.

Owner/operators or Certified UST Consultants should determine what type of contaminants and concentrations that the facility will accept prior to transporting any material to the facility. Documentation of proper treatment/disposal should be kept by the owner/operator and included in reports to regulatory agencies.

If the contaminated soil is to be temporarily stored on site prior to disposal, the soil should be placed in U.S. Department of Transportation - (DOT) approved containers/drums, or placed on and covered with plastic sheeting.

6.52 CONTAMINATED GROUNDWATER

Extracted contaminated groundwater should be stored in DOT-approved drums and be disposed of or treated within 90 days of generation. Waste recyclers may accept contaminated groundwater if it is classified as non-hazardous. Some wastewater treatment facilities (POTWs) may allow contaminated groundwater to be discharged to the sanitary sewer system, if the contaminants in the groundwater meet certain standards. These standards are specific to each POTW; therefore, the owner/operator or UST consultant should verify the requirements before discharging the groundwater. Documentation of proper disposal should be kept by the owner/operator and included in reports to regulatory agencies.

6.53 GROUNDWATER MONITORING WELL PURGE WATER

Small quantities of purge water from groundwater monitoring wells may be disposed of on site. For example, purge water may be “thin-spread” on site and allowed to evaporate or to infiltrate into the soil. No runoff may be allowed off the site onto other property or storm drains. In addition, purge water may be poured back into the well that it was removed from after sampling is completed. The owner/operator or Certified UST Consultant should verify the acceptability of these disposal methods with the DERR prior to disposing the purge water. Larger quantities of purge water should be properly stored and treated or disposed.

Lists of Utah landfills, waste disposal facilities, and treatment/recycling facilities are presented in Chapter 9.

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6.54 SPECIAL SECTION ON MTBE

The following text comes from an MTBE Fact Sheet originally prepared in early 2000:

Methyl tertiary butyl ether (MTBE) is a fuel additive used as an octane-enhancing replacement for lead primarily in high-grade gasoline at concentrations as high as 8%. It is also used as a fuel oxygenate at higher concentrations, ranging from 11% to 15%, to reduce ozone and carbon monoxide levels, in response to either the Reformulated Gasoline Program or Oxygenated Fuel Program.

MTBE has been used widely throughout the country since the mid-1980s. According to the National LUST Programs Survey (1998), 251 to 422 public water supply wells in 19 states contained detectable concentrations of the MTBE. As a result, many of these wells have been shut down, required treatment, and/or required other water sources used at much greater expense than the original water source.

6.54.1 Use of MTBE in Utah

In Utah, there are three out of six refineries using MTBE: Phillips 66, Flying J and Inland Oil. The Phillips 66 refinery uses 8% to12% MTBE in gasoline in the summer as an octane enhancer (in the winter Phillips 66 uses 9.5% ethanol in Utah County). The Flying J and Inland Oil refineries use less than 1% by volume MTBE in the gasoline sold in Utah. The rest of the refineries, Chevron, BP Amoco, and Texaco use ethanol instead of MTBE. Ethanol is not a major environmental problem because it is much more biodegradable than MTBE. For comparison, California uses about 15% by volume MTBE in the gasoline sold throughout the state.

Retailers around the state may receive deliveries of gasoline containing MTBE due to their proximity to an area in which MTBE is used to achieve compliance with the Clean Air Act Amendments.

6.54.2 Risk, Fate, and Transport of MTBE

The EPA has classified MTBE as a possible human carcinogen. No MCL has been established for the compound, as its health effects are still being studied. However, MTBE is known to be a nuisance pollutant with respect to taste and odor. The EPA Drinking Water Advisory suggests that the range of 20 to 40 micrograms per liter (μg/L) would be below the unpleasant odor and taste thresholds for a large majority of people. UDEQ relies on the EPA Health Advisory concentration of 70 μg/L as a cleanup level.

MTBE is problematic as a pollutant due to its high water solubility and low biodegradability.

- MTBE migrates at about the same velocity as the groundwater;
- MTBE generates large plumes due to its affinity to water;

- MTBE has a lower volatility than benzene in the dissolved phase;
- MTBE travels through soil rapidly since it is not sorbed to soils or organic carbon; and
- MTBE is recalcitrant to biodegradation.

Active remediation of MTBE may be required at some LUST sites where MTBE has migrated much further than conventional gasoline components, *e.g.*, BTEXN. Due to the different physical and chemical characteristics of MTBE, the preferred techniques for cleanup may differ from a conventional gasoline plume.

According to the EPA (1998), MTBE's relatively high solubility allows it to dissolve into the groundwater in "pulses" that result in rapid orders of magnitude changes in groundwater concentrations. The pulses may result from changes in groundwater elevation or infiltration of rainwater. These pulses may warrant frequent groundwater sampling events to determine actual MTBE concentrations and levels of risk to down-gradient receptors. The velocity of the groundwater and density of the groundwater monitoring well network will dictate the frequency of sampling.

More information about MTBE can be found on the EPA's website at: **http://www.epa.gov/mtbe/.**

6.54.3 Salt Lake Valley Hydrogeology and MTBE

MTBE is a concern for aquifers in the Salt Lake Valley. Generally, the predominant groundwater production aquifer (principal aquifer) in the Salt Lake Valley is relatively deep and is confined/artesian. For the most part, it is separated from shallow groundwater by thick clay layers. These attributes reduce the likelihood that shallow groundwater contamination will impact the principal aquifer.

However, the clay layers are not continuous throughout the valley and continued pumping of the principal aquifer may, at some time in the future, pull contaminated shallow groundwater into the principal aquifer. In fact, a downward vertical hydraulic gradient between the shallow groundwater and the principal aquifer currently exists in the Midvale and Sandy area. In addition, old abandoned wells (there are many in the Salt Lake Valley) can act as conduits for shallow groundwater contamination to migrate to deeper aquifers and the eastern part of the Salt Lake Valley is considered an "unprotected recharge zone." Therefore, there is a potential for MTBE, and other contaminants in shallow groundwater, to migrate to the principal aquifer in the Salt Lake Valley.

6.54.4 Potential for MTBE to Impact Municipal Wells in Utah

Statewide, as of early 2000, about 209 sites out of a total of 730 open LUST sites (29%) have MTBE contamination in the shallow groundwater. In the Salt Lake Valley, about 80 sites out of about 300 open LUST sites (27%) have MTBE contamination in the shallow groundwater. Even

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though the MTBE content of gasoline in Utah is relatively low, the compound is prevalent at LUST sites.

Use of the shallow groundwater in the Salt Lake Valley is being planned because the principal aquifer has been fully appropriated. For example, the Jordan Valley Water Conservancy District (JVWCD) has recently received approval to install wells (screened from 10 to 100 feet below grade [bgs]) in the shallow unconfined groundwater aquifer to provide water for rapidly growing areas within its service area. The JVWCD plans to install about 60 wells east of the Jordan River from about 2100 South Street to 7800 South Street.

Fortunately, there has been only one municipal (irrigation) well in Utah impacted by MTBE to date. The well is in Milford, Utah and is located about 300 feet from a gasoline station LUST site. The shallow groundwater underlying the gas station is at about 30 feet bgs and the municipal (irrigation) well is screened from about 250 to 400 feet bgs in a deeper (reportedly confined) aquifer. Without other sources contributing to the plume, there must be some type of vertical hydraulic connection between the shallow groundwater and the deeper aquifer, possibly due to a discontinuous aquitard or a leaky grout seal on the municipal-irrigation well.

CHAPTER 7
Screening/Cleanup Levels for LUST Sites

7. INTRODUCTION

The question: "How clean is clean?" is not easily answered. In a perfect world, the answer would be "non-detectable" or "pristine" or "the way it was before you spilled chemicals on it." In the real world, however, the answer is complex and depends on several factors:

- Contaminant type,
- Contaminant location,
- Contaminant migration potential (fate and transport),
- Threat or risk to human health and the environment,
- Current and future use of property, and
- Economics.

Utah's Department of Environmental Quality, Division of Environmental Response and Remediation (DERR), Leaking Underground Storage Tank (LUST) Section has developed an assessment process to evaluate risks to human health and the environment resulting from petroleum contamination from LUSTs. This process is intended to address cleanup when Maximum Contaminant Levels (MCLs), Initial Screening Levels (ISLs), or other applicable cleanup standards cannot reasonably be achieved and is based on Utah Administrative Code R311-211, *Corrective Action Cleanup Standards Policy-UST and CERCLA Sites*, referred to as *Cleanup Standards Policy* (2006). A copy of the *Cleanup Standards Policy* is provided in this Chapter. A table summarizing MCLs, ISLs, and other applicable standards is included in this Chapter.

A summary of Utah's cleanup levels for petroleum contaminated soil and groundwater can be found on the DERR's website at **www.undergroundtanks.utah.gov/docs/cleanuplevels.pdf**.

Utah's risk assessment process is derived from, and is consistent with, the United States Environmental Protection Agency's (EPA) Office of Solid Waste and Emergency Response (OSWER) Directive 9610.17 (February 24, 1994) ("EPA Directive" entitled *Use of Risk-Based Decision-Making in UST Corrective Action Programs*). The EPA Directive references the American Society for Testing Materials (ASTM) *Standard Guide for Risk-Based Corrective Action (RBCA) Applied at Petroleum Release Sites* (ASTM, 1995) which identifies and describes one method of evaluating the risk to human health and the environment posed by multiple constituents in petroleum-contaminated soil, groundwater and air.

The ASTM (1995) document provides guidance for evaluating risks at petroleum release sites using a three-tiered approach. The first tier (Tier 1) is a screening process that uses only general hydrogeologic information and conservative assumptions to ensure protection of potential receptors. The second and third tiers require increasingly more accurate site-specific data, as well as increasingly sophisticated contaminant fate and transport modeling, to achieve greater accuracy and certainty in evaluating risks to receptors. The 1995 ASTM document contains the mathematical exposure equations for calculating risk-based screening levels (RBSLs) for a specified target excess risk (TER) limit.

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Screening/Cleanup Levels for LUST Sites

Utah has generally adopted the 1995 ASTM method but has modified it into a two-tiered approach for performing risk assessments. Utah's method is designed to provide systematic and consistent determinations of risk to potential receptors in accordance with the *Cleanup Standards Policy*. Like the ASTM (1995) approach, Utah's two-tiered approach requires increasingly more accurate site-specific data and increasingly complex transient contaminant fate and transport modeling with each option upgrade in order to achieve greater accuracy and certainty in evaluating risks to receptors.

Utah's Tier 1 Screening Levels (SLs) are contaminant concentrations in soil and groundwater that are considered "safe to leave in the subsurface" at any site if all of the Tier 1 distance criteria are met. Tier 1 SLs were developed by the DERR using conservative formulas and general Utah-specific (not site-specific) input parameters. Tier 1 distance criteria are distances from contaminated subsurface soil or groundwater to "receptors".

Receptors include wells (municipal, domestic, and irrigation), surface water bodies (lakes, rivers, streams, and canals), utilities (water supply lines, storm drain pipes, and sewer lines), and property lines. In order to use Tier 1 SLs, the contaminated soil and groundwater at the site must be located over 30 feet from utilities and property lines, and over 500 feet from wells and surface water bodies. In most cases, if subsurface contamination is below Tier 1 Screening Levels and the site meets all Tier 1 criteria, then no additional cleanup work is required at the site and the case is closed.

A summary of the Tier 1 Screening Process can be found in the DERR's *Guidelines for Utah's Corrective Action Process for Leaking Underground Storage Tank Sites*, October 30, 2005. This guide is available on the DERR's website at: http://www.undergroundtanks.utah.gov/rbca.htm.

Utah's Tier 2 SLs are developed using site specific input parameters from the site and more realistic (less conservative) formulas than those used to develop the Tier 1 SLs. Details on determining Tier 2 site-specific screening levels (SSCLs) can be found in DERR's *Guidelines for Utah's Corrective Action Process for Leaking Underground Storage Tank Sites*, October 30, 2005. This guide is available on the DERR's website at: http://www.undergroundtanks.utah.gov/rbca.htm.

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7.1 FATE AND TRANSPORT OF PETROLEUM HYDROCARBONS IN THE SUBSURFACE

An understanding of contaminant fate and transport processes in the subsurface is fundamental to making informed decisions at leaking underground storage tank (LUST) sites. The behavior of petroleum hydrocarbons in the subsurface is governed by the physical and chemical properties of the contaminants, as well as the site-specific characteristics of the media (soil, groundwater, soil gas) through which the contaminants migrate. Fate and transport mechanisms are complex and the discipline is rapidly evolving.

Numerous computer software packages are available to assist in simulating fate and transport processes. In most cases, the objective of computer simulations is to generate numerical models that predict concentrations of petroleum contaminants in soil or groundwater over time. Their success in predicting actual site conditions depends on the availability and reliability of site-specific data including (but not limited to) input parameters which represent soil sorption, dispersion, and biodegradation processes.

Computer models are only as reliable as the input parameters on which they are based. Whenever possible, site-specific parameters should be utilized, and a discussion of model assumptions and limitations should always accompany the computer simulations. When valid assumptions are made, computer fate and transport modeling can be a valuable tool for planning subsurface investigations, screening remedial options, or designing corrective action systems.

7.2 DETERMINATION OF RBSL AND SSCL VALUES FOR TOTAL PETROLEUM HYDROCARBONS (TPH)

TPH fractionation is only required when a LUST site has been approved to conduct a risk assessment following RBCA protocols as outlined in *Guidelines for Utah's Corrective Action Process for Leaking Underground Storage Tank Sites.* Utah's *Guidelines for TPH Fractionation at Leaking Underground Storage Tank Sites* document can be found on the DERR's website at **http://www.undergroundtanks.utah.gov/docs/fractionation.pdf**.

7.3 SAMPLE COLLECTION

Collect a minimum of one environmental sample which is representative of each contaminated medium (*e.g.*, soil and groundwater) and the maximum concentration and composition of the petroleum contamination at the site. For sites where TPH contamination is highly variable in concentration or composition, the user should collect multiple TPH samples at representative locations to ensure a representative analysis by the laboratory.

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7.4 LABORATORY ANALYSIS

Analyze the sample(s) using EPA Methods 8260B and 8270B. Specify "Utah TPH Fractionation" on the chain-of-custody forms to ensure that the laboratory uses the reporting format specific for TPH fractionation, which differs from a typical 8260B and/or 8270B chemical parameter listing. The laboratory should report concentrations for each of the 10 different TPH fractions shown on the following flowchart. In addition, on the 8260B report, the laboratory should list values for any detectable BTEXN and MTBE. For fractions where the measured concentration is below the method reporting limit, a value of half of the method reporting limit should be used as the representative source area concentration in deriving SSCLs.

7.5 DETERMINATION OF TIER 2 RBSLS FOR EACH TPH FRACTION

Fraction-specific RBSL values must be derived for each complete exposure pathway at the site. For each TPH fraction, RBSL values can be calculated for each relevant exposure pathway using the equations provided on Table C-1 of the Tier 2 Guidance Document (Equations C.1 through C.8). Fraction-specific chemical property values and toxicological parameters to be used in the RBSL calculations are provided in Table C-2 of the Tier 2 Guidance Document.

7.6 DETERMINATION OF SSLC VALUES FOR TPH FRACTIONS

Under Tier 2 Options 2 through 4, SSCL values for the individual TPH fractions are developed in the same manner as for any other COCs (*e.g.*, BTEXN and MTBE). Using the chemical property values and toxicological parameter values, a NAF value may be derived for each TPH fraction using the Option 2 through 4 calculation methods. The NAF is then multiplied by the appropriate RBSL value to obtain an SSCL for each complete exposure pathway. The fraction that exceeds its applicable SSCL the most will ultimately drive the cleanup for all the other fractions contained within TPH at the site.

7.7 CONFIRMATION SAMPLING FOR TPH FRACTIONS FOLLOWING TPH-DRIVEN CLEANUP ACTIVITIES

After completing cleanup activities that are driven by the exceedence of the SSCLs for the TPH fraction(s), the user should obtain an appropriate number of environmental samples at representative locations and depths in order to verify the effectiveness of the cleanup at the release site. The same procedures described herein would again be employed for comparison with representative source area TPH fractionation values obtained. During cleanup, the user may elect to obtain samples for TPH fractionation, and BTEXN and MTBE (EPA Method 8020) if applicable, to measure the relative progress of the cleanup activities and to estimate the cleanup duration.

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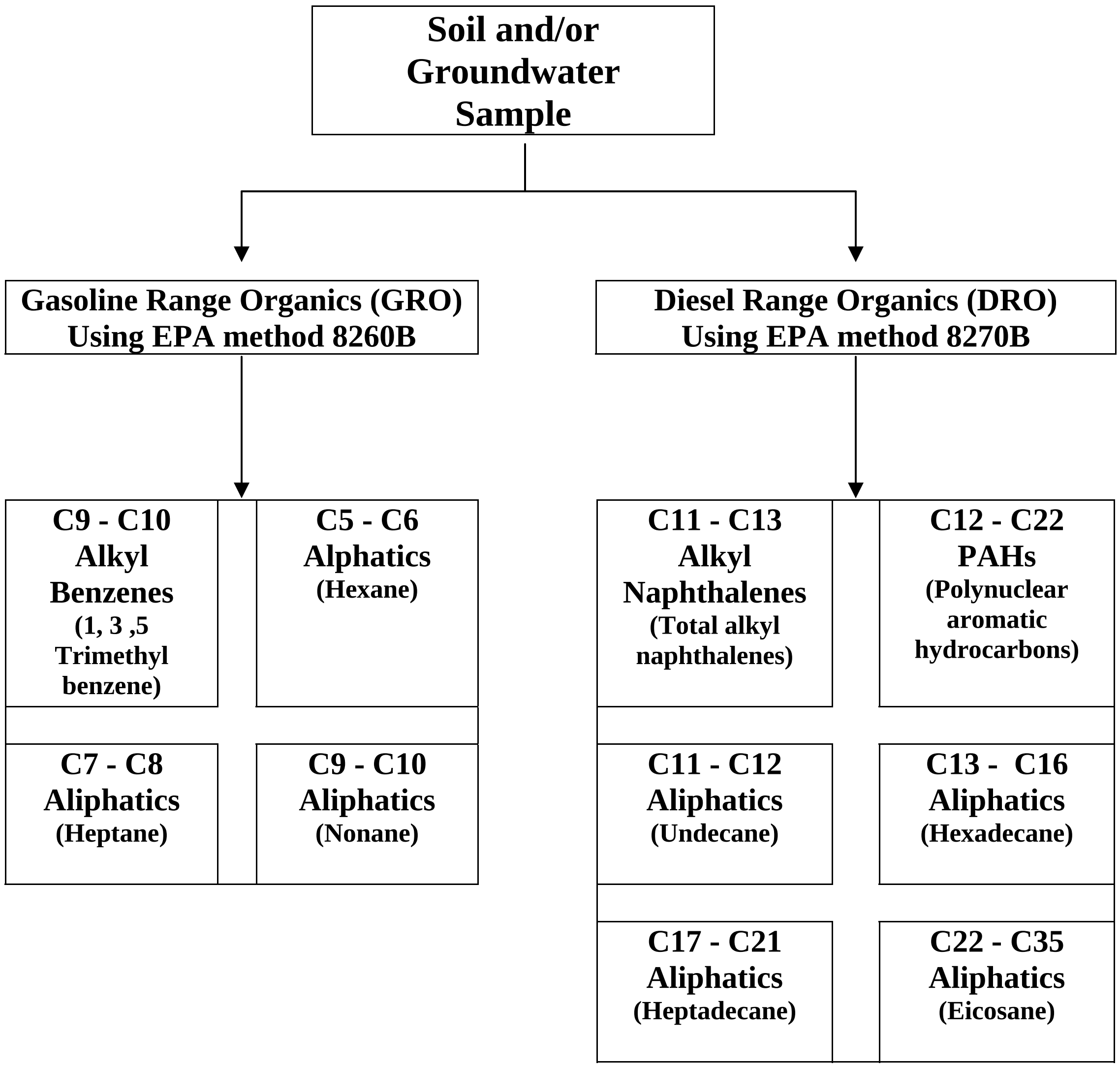
Figure 7-1 Utah's Total Petroleum Hydrocarbon Fractionation & Analytical Method Relationship



* = Surrogate Chemical used for Toxicity values (RfD) in the RBCA Document.

CHAPTER 8
Corrective Action/Remediation Technologies

8. INTRODUCTION

Corrective action is the process used to remediate petroleum contamination in soil or groundwater at LUST sites. Corrective action may be required by the Department of Environmental Response and Remediation (DERR) at LUST sites if any of the following have occurred (DERR, 1995; 1998):

- Contamination is present at significant levels as determined by the DERR.
- Established or recommended cleanup levels have been exceeded.
- Contamination poses a current or potential threat to human health or the environment.
- Exposure pathways and receptors are present or impacted.
- Significant off-site migration has occurred or is likely to occur.

In addition to the DERR requirements for corrective action outlined in this chapter, this section describes some commonly used *ex situ* and *in situ* corrective action technologies for soil and groundwater remediation at LUST sites.

8.1 DERR REQUIREMENTS

The DERR corrective action process for LUST sites is illustrated in Figure 8-1. It is good practice to involve the DERR Project Manager for the LUST site early in the corrective action process. The DERR must review and approve corrective action plans (CAPs) for LUST sites. The DERR's goals in reviewing CAPs are (DERR, 1995; 1998):

- Ensure sufficient investigation.
- Ensure that the corrective action methodology is the most cost-effective approach.
- Ensure that the appropriate cleanup technology is used.
- Ensure reasonable success for cleanup technology.
- Ensure protection of human health and the environment.

A copy of the DERR’s LUST CAP Guide can be found on the DERR’s website at: **http://www.undergroundtanks.utah.gov/remediation.htm**.

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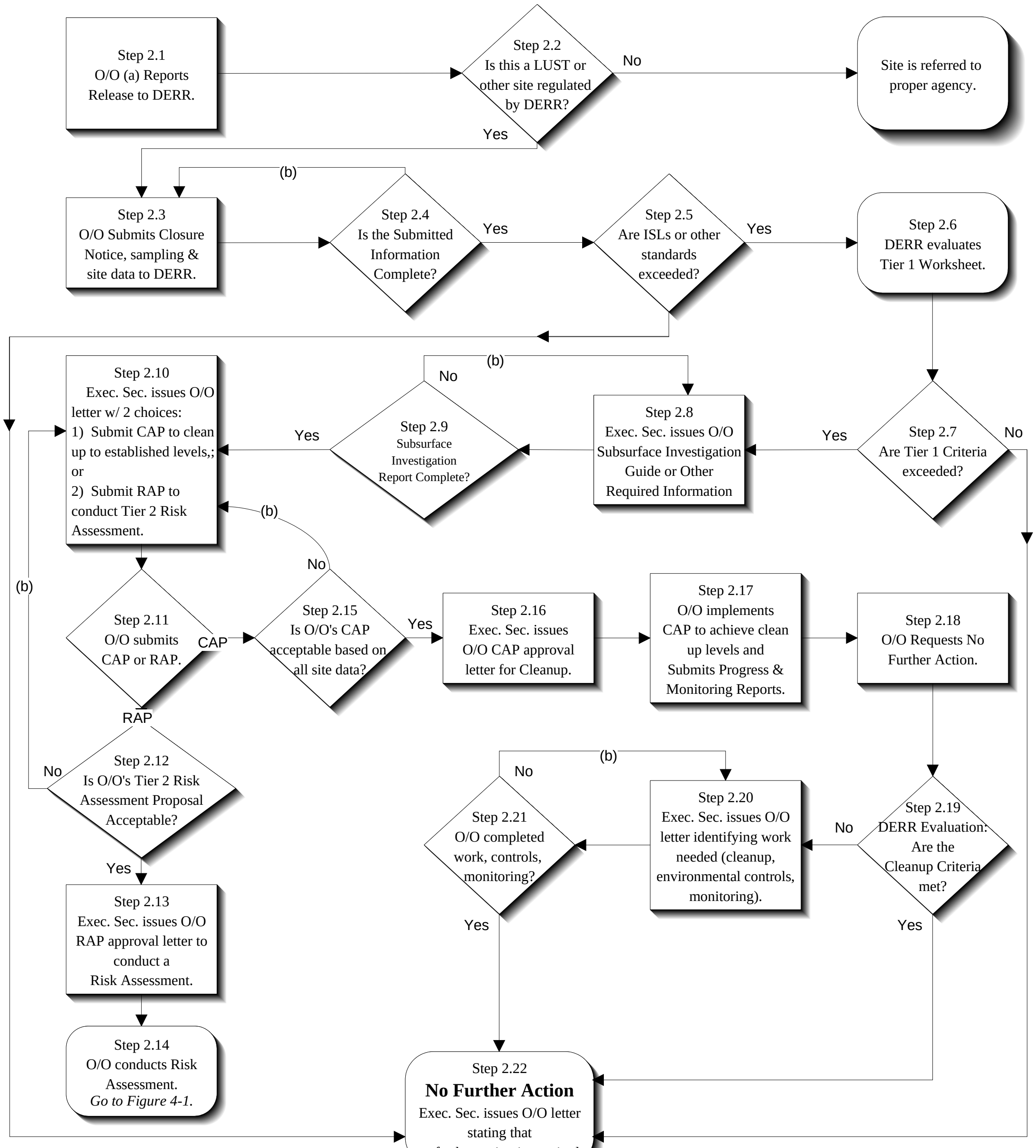
FIGURE 8-1 DERR LUST Corrective Action Process



(a) Acronyms and abbreviations

CAP Corrective Action Plan
DERR Utah Division of Environmental Response and Remediation
Exec. Sec. Executive Secretary
LUST Leaking Underground Storage Tank
MCLs Meximum Contaminant Levels
O/O Owner or operator of a LUST
RAP Risk Assessment Proposal
(b) DERR issues O/O correspondence identifying information needed.

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8.2 REMEDIATION TECHNOLOGY EVALUATION

The approach for selecting a remediation technology for a given site generally follows these basic steps:

- Define the nature and extent of contamination.
- Determine the site physical characteristics.
- Evaluate site risks and determine remediation goals.
- Assemble and evaluate remedial alternatives.
- Select and implement a remedy.

The approach is a flexible process that is slightly different for each site. The level of detail required for developing an understanding of the site and evaluating remedial technologies depends upon numerous factors, including the size and complexity of the site and the amount of risk posed by the site.

The nature and extent of contamination and site physical characteristics are used to develop a conceptual site model of the source areas, potential contaminant migration pathways, and potential receptor locations. The nature and extent of contamination includes the types and concentrations of contaminants and the locations of the contaminants. Site characteristics include properties of the contaminated media (water, soil, and/or air) and background geochemical characteristics. Remediation goals are based on the risk to receptors. The conceptual understanding of the site and the remediation goals are essential for defining the problem and providing the basis for assembling, evaluating, and selecting an appropriate remediation approach.

8.3 NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination at a site is determined using results of soil, groundwater, and surface water quality sampling. Environmental samples are collected in various locations to provide lateral and vertical distributions of contaminant types and concentrations across the site. Historical data showing variations in contaminant concentrations as a function of time are also helpful in evaluating contaminant behavior.

8.3.1 Contaminant Characteristics

The chemical, physical, and biological properties of the contaminant govern the effectiveness and applicability of a remedial technology.

Important contaminant properties to consider when selecting a remedial technology for organic compounds include molecular weight, molecular structure, water solubility, volatility, partitioning behavior, density, and biodegradability. In general, the petroleum compounds of benzene, toluene, ethylbenzene, xylenes, and naphthalene behave similarly in the environment in terms of fate and transport. A common example of an associated compound that behaves differently is methyl tertiary butyl ether (MTBE). MTBE is much more soluble in water, much more volatile in the free phase, and exhibits a low biodegradability.

8.3.2 Site Physical Characteristics

Site characterization includes defining the following site-specific parameters:

- Hydrogeology and soil properties;
- Background geochemical characteristics; and
- Locations and types of surface water bodies.

8.3.3 Hydrogeology and Soil Properties

Hydrogeology is the science of the flow of groundwater in the subsurface. Important hydrogeologic properties to consider when evaluating remedial technologies include depth to groundwater, hydraulic conductivity (K), porosity, hydraulic gradient, groundwater flow direction and rate, presence of confining layers, locations of groundwater recharge or discharge areas, and regional hydrogeology. The depth to groundwater is important because it is useful for designing groundwater treatment remedies, it determines the extent of the unsaturated zone, and because it is used to calculate the hydraulic gradient and direction of groundwater flow.

The hydraulic conductivity of a groundwater aquifer is a measure of the permeability of the soil to groundwater flow. Soil with high hydraulic conductivity, such as sand or gravel, is more permeable to groundwater flow than soil with low hydraulic conductivity, such as silt or clay. Porosity is the percentage of the soil that is occupied by void space. Hydraulic gradient is the amount of hydraulic head that drives the flow of groundwater in a given direction. Regional groundwater flow, topography, and the recharge and discharge areas influence hydraulic gradient. The hydraulic conductivity, porosity, and hydraulic gradient determine the rate of groundwater flow.

The type of soil, subsurface stratigraphy, depositional history, regional geology, and locations of preferential flow paths in the subsurface are also very important in understanding contaminant behavior in groundwater and soil and selecting remedial technologies. There are several classifications engineers and geologists use to describe soil types. Some major divisions of grain size are gravel, sand, silt, and clay. Gravels are highly permeable, whereas clays are practically impermeable and generally referred to as confining layers. The layering or stratigraphy of the soil is important because it determines the direction in which groundwater and contaminants are likely to move. Preferential flow paths, such as channels of gravel or sand, are very important because they provide potential conduits for rapid migration of contaminants.

Other important soil properties include organic carbon content and moisture content. Organic carbon content determines the degree to which soil will absorb contaminants. Soil with a high organic carbon content will adsorb organic compounds and slow down their migration in the subsurface. Moisture content is a very important parameter for biodegradation of contaminants in unsaturated soils because bacteria require moisture for biodegradation.

8.3.4 Background Geochemical Characteristics

Background geochemical characteristics define the water and soil chemistry of the area and include soil and groundwater pH, oxidation-reduction potential (Eh), dissolved oxygen (DO), alkalinity (carbonate and bicarbonate content), concentrations of dissolved cations (calcium, sodium, potassium, iron, manganese, magnesium) and anions (chloride, nitrate, sulfate, sulfide), total suspended and dissolved solids (TSS and TDS), natural organic matter content, naturally occurring levels of metals, and dissolved nutrient levels (nitrogen and phosphorous). Geochemical characteristics are useful for determining whether water samples are from the same geologic unit. Differences in geochemical characteristics between contaminated areas and non-contaminated background areas can also provide evidence for natural biodegradation of contaminants. Information about geochemical characteristics is very important for designing remediation systems because it will aid in determining the potential for fouling and scaling of equipment, which can significantly impact the operation and maintenance cost and the effectiveness of a remediation process.

8.3.5 Locations of Surface Water Bodies

Locations of surface water bodies are important for evaluating remediation technology selection because surface water bodies may act as a source or sink of contaminants. Surface water bodies may act as receptors of groundwater contaminants, they may provide a source of clean water to the subsurface that dilutes the contaminated groundwater, they may affect the geochemical characteristics of the subsurface system, or they may significantly affect the direction and rate of groundwater flow.

8.4 REMEDIATION GOALS

The risks to human health and the environment posed by a given site determine the remediation goals for the site. The RBCA Tier 1 Screening Levels may guide the level of effort for remediation if critical distance criteria are met (Chapter 7). A risk assessment may be performed to evaluate current and potential risks in an effort to propose higher cleanup standards to reduce the duration or extent of active remediation. Risks are estimated based upon knowledge of a fully characterized site. Data requirements include location of source areas, release mechanisms, contaminant toxicity, contaminant transport pathways in the environment, locations of human or ecological receptors, and exposure routes. Remediation goals are a very important component in remedy selection bec0 ause they determine the location, extent, and duration of remediation required.

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8.5 TECHNOLOGY ALTERNATIVES

After the problem is defined, the next step in planning the remedial approach is to divide the site into areas for cleanup based on contaminant types and concentrations, and the types of contaminated media. For example, a site with surface staining, contaminated subsurface soil, and contaminated groundwater may be divided into source areas, vadose and smear zone contaminated soils, and contaminated groundwater.

Remedial technologies that are applicable for each of the contaminants and media types requiring remediation are assembled for each area based on the characteristics of the contaminants, site characteristics, and project goals. The remedial technologies are organized into treatment processes or alternative for each area that may contain a number of options. At this stage in the planning process, alternatives are assembled based upon their capability to address the contaminants and media regardless of preconceived opinions of cost an optimal performance. The list of assembled remedial alternatives is evaluated based upon a predetermined set of criteria, which generally include performance, cost, and time frame.

8.5.1 Performance and Cost Evaluation

Specific performance criteria can include soil and groundwater cleanup levels, treated effluent discharge levels, reinjection concentrations, removal efficiencies, potential for formation of toxic byproducts, contaminant destruction versus transfer to another medium, reliability, implementability, constructability, and remediation timeframe. Costs are evaluated according to capital costs to purchase and install the remediation equipment and costs to operate, maintain, and monitor the remediation system. Performance and cost evaluations are conducted using literature information, engineering judgment and experience, and results of pilot-scale tests.

8.5.2 Literature Review

Available literature from industry, equipment suppliers, consultants, academic research, and governmental sources contains data on the applicability, effectiveness, potential problems, and costs of many remedial technologies. This type of information is useful for general technology screening purposes and provides an indication of the performance levels and problems associated with particular alternative, eliminate remedial technologies, and that are unlikely to perform to the desired level or which would not be applicable for a situation because of site-specific constraints.

8.5.3 Engineering Judgment and Experience

Engineering judgment based on experience with implementing different remedial technologies is one of the more effective performance- screening methods especially for evaluating the more intangible aspects of a project such as reliability, constructability, implementability, and cost.

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8.5.4 Pilot Studies

Pilot-scale studies are a valuable means for confirming the performance and establishing design parameters for a selected technology. Pilot studies can be conducted to obtain basic design data for subsequent use in the design of full-scale facilities and other technical and economic evaluations.

Well-planned pilot studies should provide information to evaluate the technical feasibility of the technology, design criteria for full-scale application, and data for estimating full-scale capital and operating costs. Once a full-scale treatment system is constructed, pilot tests can be continued to optimize performance of the system. The additional testing allows insights into how the technology will react under varying conditions and evaluation of operating parameters to improve performance or reduce cost.

8.6 TIMEFRAME ANALYSIS

The timeframe in which remediation can be accomplished may vary depending upon the type or size of the system installed. For each alternative, the time over which each aspect of the remediation process occurs must be accurately predicted. This timeframe analysis directly affects the present worth comparisons between all alternatives.

8.7 COST ANALYSIS

A cost evaluation is generally conducted to compare the costs of implementing the assembled alternatives over the lifetime of the remediation project. The key considerations when conducting a life-cycle cost analysis are:

- Technical considerations;
- Remediation time considerations; and
- Capital, operating, and present-worth costs considerations.

Technical considerations include those technical aspects of a project that affect the cost and that vary over the life of the project. For example, contaminant concentrations and flow of groundwater being pumped to a treatment system may decrease over the life of a project or flow rate may vary significantly based upon seasonal rainfall and aquifer recharge. The variability in parameters such as these which affect initial cost and operating costs of a treatment system should be estimated prior to conducting a life-cycle cost analysis.

Once the technical and timeframe aspects have been estimated, the capital costs for constructing a remediation system are developed. Then the operating costs (power, chemicals, labor, residuals disposal, monitoring costs, maintenance costs) are estimated for each alternative, considering that technologies, and thus, costs can change over time.

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8.7.1 Technology Selection

Once both capital and operating costs have estimated, the total present worth is calculated to determine which alternative achieves the cleanup goals for the lowest cost over the shortest timeframe of the remediation project. The final decision considers the three major components included in the selection of a remedial alternative:

- Technical viability and effectiveness for cleanup;
- Cost of implementation; and
- Timeframe for cleanup.

THE FOLLOWING SECTIONS PRESENT DETAILS, ADVANTAGES, AND DISADVANTAGES OF SEVERAL REMEDIATION TECHNOLOGIES.

8.8 FREE PRODUCT REMOVAL – MANUAL METHODS

The DERR and Federal regulations require that if free-phase petroleum product (LNAPL) is observed in surface water or groundwater, it must be removed to the maximum extent practicable. Emergency free product removal operations and reporting requirements were outlined in Chapter 4. Additional free product removal methods are presented below, and are described in detail in *How to Effectively Remove Free Product At Leaking Underground Storage Tank Sites* (EPA, 1996).

8.8.1 Handbailing

Handbailing is a simple technique that consists of lowering a bailer attached to a rope down a well and removing the free product. As free product is removed from the well, it is stored in approved containers, such as drums, until properly disposed. A bailer used for free product removal should be dedicated to that function. Advantages and disadvantages of bailing are presented in Table 8-1.

TABLE 8-1
Advantages and Disadvantages of Handbailing

ADVANTAGES	DISADVANTAGES
Simple to implement, can begin very quickly.	Not cost-effective for large volumes of product. Labor-intensive.
No special design needed.	Time consuming for complete removal.
	Exposes workers to a flammable liquid.

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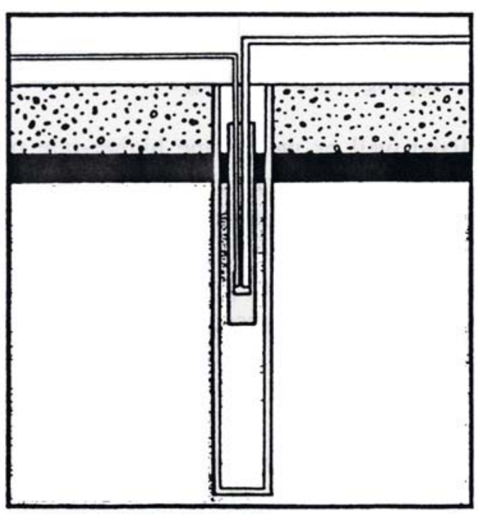
8.8.2 Absorbent Materials

Absorbent materials, such as SoakEase® can be used to manually remove free product from wells. The absorbent material repels water and absorbs petroleum-based compounds. The absorbent material is available for 2-inch diameter or 4-inch diameter wells, and moves up and down with changes in water levels. The material is suspended in the well over a period of time, and periodically removed from the well for disposal. Advantages and disadvantages of absorbent materials are listed in Table 8-2.

TABLE 8-2
Advantages and Disadvantages of Absorbent Materials

ADVANTAGES	DISADVANTAGES
Simple to implement, can begin very quickly.	Disposal of spent absorbent material may be difficult and costly.
No special design needed.	
Relatively inexpensive for removal.	
Effective for thin product thickness.	

FIGURE 8-2a Pneumatic Pumping Configurations
Drawing Courtesy of QED Groundwater Specialists



8.9 FREE PRODUCT REMOVAL - PNEUMATIC PUMPING

Note: Information provided courtesy of QED Groundwater Specialists. Inclusion of this material does not imply endorsement of the DERR.

Pneumatic (compressed-air actuated) pumping systems offer many advantages over other pumping systems (electric submersible pumps), including no shock or explosion hazard; greater reliability with lower maintenance; a much broader choice of materials; light weight and easy installation; and more advanced control options. It is important to note that the methods presented are not mutually exclusive, and in many cases are combined to provide optimum removal of free product during various phases of cleanup. For example, a project might begin with the removal of any free product, using skimming pumps combined with separate pumps to enhance the drawdown and contaminant recovery, and control the migration of contamination on the site. Once the contaminant layers have been substantially removed, pumping systems are often converted to remove total fluids from the well, pumping for longer periods at lower pumping rates.

8.9.1 Product-Only Pumping

With proper inlet positioning, one pump can "skim off" just the floating free product layer without collecting any water or using a second draw-down pump from wells, sumps or trenches.

Some systems employ a fixed, "passive" inlet that needs to be manually repositioned if the levels of hydrocarbon and/or water fluctuate during pumping. Other techniques use a floating "active" inlet, which rises and falls with changes in water/product level. In addition, some methods utilize hydrophobic screens, membranes to exclude water from the pumped products.

Advantages and disadvantages are presented in Table 8-3. A diagram of product-only pumping is presented in Figure 8-2a.

8.9.2 Groundwater Draw-Down Pumping with Floating Free Product Recovery

Uses two pumps in a centralized well or wells; one higher-rate pump (the draw-down pump) removes enough groundwater to lower the static water level in the well, creating a "cone of depression", a low spot in the water table extending outward from the well.

Floating hydrocarbon moves down the slope and pools at the bottom of the depression. A second, product pump with inlet located above the depressed water surface pumps out the hydrocarbons that collect there.

In high-permeability soils, electric submersible or high-rate pneumatic pumps can be used for draw-down, and will create a cone of depression that extends a considerable horizontal distance, allowing wells to be spaced far apart.

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TABLE 8-3
Advantages and Disadvantages of Product-Only Pumping

ADVANTAGES	DISADVANTAGES
Very useful on many projects as a "quick response" method to begin removing as much floating product as possible while waiting for permits required before groundwater can be pumped.	Recovery time may be longer in some soils than with draw-down pumping.
When working properly, delivers pure product for reuse or recycling.	Doesn't control gradient of contaminated groundwater plume.
Can minimize the amount of contaminated groundwater pumped.	Only for products that flow easily (no high viscosity liquids), such as gasoline.
Maximizes recovery along "oil-wet" pathways.	
Reduces hydrocarbon contact with new soils, which can be caused by drawdown pumping.	

In "tight," low-permeability soils, lower-flow pneumatic pumps can withdraw enough water for drawdown; in these soils, cones of depression are narrow and steeply sloped, and wells must be placed closer together. Under these conditions, lower-flow, multi-well pumping out-performs the high-flow centralized well approach, especially when the product tends to be in pockets rather than evenly distributed.

A diagram of draw-down pumping with free product recovery is presented in Figure 8-2b. Advantages and disadvantages are presented in Table 8-4.

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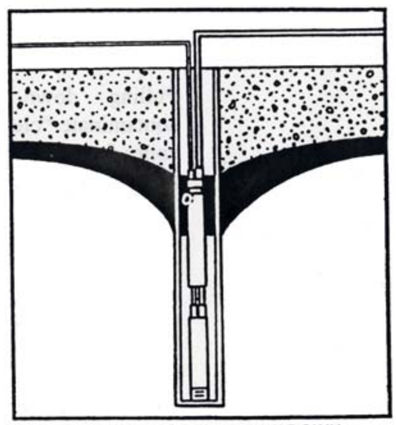
FIGURE 8-2b Pneumatic Pumping Configurations
Drawing Courtesy of QED Groundwater Specialists



PRODUCT PUMPING WITH DRAW-DOWN

8.9.3 Gradient Control Total Fluids/Groundwater Pumping:

A single high-rate pump in a central well, or a series of pumps in a “picket fence” or other arrangement of wells, can remove enough groundwater to reverse or impede the aquifer's flow gradient, pulling the outer edges of the contaminant plume back toward the well.

As an option, the pump may be placed in a top-inlet “can” so that, in addition to contaminated groundwater, it collects whatever floating layer is present. Advantages and disadvantages are presented in Table 8-5. A diagram of gradient-control total-fluids/groundwater pumping is presented in Figure 8-2c.

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TABLE 8-4
Advantages and Disadvantages of Groundwater Draw-Down Pumping with Floating Free Product Recovery

ADVANTAGES	DISADVANTAGES
In coarse sand or gravel soils with high hydraulic conductivities, it can enhance the flow of product toward the well. Can speed the recovery process by pulling the contaminant plume back toward the center, preventing product migration by changing site gradient of flow.	It is not as effective with tight clay soils, low-yield wells, and/or thin floating product layers. Implementation may be delayed by discharge permit requirements for the draw-down water. May extract more contaminated groundwater that can be treated economically. Pulling down hydrocarbon layer can contaminate “clean” or “relatively clean” soil zones formerly below the water table. Creates a “smear zone.” Mixing of recovered product and water is a high probability. In some soils, a large volume of water must be pumped to collect a very small amount of product. When electric pumps are used, additional problems can include shock and explosion hazard; excessive size, weight, and cost of pumps; unreliable performance (especially from hydrocarbon degradation of pump seals); high/low level sensing failure; sensors may require frequent cleaning (sensors are frequently the weak link in system reliability). Large diameter/high flow wells are expensive to drill.

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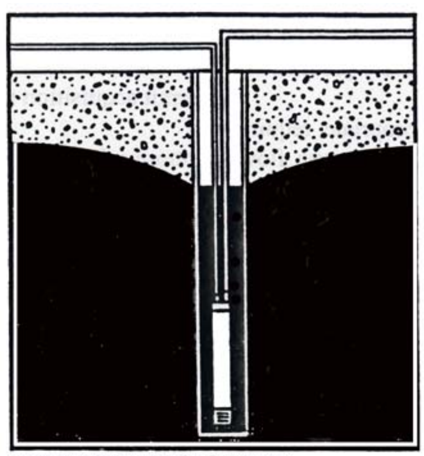
TABLE 8-5
Advantages and Disadvantages of
Gradient-Control Total-Fluids/Groundwater Pumping

ADVANTAGES	DISADVANTAGES
In sand/gravel soils, it can stop or reverse spread of contaminant plume, and speed the free product/contaminant recovery process. High flow systems, where appropriate, require fewer pumps and controls than lower flow approaches.	Higher flow systems won't work well in tight clay soils, low-yield wells. Permit acquisition may delay implementation. Bottom-inlet pump will always leave some product layer in the well (although volume of groundwater recovered may be high); top-inlet high-flow submersible pump mixes product with water to a great extent. Volatile compounds may cause air emission problems in pneumatic pump exhaust if bladder is not used. Typical problems with electric submersibles: shock or explosion hazard; excessive pump size, weight, and cost; unreliable performance, especially from attack on pump and/or seals by corrosives or aggressive organic compounds downwell; level sensor failure.

FIGURE 8-2c Pneumatic Pumping Configurations
Drawing Courtesy of QED Groundwater Specialists



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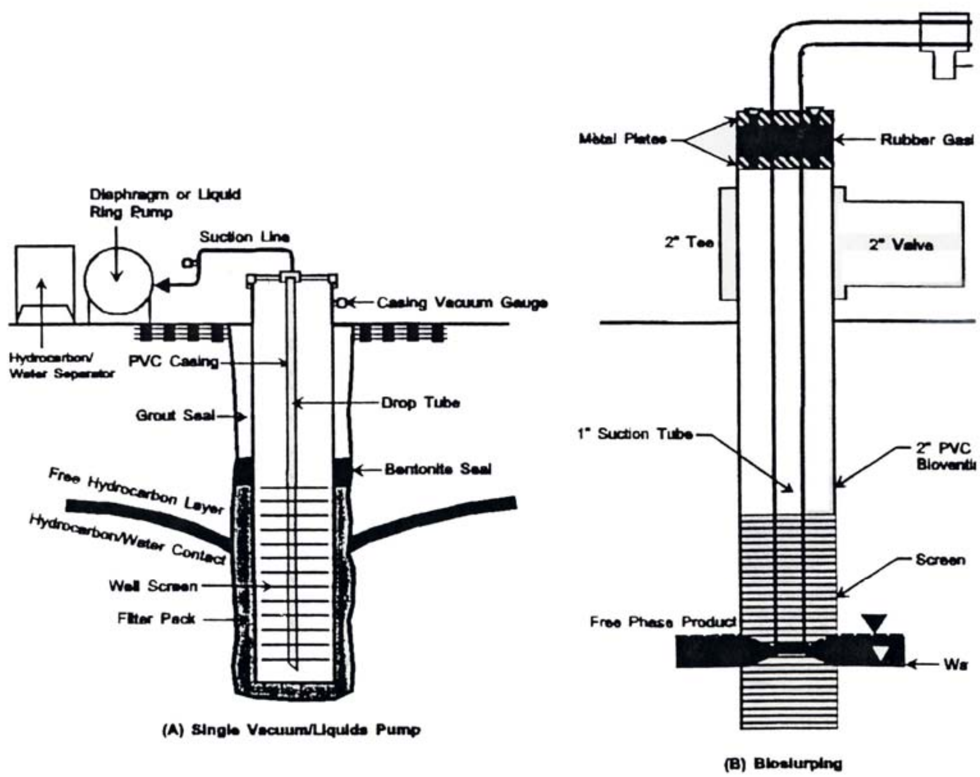
8.10 VACUUM-ENHANCED FREE-PRODUCT RECOVERY

TABLE 8-6
Advantages and Disadvantages of
Vacuum-Enhanced Free-Product Recovery

ADVANTAGES	DISADVANTAGES
Effective for medium to low permeability soils. Increases water and product flow 3 to 10 times while minimizing drawdown.	Large capital investment. Requires high-vacuum pump.

FIGURE 8-3 Vacuum-Enhanced Product Recovery



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8.11 SOIL VAPOR EXTRACTION

Note: This section has been excerpted from EPA documents. For details the reader is referred to the source document (EPA, 1994).

Soil vapor extraction (SVE), also known as soil venting or vacuum extraction, is an *in situ* remedial technology that reduces concentrations of volatile constituents in petroleum products adsorbed to soils in the unsaturated (vadose) zone. In this technology, a vacuum is applied to the soil matrix to create a negative pressure gradient that causes movement of vapors toward extraction wells. Volatile constituents are readily removed from the subsurface through the extraction wells. The extracted vapors are then treated, as necessary, and discharged to the atmosphere or reinjected to the subsurface (where permissible).

This technology has been proven effective in reducing concentrations of volatile organic compounds (VOCs) and certain semi-volatile organic compounds (SVOCs) found in petroleum products at underground storage tank (UST) sites. SVE is generally more successful when applied to the lighter (more volatile) petroleum products such as gasoline. Diesel fuel, heating oils, and kerosene, which are less volatile than gasoline, are not readily treated by SVE but may be suitable for removal by bioventing. SVE is generally not successful when applied to lubricating oils, which are non-volatile, but these oils may be suitable for removal by bioventing. A typical SVE system is shown in Figure 8-4. A summary of the advantages and disadvantages of SVE is shown in Table 8-7.

FIGURE 8-4 Typical SVE System

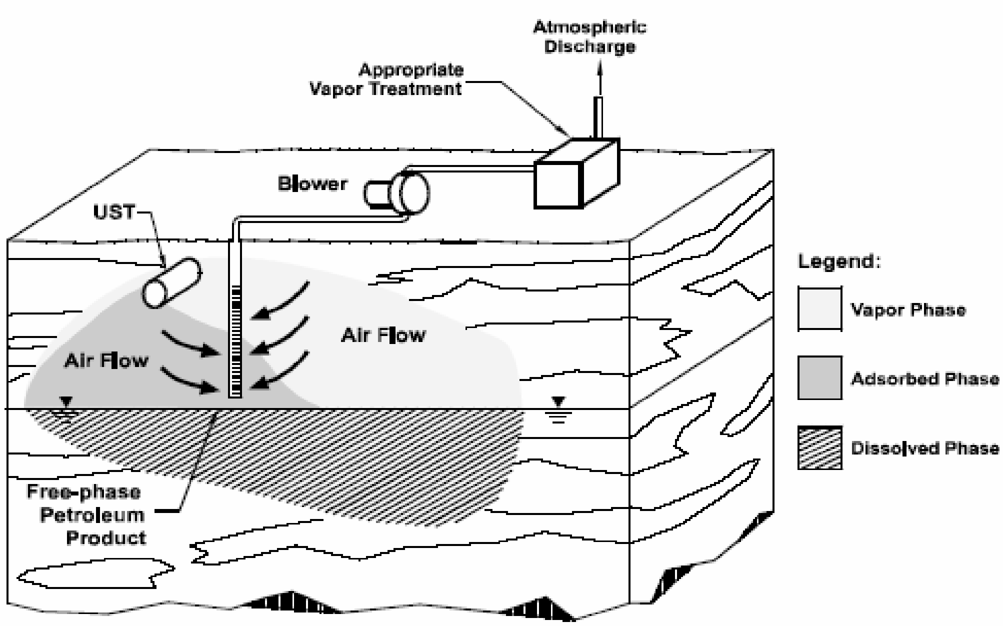

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TABLE 8-7
Advantages and Disadvantages of SVE

ADVANTAGES	DISADVANTAGES
Proven performance; readily available equipment; easy installation.	Concentration reductions greater than about 90% are difficult to achieve.
Minimal disturbance to site operations.	Effectiveness less certain when applied to sites with low-permeability soil or stratified soils.
Short treatment times: usually 6 months to 2 years under optimal conditions.	May require costly treatment for atmospheric discharge of extracted vapors.
Cost competitive: $20-50/ton of contaminated soil.	Air emissions permits generally required.
Easily combined with other technologies (*e.g.*, air sparging, bioremediation, and vacuum-enhanced dual-phase extraction).	Only treats unsaturated-zone soils; other methods may also be needed to treat saturated-zone soils and groundwater.
Can be used under buildings and other locations that cannot be excavated.	

8.12 Components of an SVE System

A typical SVE system design will include the following components and information:

- Extraction wells
- Well orientation, placement, and construction details
- Manifold piping
- Vapor pretreatment design
- Blower selection
- Instrumentation and control design
- Optional SVE components: Injection wells; surface seals; groundwater depression pumps; and vapor treatment systems

8.12.1 Extraction Wells

8.12.2 Well Orientation

An SVE system can use either vertical or horizontal extraction wells. Orientation of the wells should be based on site-specific needs and conditions. Table 8-8 lists site conditions and the corresponding appropriate well orientation.

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TABLE 8-8
Well Orientation and Site Conditions

WELL ORIENTATION	SITE CONDITIONS
Vertical Extraction Well	Shallow to deep contamination (5 to 100+ feet). Depth to groundwater > 10 feet.
Horizontal Extraction Well	Shallow contamination (> 25 feet). More effective than vertical wells at depths < 10 feet. Construction difficult at depths > 25 feet. Zone of contamination confined to a specific stratigraphic unit.

8.12.3 Well Placement and Number of Wells

Consider the following in determining well spacing.

- Use closer well spacing in areas of high contaminant concentrations to increase mass removal rates.

- If a surface seal exists or is planned for the design, space the wells slightly farther apart because air is drawn from a greater lateral distance and not directly from the surface. However, be aware that this increases the need for air injection wells.

- At sites with stratified soils, wells that are screened in strata with low intrinsic permeabilities should be spaced more closely than wells that are screened in strata with higher intrinsic permeabilities.

8.12.4 Blower Selection

The type and size of blower selected should be based on both the vacuum required to achieve design vacuum pressure at the extraction wellheads (including upstream and downstream piping losses) and the total flow rate. The flow rate requirement should be based on the sum of the flow rates from the contributing vapor extraction wells. In applications where explosions might occur, blowers must have explosion-proof motors, starters, and electrical systems.

8.12.5 Centrifugal Blowers

Centrifugal blowers (such as squirrel-cage fans) should be used for high-flow (up to 280 standard cubic feet per minute), low-vacuum (less than 30 inches of water) applications.

8.12.6 Regenerative and Turbine Blowers

Regenerative and turbine blowers should be used when a higher (up to 80 inches of water) vacuum is needed.

8.12.7 Rotary Lobe

Rotary lobe and other positive displacement blowers should be used when a very high (greater than 80 inches of water) vacuum and moderate air flow are needed.

8.12.8 Monitoring and Controls

The parameters typical monitored in an SVE system include:

- Pressure (or vacuum)
- Air/vapor flow rate
- Contaminant mass removal rates
- Temperature of blower exhaust vapors

The equipment in an SVE system used to monitor these parameters provides the information necessary to make appropriate system adjustments and track remedial progress. The control equipment in an SVE system allow the flow and vacuum pressure to be adjusted at each extraction well of the system, as necessary. Control equipment typically includes flow control valves.

8.13 OPERATION AND MONITORING PLAN

8.13.1 Start-Up Operations

The start-up phase should include 7 to 10 days of manifold valving adjustments. These adjustments should optimize contaminant mass removal by concentrating vacuum pressure on the extraction wells that are producing vapors with higher contaminant concentrations, thereby balancing flow and optimizing contaminant mass removal. Flow measurements, vacuum readings, and vapor concentrations should be recorded daily from each extraction vent, from the manifold, and from the effluent stack.

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8.13.2 Long-Term Operations

Long-term monitoring should consist of flow-balancing, flow and pressure measurements, and vapor concentration readings. Measurement should take place at biweekly to monthly intervals for the duration of the system operational period.

8.13.3 Remedial Progress Monitoring

Monitoring the performance of the SVE system in reducing contaminant concentrations in soils is necessary to determine if remedial progress is proceeding at the predicted pace.

The mass removed during long-term monitoring intervals can be calculated using vapor concentrations and flow rate measurements taken at the manifold. The instantaneous and cumulative mass removal is than plotted versus time. The contaminant mass removed during an operating period can be calculated using the equation provided below. This relationship can be used for each extraction well (and then totaled) or for the system as a whole, depending on the monitoring data that is available.

$$M = C \; x \; Q \; x \; t$$

where: M = cumulative mass removed (kg)
C = vapor concentration (kg/m^3)
Q = extraction flow rate (m^3/hr)
t = operational period (hr)

$$\text{mass removed (kg)} = kg/m^3 \; x \; m^3/hr \; x \; hr$$

Remedial progress of SVE systems typically exhibits asymptotic behavior with respect to both vapor concentration reduction and cumulative mass removal. At this point, the composition of the vapor should be determined and compared with soil vapor samples. This comparison will enable confirmation that there has been a shift in composition toward less volatile components. Soil vapor samples may indicate the composition and extent of the residual contamination. When asymptotic behavior begins to occur, the operator should closely evaluate alternatives that increase mass removal rate such as increasing flow to extraction wells with higher vapor concentrations by terminating vapor extraction from extraction wells with low vapor concentrations or pulsing. Pulsing involves the periodic shutdown and start-up operation of extraction wells (cycling) as shown in Figure 8-5 to allow the subsurface environment to come to equilibrium (shutdown) and then begin extracting vapors again (start-up). Other more aggressive steps to curb asymptotic behavior can include installation of additional injection wells or extraction wells.

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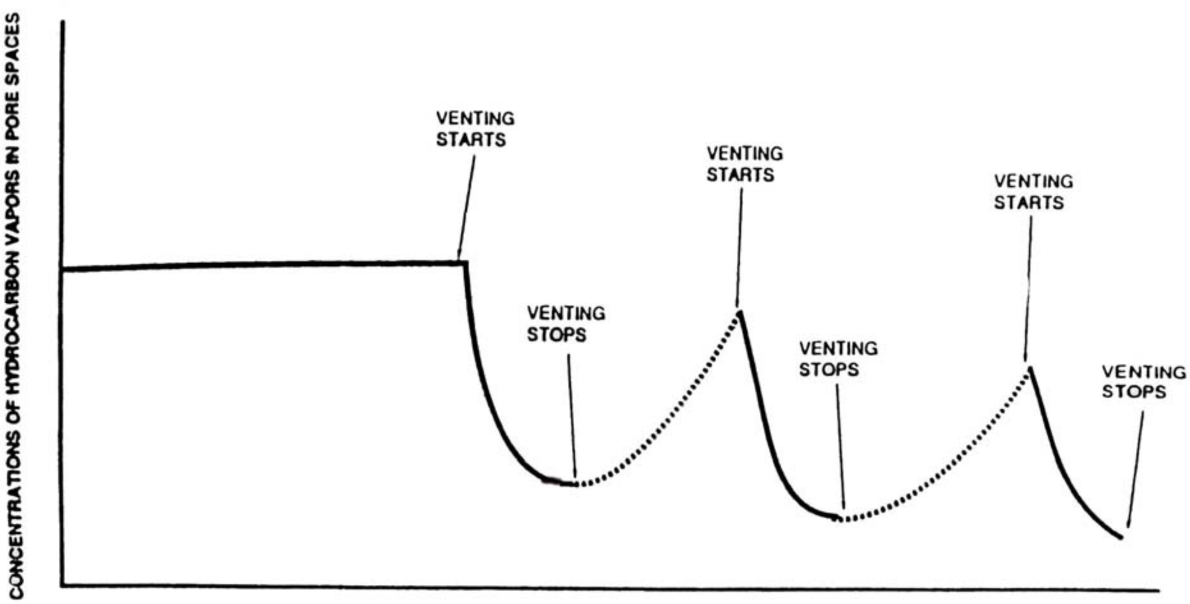
8.13.4 Confirmation Samples

Confirmation soil samples must be collected from the site to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. Typically soil borings must be drilled within the area of contamination, and soil samples be collected and analyzed. The number of soil samples will depend on the area of the site, and should be determined in consultation with the DERR project manager. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

FIGURE 8-5 Hydrocarbon Concentration Changes During Cycling of a Soil Venting System



8.14 AIR SPARGING

Note: This section has been excerpted from EPA documents. For details, the reader is referred to the source document (EPA, 1994).

Air sparging (AS) is an *in-situ* remedial technology that reduces concentrations of volatile constituents in petroleum products that are adsorbed to soils and dissolved in groundwater. This technology, which is also known as "in-situ air stripping" and "in-situ volatilization", involves the injection of contaminant-free air into the subsurface saturated zone, enabling a phase transfer of hydrocarbons from a dissolved state to a vapor phase. The air is then vented through the unsaturated zone. Air sparging is most often used together with soil vapor extraction (SVE), but it can also be used with other remedial technologies. When air sparging is combined with SVE,

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the SVE system creates a negative pressure in the unsaturated zone through a series of extraction wells to control the vapor plume migration. This combined system is called AS/SVE. A detailed discussion of SVE was presented previously.

The existing literature contains case histories describing both the success and failure of air sparging; however, since the technology is relatively new, there are few cases with substantial documentation of performance. When used appropriately, air sparging has been found to be effective in reducing concentrations of volatile organic compounds (VOCs) found in petroleum products at underground storage tank (UST) sites. Air sparging is generally more applicable to the lighter gasoline constituents (*i.e.*, benzene, ethylbenzene, toluene, and xylenes [BTEX]), because they readily transfer from the dissolved to the gaseous phase. Air sparging is less applicable to diesel fuel and kerosene. Appropriate use of air sparging may require that it be combined with other remedial methods (*e.g.*, SVE or pump-and-treat). Figure 8-6 provides an illustration of an air sparging system with SVE. Table 8-9 provides a summary of the advantages and disadvantages of air sparging.

8.14.1 Field Pilot-Scale Studies

Field pilot studies are necessary to adequately design and evaluate any air sparging system. However, pilot tests should not be conducted if free product is known to exist at the groundwater table, if uncontrolled vapors could migrate into confined spaces, sewers, or buildings, of if the contaminated groundwater is in an unconfined aquifer. The air sparge well used for pilot testing is generally located in an area of moderate constituent concentrations. Testing the system in areas of extremely low constituent concentrations may not provide sufficient data. In addition, because sparging can induce migration of constituents, pilot tests are generally not conducted in areas of extremely high constituent concentrations. The air sparging pilot study should include an SVE pilot study if SVE is included in the design of the air sparging system.

FIGURE 8-6 Air Sparging System with SVE

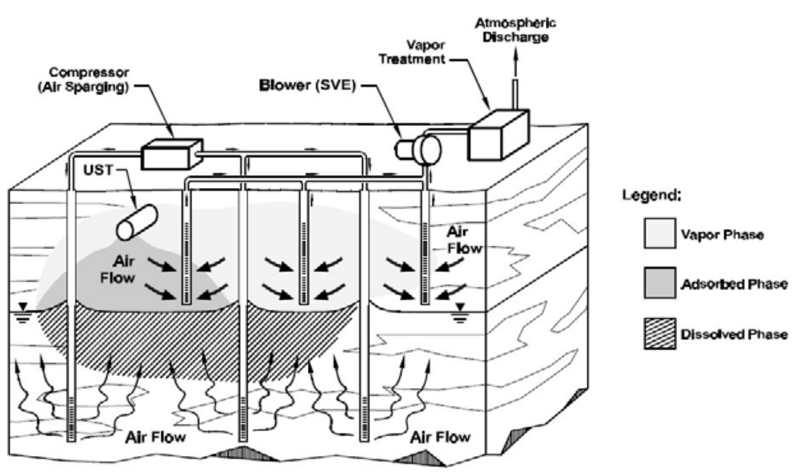

TABLE 8-9
Advantages and Disadvantages of Air Sparging

ADVANTAGES	DISADVANTAGES
Readily available equipment; easy installation.	Cannot be used if free product exists (i.e., any free product must be removed prior to air sparging).
Implemented with minimal disturbance to site operations.	Cannot be used for treatment of confined aquifers.
Short treatment times: usually less than 1 to 3 years under optimal conditions.	Stratified soils may cause air sparging to be ineffective.
At about $20-50/ton of saturated soil, air sparging is less costly than aboveground treatment systems.	Some interactions among complex chemical, physical, and biological processes are not well understood.
Requires no removal, treatment, storage, or discharge considerations for groundwater.	Lack of field and laboratory data to support design considerations.
Can enhance removal by SVE.	Potential for inducing migration of constituents.
	Requires detailed pilot testing and monitoring to ensure vapor control and limit migration.

Pilot studies for air sparging often include SVE pilot testing to determine if SVE can be used to effectively control the vapor plume. Pilot studies, therefore, should include the installation of a single sparge point, several vapor extraction points to evaluate vapor generation rates and to define the vapor plume. Existing groundwater monitoring wells (normally not fewer than three to five wells around the plume) that have been screened above the saturated zone and through the dissolved phase plume can be used to monitor both dissolved and vapor phase migration, to monitor for changes in dissolved oxygen, and to measure changes in the depth to the groundwater table surface. Additional vapor probes should be used to further define the vapor plume and identify any preferential migration pathways. These probes should be designed and installed as discussed in Soil Vapor Extraction.

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If SVE is to be used in the air sparging system, the first portion of the test should be conducted using vapor extraction only and evaluated as described in Soil Vapor Extraction with the air sparging system being operated. This portion of the pilot test will establish the baseline vapor extraction levels, the extent of the non-sparged vapor plume, the SVE well radius of influence, and the intrinsic permeability of the unsaturated zone. The air-sparging portion of the test should be conducted with the sparging point operating at variable sparge pressures (*e.g.*, 5 pounds per square inch-gauge [psig], 10 psig), and different depths (*e.g.*, 5 feet, 10 feet below the dissolved phase plume). It is essential that vapor equilibrium be obtained prior to changing the sparge rate or depth. When no change in vapor emission rates from baseline occurs, the air sparging system may not be controlling the sparge vapor plume, possibly due to soil heterogeneity. Assess the potential for this problem by reviewing the site's soil lithology, typically documented on soil boring logs. During this test, the hydraulic gradient and VOC concentrations in soil vapors extracted from monitoring wells must be monitored until equilibrium is reached.

The final portion of the pilot test is the concurrent operation of the SVE pilot system and the air sparging system. This portion of the test will determine the optimum SVE system (*i.e.*, the number and orientation of wells) that will capture the sparged VOCs for various sparging rates. In addition, this portion of the test requires monitoring of VOC emissions, sparging pressure and low rates, SVE vacuum and flow rates, monitoring well vapor concentrations, and dissolved constituent concentrations.

8.14.2 Components of an Air Sparging System

A typical air sparging system design may include the following components and information:

- Well orientation, placement, and construction details
- Manifold piping
- Compressed air equipment
- Monitoring and controls

If an SVE system is used for vapor control, the following components and information will also be needed:

- Vapor pretreatment design
- Vapor treatment system selection
- Blower specification.

8.14.3 Monitoring and Controls

The parameters typically monitored in an air sparging system include:

- Pressure (or vacuum)
- Air/vapor flow rate

The equipment is an air sparging system used to monitor these parameters, provides the information necessary to make appropriate system adjustments, and track remedial progress. The control equipment in an air sparging system allow the flow and sparge pressure to be adjusted at each sparging well of the system, as necessary. Control equipment typically includes flow control valves/regulators.

8.15 OPERATION AND MAINTENANCE PLAN

8.15.1 Start-Up Operations

The start-up phase should begin with only the SVE portion of the system (if used). After the SVE system is adjusted, the air sparging should be started. Start-up operations should include 7 to 10 days of manifold valving adjustments to balance injection rates and optimize mass flow rates. Injection and extraction rates, pressures, depth to groundwater, hydraulic gradient, and VOC levels should be recorded hourly during initial start-up until the flow is stabilized. Injection rates should then be monitored daily. Vapor concentration should also be monitored in any nearby utility lines, basements, or other subsurface confined spaces. Other monitoring of the system should be done in accordance with the SVE requirements.

8.15.2 Long-Term Operations

Long-term monitoring should consist of contaminant level measurements (in the groundwater, vapor wells, and blower exhaust), flow balancing (including flow and pressure measurements), and vapor concentration readings. Measurements should take place at biweekly to monthly intervals for the duration of the system operational period.

Samples collected during sparging operations may give readings that show lower concentrations of dissolved contaminants than those found in the surrounding aquifer. These readings could lead to the erroneous conclusion that remediation is occurring throughout the aquifer. Therefore, contaminant concentrations should be determined shortly following system shutdown, when the subsurface environment has reached equilibrium.

8.15.3 Remedial Progress Monitoring

Monitoring the performance of the air sparging system in reducing contaminant concentrations in the saturated zone is necessary to determine if remedial progress is proceeding at a reasonable pace. A variety of methods can be used. One method includes monitoring contaminant levels in the groundwater and vapors in the monitoring wells and blower exhaust, respectively. The vapor and contaminant concentrations are then each plotted against time.

Remedial progress of air sparging systems typically exhibit asymptotic behavior with respect to both dissolved-phase and vapor-phase concentration reduction. Systems that use SVE can monitor progress through mass removal calculations. When asymptotic behavior begins to occur, the operator should evaluate alternatives that increase the mass transfer removal rate (*e.g.*, pulsing, or turning off the system for a period of time and then restarting it). Other more aggressive steps to further reduce constituent concentrations can include installation of additional air sparging or extraction wells.

If asymptotic behavior is persistent for periods greater than about 6 months and the concentration rebound is sufficiently small following periods of temporary system shutdown, the appropriate regulatory officials should be consulted; termination of operations may be appropriate.

8.15.4 Groundwater Monitoring

Periodic monitoring of groundwater is typically required by the DERR from the time groundwater contamination is first reported to the DERR, through the subsurface investigation and corrective action phases. Quarterly sampling and analysis is the most common period, although the interval may be lengthened or shortened depending on site-specific conditions. Groundwater samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN. Groundwater monitoring results will indicate how well the treatment is progressing, and will form the basis for determining when corrective action cleanup goals have been achieved.

8.16 TOTAL-FLUIDS HIGH-VACUUM EXTRACTION

Note: This section has been excerpted from an EPA document. For details the reader is referred to the source document: (EPA 542-R-99-004, June 1999, Multi-Phase Extraction: State-of-the-Practice).

Total-fluids high-vacuum extraction is a generic term for technologies that extract VOCs in soil vapor and groundwater, simultaneously. Total-fluids high-vacuum extraction couples soil vapor extraction and groundwater pump-and-treat system by applying a vacuum on a sealed recovery well.

Total-fluids high-vacuum extraction is typically applied in recovery wells with some portion of the well screen extending above the water table into the vadose zone. Groundwater recovery is achieved by pumping at or below the water table. The applied vacuum extracts soil vapor and enhances groundwater recovery. Liquid flow rates are increased due to the increased pressure gradient applied on the system. In some configurations, the vacuum increases the effective drawdown locally near the pumped well without significantly lowering the water table surface away from the pumped well.

Applying a vacuum to an extraction well enhances the hydraulic gradient. The hydraulic gradient is defined as the difference in hydraulic head between two points divided by the length of the flow path. From Darcy's Law, it is known that the rate of flow through the aquifer is directly proportional to the hydraulic gradient. When drawdown is maximized, lowering the water level cannot increase the head difference. However, applying negative pressure (a vacuum) to the extraction well can increase the effective head difference. Thus, the hydraulic gradient increases and a resulting increase in the rate of groundwater extraction is realized.

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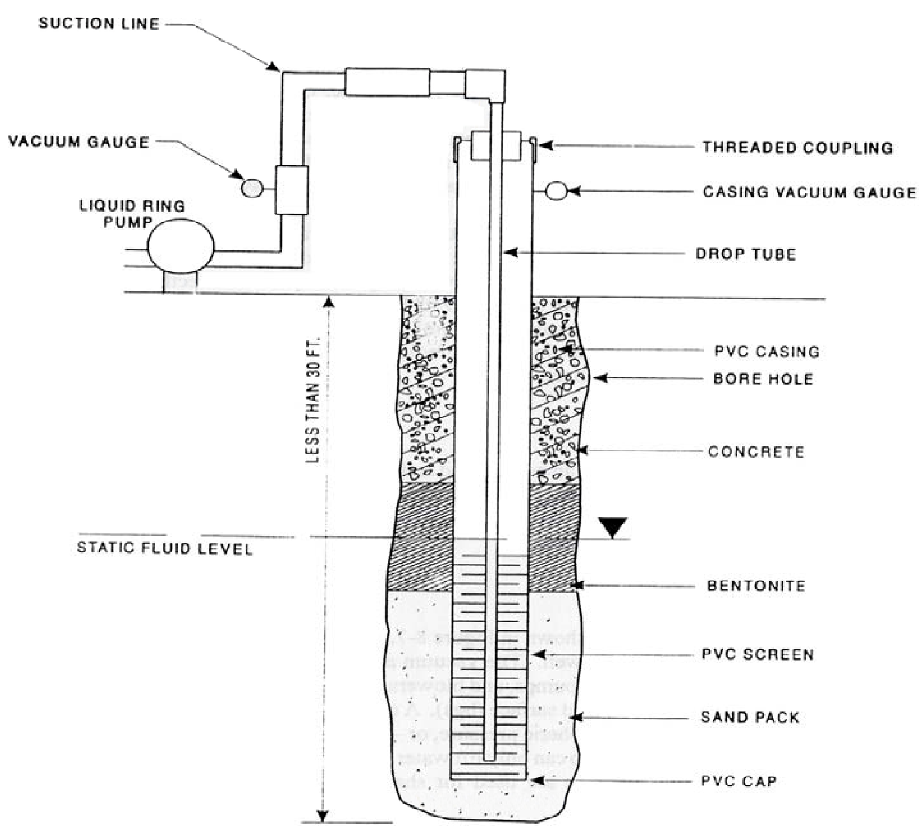
8.17 TECHNOLOGY CONFIGURATIONS

Total-fluids high-vacuum extraction can be designed and implemented in a variety of configurations. The three main forms of total-fluids high-vacuum extraction are the single and two pump configurations and bioslurping. The latter is essentially a minor variation of the single pump configuration used to recover free product.

8.17.1 Single-Pump Configuration

In the single pump configuration, as shown in Figure 8-7, a single drop tube is employed to extract both liquid and vapor from a single well. The vacuum and liquid suction lift is achieved by one vacuum pump (liquid-ring pumps, jet pumps, and blowers are typical). This configuration is limited to depths of about 30 feet below ground surface (bgs). A complete vacuum would be achieved at an equal and opposite value of the atmospheric pressure, or –14.7 psi, which equates to 34 feet of water column. In theory, a vacuum lift pump can only lift water a height equal to the atmospheric pressure. As such, single pump configurations are used for shallow (less than 30 feet bgs) water-table remediation.

FIGURE 8-7 Single-Pump Configuration, Extraction Well 1



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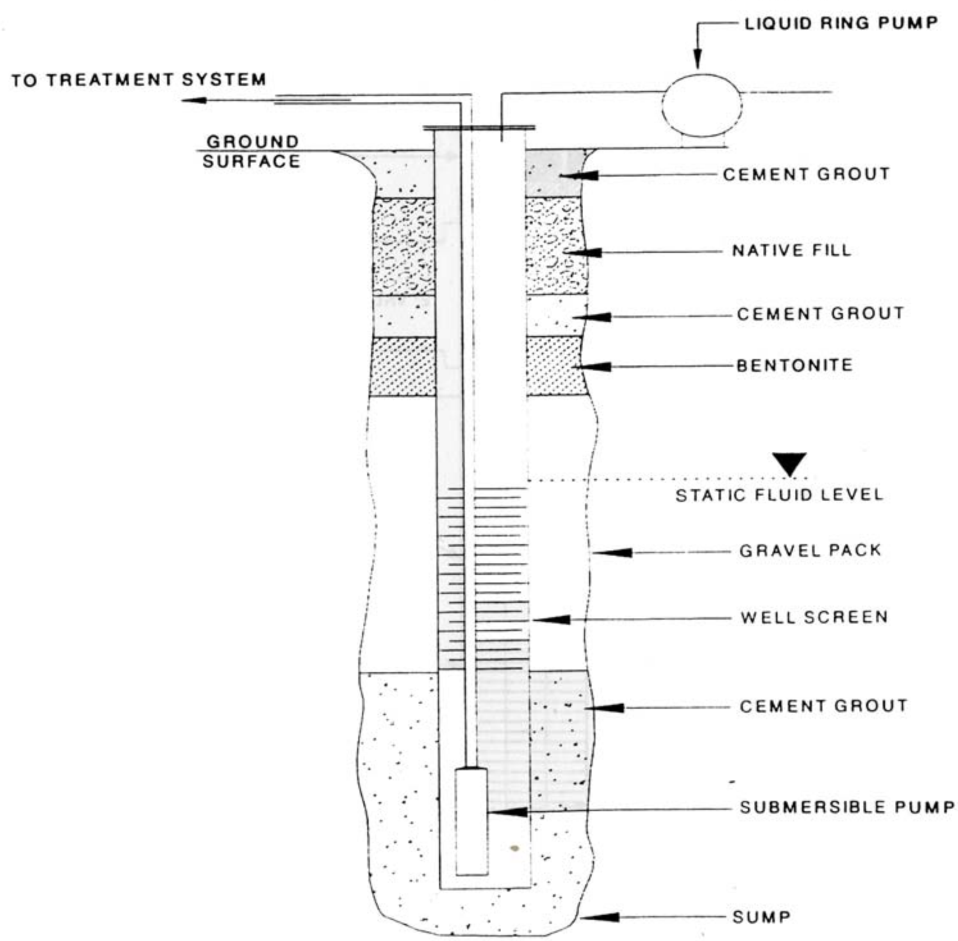
8.17.2 Dual-Pump Configuration

Depth limitations can be overcome with the second configuration, the dual-pump total-fluids high-vacuum extraction system shown in Figure 8-8. This system utilizes a submersible pump for groundwater recovery in conjunction with a separate vacuum applied at the sealed wellhead. In this configuration, liquid and vapor streams are separate from one another. Conductivity type level sensors can be utilized for pump control. Level control may be necessary to prevent the vacuum from causing the pump to lose positive suction head and cavitate. Depending on the application, two-pump systems can utilize electric or pneumatic submersible pumps for groundwater recovery and liquid ring pumps or blowers to induce vacuum. Applications for the recovery of a free product, or light, non-aqueous phase liquid (LNAPL), typically employ pneumatic submersible pumps for liquid recovery.

FIGURE 8-8 Dual-Pump Configuration, Extraction Well 2

(Modified from Suthersan, 1997).



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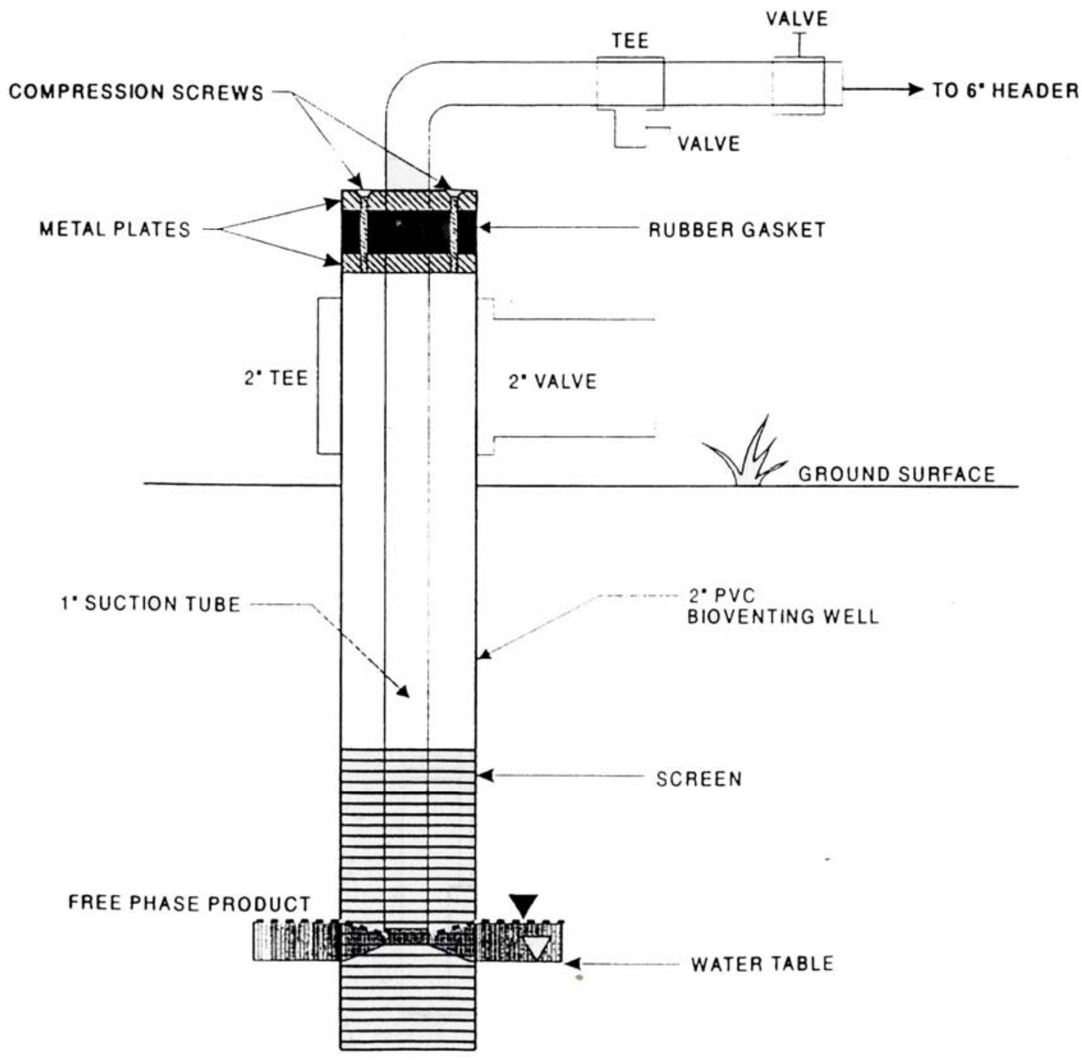
8.17.3 Bioslurping

The last total-fluids extraction configuration is often referred to as bioslurping. This configuration is the same as the single-pump total-fluids extraction scheme; however, the drop tube in a bioslurping application is set at, or just below, the liquid-air interface. This configuration has shown to be effective at free product recovery and is primarily used for that purpose. The bioslurping system extracts water, LNAPL, and air from a single 1-inch drop tube in a 2-inch diameter well. The extraction point alternates from recovering liquid to air, emanating a slurping sound. A secondary goal of bioslurping is the enhancement of *in situ* aerobic biodegradation of aromatic hydrocarbons as a result of increased airflow. Figure 8-9 illustrates a typical bioslurping configuration.

FIGURE 8-9 Bioslurping, Extraction Well 3

(Kittel, et al., 1994).



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8.18 COMPONENTS OF A TOTAL-FLUIDS HIGH-VACUUM EXTRACTION SYSTEM

A typical total-fluids high-vacuum extraction system design includes the following components and information:

- Total-fluids high-vacuum extraction well orientations, placement, and construction detail
- Well head completion and drop tube specifications
- Manifold piping
- Gas-liquid separator tank
- NAPL/Water separator tank
- Blower selection specification
- Gas, LNAPL, and water discharges
- Optional Gas/water treatment systems
- Monitoring and control equipment

Figure 8-10 shows the components of a typical total-fluids high-vacuum extraction system. The advantages and disadvantages are listed in Table 8-10.

FIGURE 8-10 Total-Fluids High-Vacuum Extraction Components

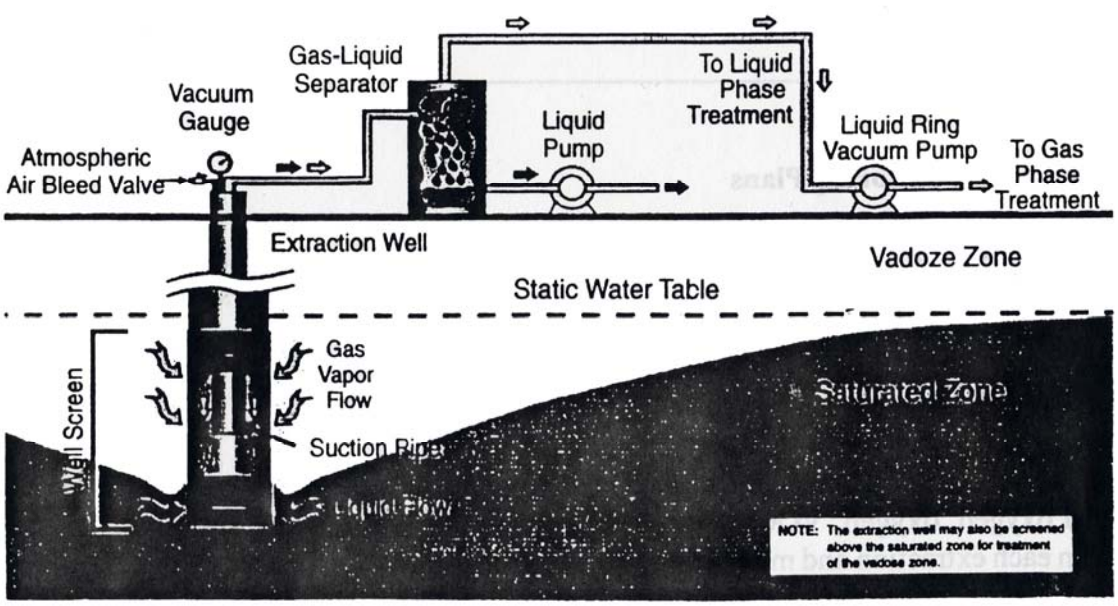

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TABLE 8-10
Advantages and Disadvantages of Total-Fluids High-Vacuum Extraction

ADVANTAGES	DISADVANTAGES
Increase in groundwater recovery rates, compared to conventional pumping practices.	If applied outside of the appropriate conditions, total-fluids high-vacuum extraction may be ineffective and less cost effective than other technologies.
Increase in radius of influence of individual groundwater recovery wells.	Potentially higher capital costs compared to conventional treatments.
Remediation of shallow layer of floating, free product, capillary fringe and smear zone.	May require air and/or groundwater discharge treatment and/or permitting.
Simultaneous remediation of soil and groundwater.	Initial startup and adjustment periods may be longer compared to conventional pumping approaches.
Total-fluids extraction is most applicable to fine-grained sands and silts (hydraulic conductivity, $K = 10^{-3}$ to 10^{-5} cm/s) with possible applications to lower conductivity.	Depth limitations apply to some total-fluids extraction configurations.
Increased airflow and introduction of oxygen stimulates biodegradation.	

8.19 OPERATION AND MONITORING PLANS

The system operations and monitoring plan should include both system start-up and long-term operations. Operations and monitoring are necessary to ensure optimal system performance and to track the rate of contaminant mass removal/reduction.

8.19.1 Start-Up Operation

System start-up and monitoring operations begin by measuring the background concentrations of dissolved oxygen, oxygen, VOCs, pH, redox potential, depth to water and LNAPL, and carbon dioxide in each extraction and monitoring well. The drop tubes are then set to a predetermined level as determined by the depth to groundwater. The system is then started and minor adjustments are made to reduce or increase groundwater and/or vapor flow rates. With the system in operation, wellhead vacuum measurements are taken to adjust the flow rate to each extraction well.

Oxygen, carbon dioxide, and VOC levels are monitored at the stack discharge points to optimize contaminant removal, and air and water samples are collected for permit compliance. Depth to water measurements are taken from each monitoring well at regular intervals to determine the groundwater draw-down radius of influence. Monitoring of the oxygen, carbon dioxide, and VOC levels at the discharge stack continue hourly until the readings reach a steady state. Additional air and water samples are collected at this point. Vapor concentrations and oxygen levels should also be monitored at each wellhead or monitoring well to ensure high oxygen readings and low VOC readings.

8.19.2 Long-Term Operations

To evaluate the performance of a biosparging system the following parameters should be monitored weekly for the first month and monthly thereafter:

- Carbon dioxide, oxygen, VOCs, and flow in the blower discharge stack.
- Vacuum, oxygen, carbon dioxide, depth to water, and VOCs at each wellhead or monitoring point.
- Contaminant levels, dissolved oxygen, and pH in the groundwater discharge.
- Dissolved oxygen, redox potential, and depth to water in the monitoring wells.
- Air and water contaminant concentration samples.

8.19.3 Remedial Progress Monitoring

Several plots of the remediation progress are used to evaluate the total-fluids extraction system for contamination reduction. Examples of these plots include carbon dioxide and oxygen percentage versus time, Cumulative hydrocarbons degraded versus time, VOC concentrations versus time, and air and groundwater concentrations versus time. As remediation progresses the amount of carbon dioxide in the discharged vapors decreases while oxygen levels increase to near atmospheric conditions. VOC and air contaminant levels should decrease to below detection limits, and groundwater concentrations should decrease to below MCLs.

When asymptotic behavior begins to occur, the operator should make necessary system adjustments to maximize VOC removal. Once the monitoring levels continue at near cleanup levels the system should be turned off for a period of time and restarted or pulsed. Monitoring wells should be tested after a minimum period of one week for VOCs, oxygen, carbon dioxide, groundwater contaminant concentrations, dissolved oxygen, pH, redox potential, and depth to water. If the contamination has rebounded, the system is again started and operated until asymptotic levels are achieved. This process is repeated until the remedial goals have been achieved.

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8.20 BIOVENTING

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Bioventing is an in-situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents adsorbed to soils in the unsaturated zone. Soils in the capillary fringe and the saturated zone are not affected. In bioventing, the activity of the indigenous bacteria is enhanced by inducing air (or oxygen) flow into the unsaturated zone (using extraction or injection wells) and, if necessary, by adding nutrients. A bioventing layout using extraction wells is shown in Figure 8-10; air flow would be reversed if injection wells were used.

When extraction wells are used for bioventing, the process is similar to soil vapor extraction (SVE). However, while SVE removes constituents primarily through volatilization, bioventing systems promote biodegradation of constituents and minimize volatilization (generally by using lower air flow rates than for SVE). In practice, some degree of volatilization and biodegradation occurs when either SVE or bioventing is used.

All aerobically biodegradable constituents can be treated by bioventing. In particular, bioventing has proven to be very effective in remediation releases of petroleum products including gasoline, jet fuels, kerosene, and diesel fuel. Bioventing is most often used at sites with mid-weight petroleum products (*e.g.*, diesel fuel and jet fuel), because lighter products (*e.g.*, gasoline) tend to volatilize readily and can be removed more rapidly using SVE. Heavier products (*e.g.*, lubricating oils) generally take longer to biodegrade than the lighter products. A summary of the advantages and disadvantages of bioventing is shown in Table 8-11.

8.20.1 Initial Screening of Bioventing Effectiveness

The key factors that should be used to decide whether bioventing has the potential to be effective at a particular site are:

- The ***permeability*** of the petroleum-contaminated soils. This will determine the rate at which oxygen can be supplied to the hydrocarbon-degrading microorganisms found in the surface.

- The ***biodegradability*** of the petroleum constituents. This will determine both the rate at which and the degree to which the constituents will be metabolized by microorganisms.

In general, the type of soil will determine its *permeability*. Fine-grained soils (*e.g.*, clays and silts) have lower permeabilities than coarse-grained soils (*e.g.*, sands and gravels.). The *biodegradability* of a petroleum product constituent is a measure of its ability to be metabolized by hydrocarbon-degrading bacteria that produce carbon dioxide and water as byproducts of microbial respiration. Petroleum products are generally biodegradable regardless of their molecular weight, as long as indigenous microorganisms have an adequate supply of oxygen and nutrients. For heavier constituents (which are less volatile and less soluble than many lighter components), biodegradation will exceed volatilization as the primary removal mechanism, even though biodegradation is generally slower for heavier constituents than for lighter constituents.

TABLE 8-11
Advantages and Disadvantages of Bioventing

ADVANTAGES	DISADVANTAGES
Uses readily available equipment; easy to install.	High constituent concentrations may initially be toxic to microorganisms.
Creates minimal disturbance to site operations. Can be used to address inaccessible areas (e.g., under buildings).	Not applicable for certain site conditions (e.g., low soil permeabilities, high clay content, insufficient delineation of subsurface conditions).
Requires short treatment times: usually 6 months to 2 years under optimal conditions.	Cannot always achieve very low cleanup standards.
Is cost competitive: $45-140/ton of contaminated soil.	Permits generally required for nutrient injection wells (if used). (A few states also require permits for air injection).
Easily combined with other technologies (e.g., air sparging, groundwater extraction).	
May not require costly offgas treatment.	

8.20.2 Pilot-Scale Studies

In general, remedial approaches that rely on biological processes should be subject to field pilot studies to verify and quantify the potential effectiveness of the approach and provide data necessary to design the system. For bioventing, these studies may range in scope and complexity from a simple soil column test or microbial count to field respirometry tests and soil vapor extraction (or injection) pilot studies. The scope of pilot testing or laboratory studies should be commensurate with the size of the area to be remediated, the reduction in constituent concentration required, and the results of the initial effectiveness screening.

A list and description of commonly used laboratory and pilot-scale studies is provided below.

- ***Soil Vapor Extraction and Injection Treatability*** *Tests* are generally used to determine the radius of influence that an extraction well or injection well can exert in the surrounding soils, the optimum vapor flow rate and pressure (or vacuum) that should be applied to the wells, and the concentrations of petroleum constituents in the induced air stream. The test most often includes short-term vapor extraction or air injection from a single well while measuring the pressure effect in monitoring wells or probes spaced at increasing distances from the extraction well or the injection well. The test can assist in determining the spacing, number, and type of wells needed for the full-scale system. It is usually not economically attractive to perform this test for sites with areas smaller than 5,000 cubic yards of *in-situ* contaminated soil or for sites with soil permeabilities greater than 10^{-8} cm^2.

- ***Respirometry** Studies* are generally used to determine the oxygen transport capacity of the site soils and to estimate the biodegradation rates under field conditions. The test includes short-term injection of an oxygen/inert gas mixtures into a well that has been screened in the contaminated soil horizon. Carbon dioxide, inert gas (typically helium), and oxygen concentrations are measured in the injection well and surrounding wells periodically for about 1 to 5 days. The measurements are then compared to baseline concentrations of the gases prior to injection. Increases in carbon dioxide and decreases in oxygen concentrations are indications of biological metabolism of constituents; the inert gas concentration provides the baseline for these calculations. Temperature of the extracted vapor may also be monitored to serve as an additional indicator of biological activities. Field respirometry studies are usually only needed for sites with large areas of contamination, perhaps greater than 100,000 cubic yards of *in-situ* soils requiring remediation; at sites where soil permeability is less than 10^{-8} cm^2; or when reductions of more than 80 percent of the constituents that have vapor pressure less than 0.5 mm Hg are required.

- ***Laboratory Microbial Screening*** tests are used to determine the presence of a population of naturally-occurring bacteria that may be capable of degrading petroleum product constituents. Samples of soils from the site are analyzed in an offsite laboratory. Microbial plate counts determine the number of colony forming units (CFU) of heterotrophic bacteria and petroleum-degrading bacteria are present per unit mass of dry soil. These tests are relatively inexpensive.

- ***Laboratory Biodegradation Studies*** can be used to estimate the rate of oxygen delivery and to determine if the addition of inorganic nutrients is necessary. However, laboratory studies cannot duplicate field conditions, and field tests are more reliable. There are two kinds of laboratory studies: *slurry studies* and *common studies.* ***Slurry studies***, which are more common and less costly, involve the preparation of numerous "soil microcosms" consisting of small samples of site soils mixed into a slurry with site groundwater. The microcosms are divided into several groups which may include control groups that are "poisoned" to destroy any bacteria, non-nutrified test groups that have been provided oxygen but not nutrients, and nutrified tests groups which are supplied which are supplied both oxygen and nutrients. Microcosms from each group are analyzed periodically (usually weekly) for the test period duration (usually 4 to 12 weeks) for bacterial population counts and constituent concentrations. Results of slurry studies should be considered as representing optimal conditions because slurry microcosms do not consider the effects of limited oxygen delivery or soil heterogeneity. ***Column studies*** are set up in a similar way using columns of site soils and may provide more realistic expectations of bioventing performance.

8.21 COMPONENTS OF A BIOVENTING SYSTEM

A typical bioventing system design (Figure 8-11) will include the following components and information:

- Extraction well (for injection well) orientation, placement, and construction details
- Piping design
- Vapor pretreatment design (if necessary)
- Vapor treatment system selection (if necessary)
- Blower specification
- Instrumentation and control design
- Monitoring locations

Nutrient additions are sometimes included in bioventing designs. If nutrients are added, the design should specify the nutrient addition well orientation, placement, and construction details. Note that state regulations may either require permits for nutrient injection wells or prohibit them entirely.

8.21.1 Well Placement and Number of Wells

The number and location of extraction wells can be determined as outlined in the section on soil vapor extraction.

Consider the following additional factors in evaluating proposed well spacing.

- In areas of high contaminant concentrations, closer well spacing is desired to increase oxygen flow and accelerate contaminant degradation rates.

- Wells may be spaced slightly farther apart if a surface seal is planned for installation or if one already exists. A surface seal increases the radius of influence by forcing air to be drawn from a greater distance by preventing short-circuiting from land surface. However, passive vent wells or air injection wells may be required to supplement the flow of air in the subsurface.

- In stratified or structured soils, well spacings may be irregular. Wells screened in zones of lower intrinsic permeability must be spaced closer together than wells screened in zones of higher intrinsic permeability.

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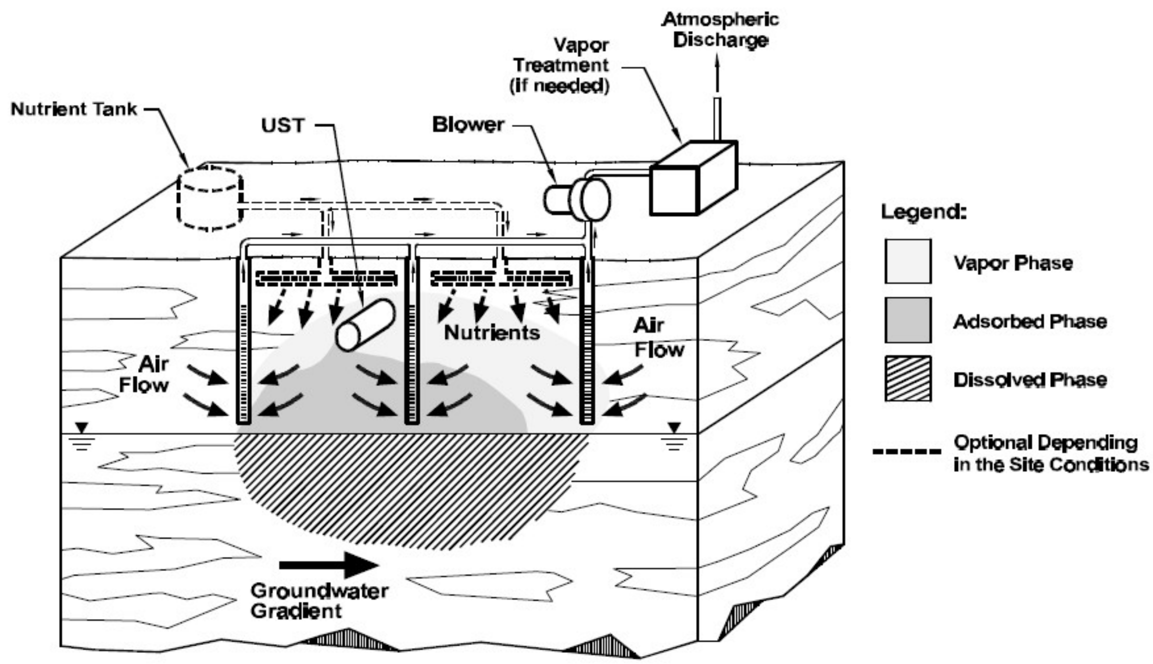
8.22 OPERATION AND MONITORING PLANS

Operations and monitoring are necessary to ensure that system performance is optimized and contaminant mass extraction and degradation are tracked. Monitoring of remedial progress for bioventing systems is more difficult than for SVE systems in that mass removal cannot be directly measured in extracted vapors. Typically, both VOC concentrations (extracted mass) and carbon dioxide concentrations (a product of microbial respiration) must both be monitored.

FIGURE 8-11 Typical Bioventing System Using Vapor Extraction



Systems involving only injection wells will have an especially limited capability for performance monitoring because it is not possible to collect the off gas. The monitoring plan should include subsurface soil sampling to track constituent reduction and biodegradation conditions. Also, to ensure the injected air is not causing contamination of the atmosphere or previously uncontaminated soil or groundwater, samples from each medium should be analyzed for potential constituents.

8.22.1 Start-Up Operations

The start-up phase should include 7 to 10 days of manifold valving adjustments. These adjustments should balance flow to optimize carbon dioxide production and oxygen uptake rate while, to the extent possible, minimizing volatilization by concentrating pressure (or vacuum) on the wells that are in areas of higher contaminant concentrations. To accomplish this, flow measurements, pressure or vacuum readings, carbon dioxide concentrations, oxygen concentrations, and VOC concentrations should be recorded daily from each extraction well, from the manifold, and from the effluent stack. Nutrient delivery (if needed) should not be performed until after start-up operations are complete.

8.22.2 Long-Term Operations

Long-term monitoring should consist of flow balancing, flow and pressure measurements, carbon dioxide measurements, oxygen measurements, and VOC concentration readings. Measurements should take place at weekly or biweekly intervals for the duration of the system operation period. Nutrient addition, if necessary, should occur on a periodic basis rather than continuously. Some literature suggests that nutrient solutions be injected in wells or trenches or applied to the surface at monthly or quarterly intervals.

8.22.3 Remedial Progress Monitoring

Monitoring the performance of the bioventing system in reducing contaminant concentrations in soils is necessary to determine if remedial progress is proceeding at a reasonable pace. A variety of methods can be used. Since concentrations of petroleum constituents may be reduced due to volatilization and biodegradation, both processes should be monitored in order to track the cumulative effect. The constituent mass extraction component can be tracked and calculated using the VOC concentrations measured in the extraction multiplied by the extraction flow rate. The constituent mass that is degraded is more difficult to quantify, but can be monitored qualitatively by observing trends in carbon dioxide and oxygen concentrations in the extracted soil vapors.

Remedial progress of bioventing systems typically exhibits asymptotic behavior with respect to VOC, oxygen, and carbon dioxide concentrations in extracted vapors. When asymptotic behavior begins to occur, the operator should closely evaluate alternatives that may increase bioventing effectiveness (*e.g.*, increasing extraction flow rate or nutrient addition frequency). Other, more aggressive steps to curb asymptotic behavior can include adding injection wells, additional extraction wells, or injecting concentrated solutions of bacteria.

If asymptotic behavior is persistent for periods greater than about 6 months, modification of the system design and operations (*e.g.*, pulsing of injection or extraction air flow) may be appropriate. If asymptotic behavior continues, termination of operations may be appropriate.

8.22.4 Confirmation Samples

Confirmation soil samples must be collected from the site to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. Typically soil borings must be drilled within the are of contamination, and soil samples be collected and analyzed. The number of soil samples will depend on the area of the site, and should be determined in consultation with the DERR project manager. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

8.23 BIOSPARGING

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Biosparging is an in-situ remediation technology that uses indigenous microorganisms to biodegrade organic constituents in the saturated zone. In biosparging, air (or oxygen) and nutrients (if needed) are injected into the saturated zone to increase the biological activity of the indigenous microorganisms. Biosparging can be used to reduce concentrations of petroleum constituents that are dissolved in groundwater, adsorbed to soil below the water table, and within the capillary fringe. Although constituents adsorbed to soils in the unsaturated zone can also be treated by biosparging, bioventing is typically more effective for this situation.

The biosparging process is similar to air sparging. However, while air sparging removes constituents primarily through volatilization, biosparging promotes biodegradation of constituents rather than volatilization (generally by using lower flow rates than are used in air sparging). In practice, some degree of volatilization and biodegradation occurs when either air sparging or biosparging is used. When volatile constituents are present, biosparging is often combined with soil vapor extraction or bioventing (collectively referred to as vapor extraction in this chapter), and can also be used with other remedial technologies. When biosparging is combined with vapor extraction, the vapor extraction system creates a negative pressure in the vadose zone through a series of extraction wells that control the vapor plume migration. Figure 8-12 provides a conceptual drawing of a biosparging system with vapor extraction.

The existing literature contains case histories describing both the successes and failures of biosparging; however, because the technology is relatively new, few cases provide substantial documentation of performance. When used appropriately, biosparging is effective in reducing petroleum products at underground storage tank (UST) sites. Biosparging is most often used at sites with mid-weight petroleum products (*e.g*. diesel fuel, jet fuel); lighter petroleum products (*e.g.*, gasoline) tend to volatilize readily and to be removed more rapidly using air sparging. Heavier products (*e.g*. lubricating oils) generally take longer to biodegrade than the lighter products, but biosparging can still be used at these sites. Table 8-12 provides a summary of the advantages and disadvantages of biosparging.

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8.23.1 Components of a Biosparging System

A typical biosparging system design includes the following components and information:

- Sparging well orientation, placement, and construction details
- Manifold piping
- Compressed air equipment
- Monitoring and control equipment

FIGURE 8-12 Biosparging System Used with Soil Vapor Extraction

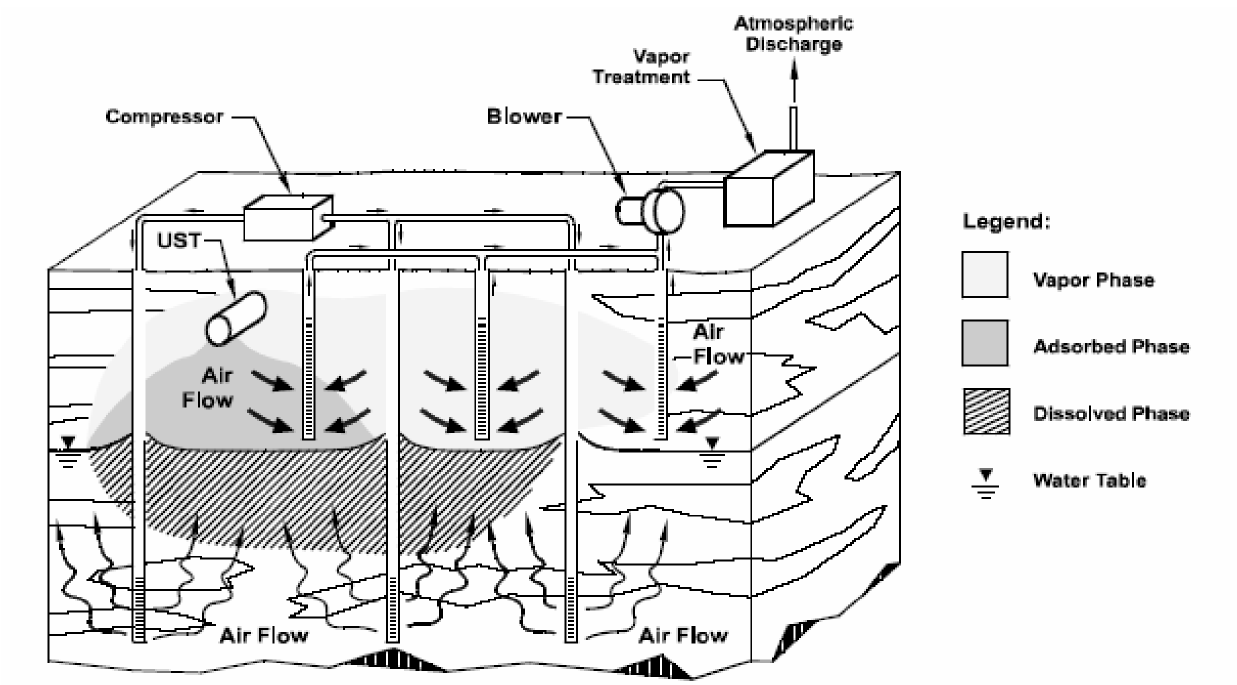

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TABLE 8-12
Advantages and Disadvantages of Biosparging

ADVANTAGES	DISADVANTAGES
Readily available equipment; easy to install.	Can only be used in environments where air sparging is suitable (*e.g.*, uniform and permeable soils, unconfined aquifer, no free-phase hydrocarbons, no nearby subsurface confined spaces).
Creates minimal disturbance to site operations.	Some interactions among complex chemical, physical, and biological process are not well understood.
Short treatment times, 6 months to 2 years under favorable conditions.	Lack of field and laboratory data to support design considerations.
Is cost competitive.	Potential for inducing migration of constituents.
Enhances the effectiveness of air sparging for treating a wider range of petroleum hydrocarbons.	
Requires no removal, treatment, storage, or discharge of groundwater.	
Low air injection rates minimize potential need for vapor capture and treatment.	

A nutrient delivery system is sometimes included in biosparging design. If nutrients are added, the design should specify the type of nutrient addition and the construction details. Note that state regulations may either require permits for nutrient injection wells or prohibit them entirely.

If an SVE system is used for vapor control, the following components and information will also be needed:

- Vapor pretreatment design
- Vapor treatment system selection
- Blower specification

8.24 OPERATION AND MONITORING PLANS

The system operation and monitoring plan should include both system start-up and long-term operations. Operations and monitoring area necessary to ensure optimal system performance and to track the rate of contaminant mass removal/reduction.

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8.24.1 Start-Up Operations

The start-up phase should begin with only the SVE portion of the system. After the SVE system is adjusted, the air sparging system should be started. Generally 7 to 10 days of manifold valving adjustments are required to adjust the air sparging system. These adjustments should balance flow to optimize the carbon dioxide production and oxygen uptake rate. Monitoring data should include sparge pressure and flows, vacuum readings for SVE, depth of groundwater, vapor concentrations, dissolved oxygen levels, CO_2 levels, and pH. During the initial start-up, these parameters should be monitored hourly once the flow is stabilized. Vapor concentration should also be monitored in any nearby utility lines, basements, or other subsurface confined spaces.

8.24.2 Long-Term Operations

To evaluate the performance of a biosparging system the following parameters should be monitored weekly to biweekly after the start-up operation:

- Contaminant levels, carbon dioxide level, dissolved oxygen level, and pH in the groundwater.

- Contaminant level, oxygen, and carbon dioxide in the effluent stack and the manifold of the SVE system (is used).

- Pressures and flow rates in the sparging wells and, if SVE is used, in the extraction wells.

It should be noted that the samples from the groundwater monitoring wells that will be analyzed to track dissolved contaminant concentrations should be collected after a short period of time following system shutdown. Sampling at these times allows the subsurface environment to reach equilibrium. Samples collected during sparging operations may have lower concentrations of dissolved contaminants than does the surrounding aquifer. This result could lead to the erroneous conclusion that remediation is occurring throughout the aquifer because the monitoring wells may serve as preferential flow paths for the injected air.

8.24.3 Remedial Progress Monitoring

Monitoring the performance of the biosparging system in reducing contaminant concentrations in the saturated zone is necessary to determine if remedial progress is proceeding at a reasonable pace. A variety of methods can be used. One method includes monitoring contaminant levels in the groundwater in monitoring wells and, if vapor extraction is used, vapors in the blower exhaust. The vapor and contaminant concentrations are then each plotted against time.

The plot can be used to show the impact of the biosparging operation. As biosparging reaches the limit of its ability to biodegrade further, the reduction of dissolved constituents reaches asymptotic conditions. This effect is also reflected in the concentrations of oxygen, CO_2, and

VOC in the vapors released from the system. When asymptotic behavior begins to occur, the operator should evaluate alternatives that increase the mass transfer removal rate (*e.g.*, pulsing, or turning off the system for a period of time and then restarting it). Other more aggressive steps to further reduce constituent concentrations can include the installation of additional sparging points or vapor extraction wells.

If asymptotic behavior is persistent for periods greater than about six months and the concentrations rebound is sufficiently small following periods of temporary system shutdown, the performance of the biosparging system should be reviewed with regulatory agencies to determine whether remedial goals have been reached. If further contaminant reduction is desired, another remedial technology may need to be considered.

8.24.4 Groundwater Monitoring

Periodic monitoring of groundwater is typically required by the DERR from the time groundwater contamination is first reported to the DERR, through the subsurface investigation and corrective action phases. Quarterly sampling and analysis is the most common period, although the interval may be lengthened or shortened depending on site specific conditions. Groundwater samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN. Groundwater monitoring results will indicate how well the treatment is progressing, and will form the basis for determining when corrective action cleanup goals have been achieved.

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8.25 SOIL EXCAVATION AND ON-SITE AERATION

Treatment of contaminated soil using on-site aeration must be performed in accordance with DERR "Guidelines for the Disposition and Treatment of Petroleum Contaminated Soils from Underground Storage Tank Sites." A copy of this guideline is presented in Chapter 4.

TABLE 8-13
Advantages and Disadvantages of On-Site Aeration

ADVANTAGES	DISADVANTAGES
Short treatment times: usually 6 months to 2 years under optimal conditions.	Requires a large land area for treatment.
Cost competitive: no off-site disposal costs.	Dust and vapor generation during landfarm aeration may pose air quality concerns.
	May require bottom liner if leaching from the landfarm is a concern.
	Presence of significant heavy metal concentrations (> 2,500 ppm) may inhibit microbial growth.

8.26 SOIL EXCAVATION AND DISPOSAL

Excavation and disposal, also referred to as "dig and haul," technology is a simple, yet effective, *ex situ* technology for removing contaminated soil from UST sites. During UST removal, the term "overexcavation" is often used to describe the removal of soils from the UST excavation pit after the USTs and tank bed material has been removed. Excavation and disposal is currently the only corrective action that may proceed without prior approval of the DERR. However, the DERR should be informed as soon as possible that soil has been excavated and disposal has occurred. Advantages and disadvantages of excavation and disposal are presented in Table 8-14.

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TABLE 8-14
Advantages and Disadvantages of Excavation and Disposal

ADVANTAGES	DISADVANTAGES
Fast - generally takes place right after tank removal. Typical completed in 1 to 3 days.	Usually not cost-effective for large volumes, or soils with low contaminant concentrations. Increasing costs due to testing and limited disposal locations.
Can quickly meet State cleanup standards—with proper confirmation samples.	Non-destructive technology - no decrease in contamination; only results in a change in contaminant locations.
Accepted Technology - thousands of sites across the country closed using this technology.	
Simple Technology - no special training or design needed.	

Contaminated or potentially contaminated soil is excavated with a backhoe or trackhoe, and loaded onto trucks for transportation to an appropriate disposal facility. It is important to document how much soil is removed and transported to the disposal facility. The disposal facility may require additional profile sampling and laboratory analysis of the soil to ensure that the soil contaminant concentrations are within permit limits for the disposal facility.

During excavation activities the soil is frequently monitored with a photoionization detector (PID) for volatile organic compounds to aid in determining the approximate limits of excavation. The presence or absence of visible petroleum staining in the soil, the presence of free-phase petroleum product, and petroleum odors are also used to limit the amount of excavation.

8.26.1 Confirmation Samples

Confirmation soil samples must be collected from the excavation pit sidewalls and pit bottom to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. A minimum of one soil sample should be collected from each sidewall and the pit bottom. Large excavation pits with long sidewalls may require two or more soil samples be collected from each sidewall for analysis. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

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8.27 LOW-TEMPERATURE THERMAL DESORPTION

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Low-temperature thermal desorption (LTTD), also known as low-temperature thermal volatilization, thermal stripping, and soil roasting, is an *ex-situ* remedial technology that uses heat to physically separate petroleum hydrocarbons from excavated soils. Thermal desorbers are designed to heat soils to temperatures sufficient to cause constituents to volatilize and desorb (physically separate) from the soil. Although they are not designed to decompose organic constituents, thermal desorbers can, depending upon the specific organic compounds present and the temperature of the desorber system, cause some of the constituents to completely or partially decompose. The vaporized hydrocarbons are generally treated in a secondary treatment unit (*e.g.*, an afterburner, catalytic oxidation chamber, condenser, or carbon adsorption unit) prior to discharge to the atmosphere. Afterburners and oxidizers destroy the organic constituents. Condensers and carbon adsorption units trap organic compounds for subsequent treatment or disposal.

Some pre- and post-processing of soils is necessary when using LTTD. Excavated soils are first screened to remove large (>2 inches in diameter) objects. These may be sized (*e.g.,* crushed or shredded) and then introduced back into the feed material. After leaving the desorber, soils are cooled, re-moistened to control dust, and stabilized (if necessary) to prepare them for disposal/reuse. Treated soil may be redeposited on site, used as cover in landfills, or incorporated into asphalt.

Thermal desorption systems fall into two general classes--stationary facilities and mobile units. Contaminated soils are excavated and transported to stationary facilities: mobile units can be operated directly onsite. Desorption units are available in a variety of process configurations including rotary desorbers, asphalt plant aggregate dryers, thermal screws, and conveyor furnaces.

LTTD has proven very effective in reducing concentrations of petroleum products including gasoline, jet fuels, kerosene, diesel fuel, heating oils, and lubricating oils. LTTD is applicable to constituents that are volatile at temperatures as great as 1,200^{o}F. Figure 8-13 provides an illustration of a typical LTTD operation. The advantages and disadvantages of LTTD are listed in Table 8-15.

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8.27.1 Types of Low-Temperature Thermal Desorption Systems

The term thermal desorber describes the primary treatment operation that heats petroleum-contaminated materials and desorbs organic materials into a purge gas. Mechanical design features and process operating conditions vary considerably among the various types of LTTD systems. Desorption units are available in the following configurations: rotary dryer, asphalt plant aggregate dryer, thermal screw, and conveyor furnace. Systems may either be stationary facilities or mobile units. Contaminated soils are excavated and transported to stationary facilities, while mobile units can be operated directly on the site of the contaminated soil.

Figure 8-13

Parallel Flow (Co-Current) Rotary Low Temperature Thermal Desorption System

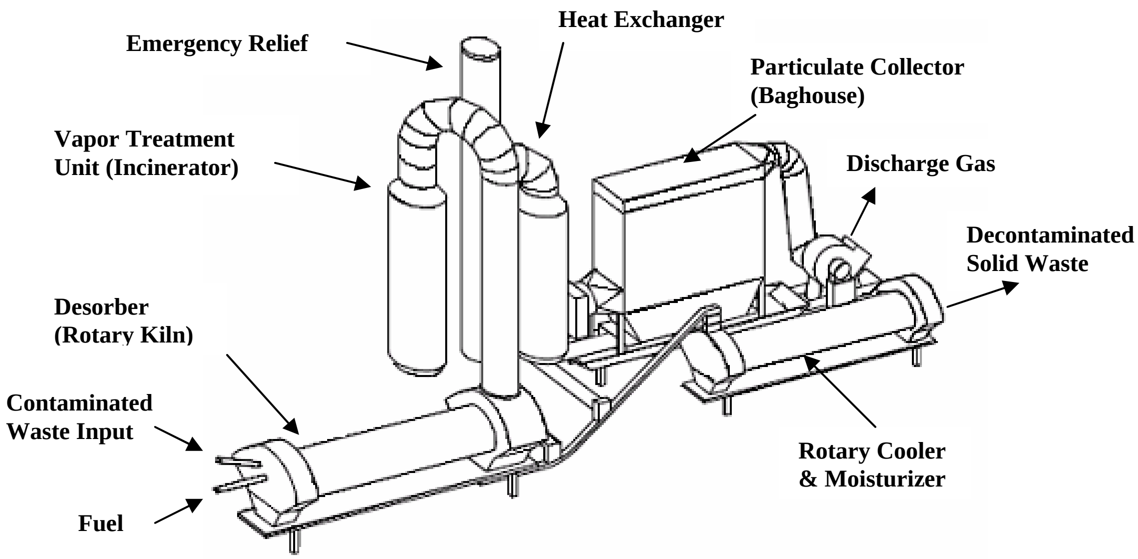

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TABLE 8-15
Advantages and Disadvantages of LTTD

ADVANTAGES	DISADVANTAGES
Readily available equipment for onsite or offsite treatment.	Requires excavation of soils; generally limited to 25 feet below land surface.
Very rapid treatment time; most commercial systems capable of over 25 tons per hour throughput.	On-site treatment will require significant area (> 2 acre) to locate LTTD unit and store process soils.
Cost competitive for large volumes (>1,000 yd^3) of soils: $30-70/ton of contaminated soil, exclusive of excavation and transportation costs.	Off-site treatment will require costly transportation of soils and possibly manifesting.
Can be used to mitigate "hot spot" source areas with very high concentrations of petroleum hydrocarbons.	Soils excavated from below the groundwater table require dewatering prior to treatment because of high moisture content.
Easily combinable with other technologies, such as air sparging or groundwater extraction.	
Treated soil can be redeposited onsite or used for landfill cover (if permitted by a regulatory agency).	
Can consistently reduce TPH to below 10 mg/Kg and BTEX below 100 ppb (and sometimes lower).	

Although all LTTD systems use heat to separate (desorb) organic contaminants from the soil matrix, each system has a different configuration with its own set of advantages and disadvantages. The decision to use one system over another depends on the nature of the contaminants as well as machine availability, system performance, and economic considerations. System performance may be evaluated on the basis of pilot tests (*e.g.*, test burns) or examinations of historical machine performance records. Pilot tests to develop treatment conditions are generally not necessary for petroleum-contaminated soils.

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8.27.2 Off-Gas Treatment

Treatment systems for LTTD system offgas are designed to address three types of air pollutants: particulates, organic vapors, and carbon monoxide. Particulates are controlled with both wet (*e.g.*, venturi scrubbers) and dry (*e.g.* cyclones, baghouses) unit operations. Rotary dryers and asphalt aggregate dryers most commonly use dry gas cleaning unit operations. Cyclones are used to capture large particulates and reduce the particulate load to the baghouse. Baghouses are used as the final particulate control device. Thermal screw systems typically use a venturi scrubber as the primary particulate control.

The control of organic vapors is achieved by either destruction or collection. Afterburners are used downstream of rotary dryers and conveyor furnaces to destroy organic contaminants and oxidize carbon monoxide. Conventional afterburners are designed so that exit gas temperatures reach 1,400^{o} to 1,600^{o}F. Organic destruction efficiency typically ranges from 95 to greater than 99 percent.

Condensers and activated carbon may also be used to treat the off gas from thermal screw systems. Condensers may be either water-cooled or electrically cooled systems to decrease offgas temperatures to 100^{o} to 140^{o}F. The efficiency of condensers for removing organic compounds ranges from 50 to greater than 95 percent. Non-condensable gases exiting the condenser are normally treated by a vapor-phase activated carbon treatment system. The efficiency of activated carbon adsorption systems for removing organic contaminants ranges from 50 to 99 percent. Condensate from the condenser is processed through a phase separator where the non-aqueous phase organic component is separated and disposed of or recycled. The remaining water is then processed through activated carbon and used to rehumidify treated soil.

8.27.3 Determination of the Practicality of LTTD

The economics of LTTD as a remedial option are highly site-specific. Economic factors include site usage (because excavation and on-site soil treatment at a retail site (*e.g.*, gasoline station, convenience store) will most likely prevent the business from operating for an extended period of time), the cost of LTTD per unit volume of soil relative to other remedial options, and the location of the nearest applicable LTTD system (because transportation costs are a function of distance). Further discussion of the economics of LTTD use is beyond the scope of this manual.

8.27.4 Vertical and Horizontal Extent of Contamination

Because soils to be treated in an LTTD unit must be excavated, their location must be suitable for removal by excavation techniques. Soils that are located more than 25 feet below the land surface cannot be removed by conventional equipment. Soils that are located beneath a building or near building foundations cannot be excavated without removal of the building itself. In addition, soils located beneath the groundwater table can be excavated but generally cannot be treated in the LTTD unit unless dried, dewatered, or blended with other soils to reduce moisture content.

The vertical and horizontal extent of contamination determines the volume of soil that must be treated. The cost of remediation and time required for processing is directly proportional to the volume of contaminated soil to be treated. Volume also determines whether onsite treatment is viable. A small mobile LTTD system with a throughput capacity of 5 to 15 tons per hour may be able to stockpile materials and operate in an area as small as 2 acres.

8.27.5 Site Layout

Site layout factors influence whether excavation of soils is possible at all. If excavation is possible, consideration can be given to whether onsite thermal treatment is a viable option. Site layout factors that must be considered in evaluating onsite thermal desorption treatment include:

- Amounts of space available for stockpiling treated and untreated materials and operating process equipment.
- Space required for continuation of daily business, and
- Minimum distances required by fire and safety codes for operating thermal desorption equipment in the vicinity of petroleum storage facilities.

The amount of area available to stockpile soils and operate processing equipment may dictate the maximum size of the treatment system that can be operated at the site. In general, on-site treatment operations will require a minimum of 2 acres. This has further economic implications because the costs associated with LTTD are strongly affected by the physical size and soil processing capacity of the thermal treatment system.

8.27.6 Adjacent Land Use

When land adjacent to an UST site is being used for schools, parks, health care facilities, high-value commercial development, or dense residential development, problems may develop in obtaining permits for the use of onsite thermal desorption. Air discharge restrictions may require the use of expensive control measures that could make onsite treatment economically infeasible. Thermal desorption units are most economical when they are operated on a 24-hour-per-day schedule. However, noise considerations may limit hours of operation in some locations.

8.27.7 Other Considerations

Treatment goals are also important when considering the use of LTTD. For soils contaminated with lighter petroleum hydrocarbons, residual TPH levels can be reduced to 10 mg/Kg or less. Some newer rotary units can consistently achieve TPH levels of <1 mg/Kg and BTEX levels <100 mg/Kg. System effectiveness can be evaluated based on the treatment records for a specific machine.

Treated soils are typically disposed of in a landfill, used as cover in landfills, incorporated into asphalt, or returned to the site to backfill the excavation. Final disposition of the soil depends upon the residual levels of contaminants in the treated soil and economic factors such as transportation and disposal costs, as well as costs for clean material to backfill the excavation. It should be noted that treatment processes may alter the physical properties of the material. A thorough geotechnical evaluation of the treated material may be necessary to determine its suitability for use in an engineering application (*e.g.*, road bed, building foundation support, grading and filling).

8.27.8 Confirmation Samples

Confirmation soil samples must be collected from the biopile soils to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. The number of soil samples will depend on the size of the biopile, and should be determined in consultation with the DERR project manager. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

8.28 ASPHALT BATCHING

Asphalt batching, also known as soil recycling, is an aboveground remediation technology for soils that reuses petroleum contaminated soil in mixtures of both cold and hot asphalt. Due to air emission compliance issues, contaminated soils are least often used in the production of hot mix asphalt. Petroleum contaminated soil can also be incorporated into road base, which is generally used below a surface such as asphalt or concrete. Road base is a layer of very high stability and density and is usually composed of well-graded aggregates. Its principal purpose is to distribute the stress created by wheel loads acting on the wearing surface. Asphalt batching can be performed as a mobile (on-site) process or at an asphalt facility. The technology is currently limited to diesel and oil contaminated soil, however heavy metals stabilization in the soils is possible. Batch and drum type asphalt plants, as well as mobile pugmills are used to finish products for use on state, county, city and private projects.

8.28.1 Process Description

Batch processing technology usually involves bench testing, preprocessing, mixing, and final testing. Preprocessing consists of crushing and/or screening to produce a physically uniform material. The material is then passed through a power screen hopper, mister, and screen to maintain the soil moisture and separate suitably sized particles. Pre-processed soils are blended with asphalt emulsions. If heavy metals are present in the contaminated soil, pozzolanic additives such as portland cement, quick lime, cement kiln dust, and coal fly ash may be added. These products allow the stabilization of the soil for materials that have failed the TCLP analysis. After the soils have been separated and mixed, they are stored until analysis confirms its TCLP reduction is below acceptable regulatory levels.

8.28.2 Liability and Benefits

The benefits of soil recycling are practical. The recycling process removes the liability associated with contaminated soil and is one of the most cost-effective regulatory acceptable alternatives for the management of contaminated soils. In situations where contamination arises from petroleum alone, it can be economically feasible to recycle as small a quantity as 500 to 1000 tons of soil. A general cost savings of 30% to 70% can be realized with on-site asphalt batching rather than off-site disposal, and the need for landfills and other costly disposal methods is eliminated. Advantages and disadvantages are listed below in Table 8-16.

TABLE 8-16
Advantages and Disadvantages of Asphalt Batching

ADVANTAGES	DISADVANTAGES
No design required.	Not applicable for gasoline-contaminated soils.
Low cost method for contaminated soil disposal.	Not cost-effective for volumes of soil <500 tons.
Effective on both low and high contaminant soil concentrations.	
Destructive process reduces liability.	
Remedial progress monitoring is not required.	

8.29 SOIL WASHING

Soil washing and solvent extraction technologies are used to separate organic contaminants from the soil matrix; however, in some cases these techniques may also be used to remove toxic metals. The contaminated soil is mixed with a solvent or surfactant solution that solubilizes the organic material on the soil particles. The extractant is then separated from the soil and treated to remove or destroy the contaminant in solution. Usually multiple extractions are necessary to achieve cleanup goals. Solvents are typically distilled and reused while surfactant solutions may be treated biologically or chemically to destroy the contaminant or release it from the emulsified form.

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Following solvent extraction, the soil may have to be further treated using vapor extraction or other techniques to remove residual solvent. Depending on the soil characteristics, metals removal by extraction may be performed using an acid solution to solubilize the metals. The acid solution is then rinsed from the soil to restore the soil pH and the acid is treated to remove the dissolved metal. In general, soil extraction processes are relatively expensive because of the disposal or recycle of the extracted material and the costs associated with further treatment of the soil to remove residual extraction solvents. The advantages and disadvantages are listed below in Table 8-17.

TABLE 8-17
Advantages and Disadvantages of Soil Washing

ADVANTAGES	DISADVANTAGES
Reduces the amount of soil needing further Cleanup.	May not be cost-effective for small amounts of pollution.
Lowers the cost of cleanup by reducing contaminated soil volumes and associated disposal fees.	Not as cost-effective on soils with a large amount of silt or clay.
Can remove many types of pollution.	
Works when the soil is very polluted.	

8.30 LANDFARMING

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Landfarming, also known as land treatment or land application, is an aboveground remediation technology for soils that reduces concentrations of petroleum constituents through biodegradation. This technology usually involves spreading excavated contaminated soils in a thin layer on the ground surface and stimulating aerobic microbial activity within the soils through aeration and/or the addition of minerals, nutrients, and moisture. The enhanced microbial activity results in degradation of adsorbed petroleum product constituents through microbial respiration. If contaminated soils are shallow (*i.e.*, less than or equal to 3 feet below ground surface), it may be possible to effectively stimulate microbial activity without excavating the soils. If petroleum-contaminated soil is deeper than 5 feet, the soils should be excavated and reapplied on the ground surface. A typical landfarming operation is shown in Figure 8-14.

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Landfarming has been proven effective in reducing concentrations of nearly all the constituents of petroleum products typically found at underground storage tank (UST) sites. Lighter (more volatile) petroleum products (e.g., gasoline) tend to be removed by evaporation during landfarm aeration processes (i.e., tilling or plowing) and, to a lesser extent, degraded by microbial respiration. Depending upon your state's regulation for air emissions of volatile organic compounds (VOCs), you may need to control the VOC emissions. Control involves capturing the vapors before they are emitted to the atmosphere, passing them through an appropriate treatment process, and then venting them to the atmosphere. The State of Utah allows such aeration, subject to the Division of Air Quality (DAQ) regulations R307-401 which are discussed in Chapter 9.

The mid-range hydrocarbon products (e.g., diesel fuel, kerosene) contain lower percentages of lighter (more volatile) constituents than does gasoline. Biodegradation of these petroleum products is more significant than evaporation. Heavier (non-volatile) petroleum products (e.g., heating oil, lubricating oils) do not evaporate during landfarm aeration; the dominant mechanism that breaks down these petroleum products is biodegradation. However, higher molecular weight petroleum constituents such as those found in heating and lubricating oils, and, to a lesser extent, in diesel fuel and kerosene, require a longer period of time to degrade than do the constituents in gasoline. A summary of the advantages and disadvantages of landfarming is shown in Table 8-18.

8.30.1 Concentration and Toxicity

The presence of very high concentrations of petroleum organic compounds or heavy metals in site soils can be toxic or inhibit the growth and reproduction of bacteria responsible for biodegradation in landfarms. Conversely, very low concentrations of organic material will result in diminished levels of microbial activity.

In general, soil concentrations of total petroleum hydrocarbons (TPH) in the range of 10,000 to 50,000 mg/Kg, or heavy metals exceeding 2,500 mg/Kg, are considered inhibitory and/or toxic to most microorganisms. If TPH concentrations are greater than 10,000 gpm, or the concentration of heavy metal is greater than 2,500 mg/Kg, then the contaminated soil should be thoroughly mixed with clean soil to dilute the contaminants so that the average concentrations are below toxic levels.

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FIGURE 8-14 Typical Landfarming Operation

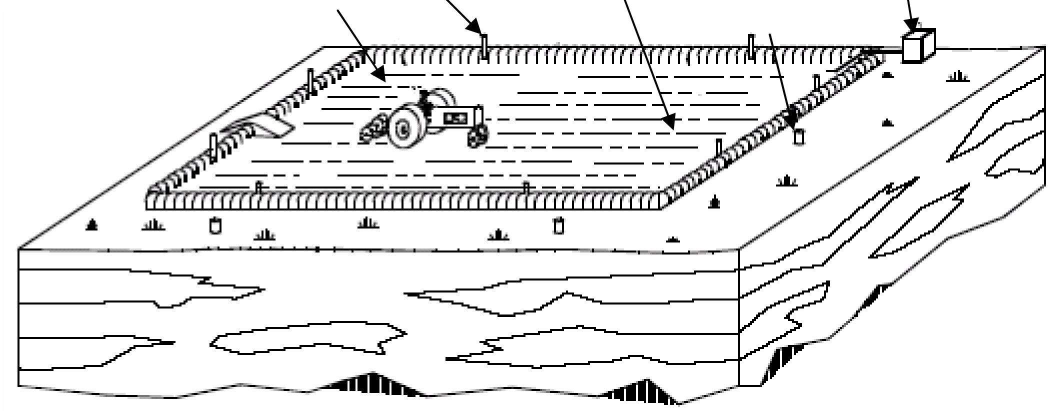

TABLE 8-18
Advantages and Disadvantages of Landfarming

ADVANTAGES	DISADVANTAGES
Relatively simple to design and implement.	Concentration reductions > 95% and constituent concentrations < 0.1 mg/Kg are very difficult to achieve.
Short treatment times: usually 6 months to 2 years under optimal conditions.	May not be effective for high constituent concentrations (>50,000 mg/Kg total petroleum hydrocarbons).
Cost competitive: $30-60/ton of contaminated soil.	Presence of significant heavy metal concentrations (> 2,500 mg/Kg) may inhibit microbial growth.
Effective on organic constituents with slow biodegradation rates.	Volatile constituents tend to evaporate rather than biodegrade during treatment.
	Requires a large land area for treatment.
	Dust and vapor generation during landfarm aeration may pose air quality concerns.
	May require bottom liner if leaching from the landfarm is a concern.

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8.30.2 Remedial Progress Monitoring Plan

The monitoring plan for the landfarm includes monitoring of landfarm soils for constituent reduction and biodegradation conditions (*e.g.*, CO_2, O_2, CH_4, H_2S), air monitoring for vapor emissions if volatile constituents are present, soil and groundwater monitoring to detect potential migration of constituents beyond the landfarm, and runoff water sampling (if applicable) for discharge permits. Make sure that the number of samples collected, sampling locations, and collection methods are in accordance with state regulations. Soils within the landfarm should be monitored at least quarterly during the landfarming season to determine pH, moisture content, bacterial population, nutrient content, and constituent concentrations. The results should be used to adjust aeration frequency, nutrient application rates, moisture addition frequency and quantity, and pH. Optimal ranges for these parameters should be maintained to achieve maximum degradation rates.

8.30.3 Confirmation Samples

Confirmation soil samples must be collected from the landfarm soils to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. The number of soil samples will depend on the size of the landfarm, and should be determined in consultation with the DERR project manager. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

8.31 BIOPILES

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Biopiles, also known as biocells, bioheaps, biomounds, and compost piles, are used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. This technology involves heaping contaminated soils into piles (or "cells") and stimulating aerobic microbial activity within the soils through the aeration and/or addition of minerals, nutrients, and moisture. The enhanced microbial activity results in degradation of adsorbed petroleum-product constituents through microbial respiration. Biopiles are similar to landfarms in that they are both above-ground, engineered systems that use oxygen, generally from air, to stimulate the growth and reproduction of aerobic bacteria which, in turn, degrade the petroleum constituents adsorbed to soil. While landfarms are aerated by tilling or plowing, biopiles are aerated most often by forcing air to move by injection or extraction through slotted or perforated piping placed throughout the pile. A typical biopile cell is shown in Figure 8-15.

Biopiles, like landfarms, have been proven effective in reducing concentrations of nearly all the constituents of petroleum products typically found at underground storage tank (UST) sites. Lighter (more volatile) petroleum products (*e.g.*, gasoline) tend to be removed by evaporation during aeration processes (*i.e.*, air injection, air extraction, or pile turning) and, to a lesser extent, degraded by microbial respiration. Depending upon the level of air emissions from volatile organic compounds (VOCs), you may need to control the VOC emissions. Control involves capturing the vapors before they are emitted to the atmosphere, passing them through an appropriate treatment process, and then venting them to the atmosphere. The mid-range hydrocarbon products (*e.g.*, diesel fuel, kerosene) contain lower percentages of lighter (more volatile) constituents than does gasoline.

Biodegradation of these petroleum products is more significant then evaporation. Heavier (non-volatile) petroleum products (*e.g.* heating oil, lubricating oils) do not evaporate during biopile aeration; the dominant mechanism that breaks down these petroleum products is biodegradation. However, higher molecular weight petroleum constituents such as those found in heating and lubricating oils, and, to a lesser extent, in diesel fuel and kerosene, require a longer period of time to degrade than do the constituents in gasoline. A summary of the advantages and disadvantages of biopiles is shown in Table 8-19.

8.31.1 Concentration and Toxicity

The presence of very high concentrations of petroleum organic compounds or heavy metals in site soils can be toxic or inhibit the growth and reproduction of bacteria responsible for biodegradation in biopiles. Conversely, very low concentrations of organic material will result in diminished levels of microbial activity.

FIGURE 8-15 Typical Biopile System

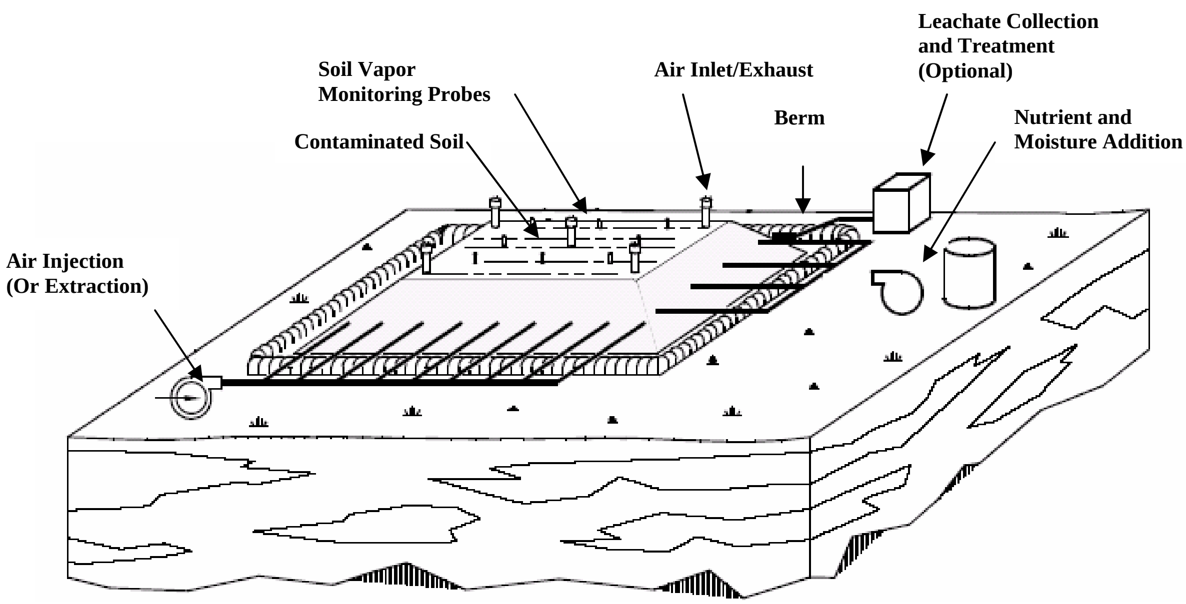

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TABLE 8-19
Advantages and Disadvantages of Biopiles

ADVANTAGES	DISADVANTAGES
Relatively simple to design and implement.	Concentration reductions > 95% and constituent concentrations < 0.1 mg/Kg are very difficult to achieve.
Short treatment times: usually 6 months to 2 years under optimal conditions.	May not be effective for high constituent concentrations (>50,000 mg/Kg total petroleum hydrocarbons).
Cost competitive: $30-90/ton of contaminated soil.	Presence of significant heavy metal concentrations (> 2,500 mg/Kg) may inhibit microbial growth.
Effective on organic constituents with slow biodegradation rates.	Volatile constituents tend to evaporate rather than biodegrade during treatment.
Requires less land area than landfarms.	Requires a large land area for treatment, although less than landfarming.
Can be designed to be a closed system; vapor emissions can be controlled.	Vapor generation during aeration may require treatment prior to discharge.
Can be engineered to be potentially effective for any combination of site conditions and petroleum products.	May require bottom liner if leaching from the biopile is a concern.

In general, soil concentrations of TPH in the range of 10,000 to 50,000 mg/Kg, or heavy metals exceeding 2,500 mg/Kg, are considered inhibitory and/or toxic to most microorganisms. If TPH concentrations are greater than 10,000 gpm, or the concentration of heavy metal is greater than 2,500 mg/Kg, then the contaminated soil should be thoroughly mixed with clean soil to dilute the contaminants so that the average concentrations are below toxic levels.

8.31.2 Evaluation of the Biopile Design

The CAP should include a discussion of the rationale for the design and present the conceptual engineering design. Detailed engineering design documents might also be included, depending on state requirements.

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Further information is provided below.

- **Land Requirements** can be determined by dividing the amount of soil to be treated by the height of the proposed biopile(s). The typical height of biopiles varies between 3 and 10 feet. Additional land area around the biopile(s) will be required for sloping the sides of the pile, for containment berms, and for access. The length and width of biopiles is generally not restricted unless aeration is to occur by manually turning the soils. In general, biopiles which will be turned should not exceed 6 to 8 feet in width.

- **Biopile Layout** is usually determined by the configuration of and access to the land available for the biopile(s). The biopile system can include single or multiple piles.

- **Biopile Construction** includes: site preparation (grubbing, clearing, and grading); berms; liners and covers (if necessary); air injection, extraction and/or collection piping arrangement; nutrient and moisture injection piping arrangement; leachate collection and treatment systems; soil pretreatment methods (*e.g.*, shredding, blending, amendments for fluffing, pH control); and enclosures and appropriate vapor treatment facilities (where needed). The construction design of a typical biopile is shown as Figure 8-16.

- **Aeration Equipment** usually includes blowers or fans, which will be attached to the aeration-piping manifold unless aeration is to be accomplished by manually turning the soil.

- **Water Management** systems for control of run-on and run-off are necessary to avoid saturation of the treatment area or washout of the soils in the biopile area. Earthen berms or ditches that intercept and divert the flow of stormwater usually control runon. Runoff can be controlled by diversion within the bermed treatment area to a retention pond where the runoff can be stored, treated, or released under a National Pollution Discharge Elimination System (NPDES) permit.

- **Soil Erosion Control** from wind or water generally includes sloping the sides of the pile, covering the pile, constructing water management systems, and spraying to minimize dust.

- **pH Adjustment, Moisture Addition, and Nutrient Supply** methods usually include incorporation of solid fertilizers, lime and/or sulfur into the soils while constructing the biopile, or injection of liquid nutrients, water and acid/alkaline solutions preferably through a dedicated piping system during operation of the biopile. The composition of nutrients and acid or alkaline solutions/solids for pH control is developed in biotreatability studies, and the frequency of their application is modified during biopile operation as needed.

- **Site Security** may be necessary to keep trespassers out of the treatment area. If the biopile is accessible to the public, a fence or other means of security is recommended to deter public contact with the contaminated material within the biopile area.

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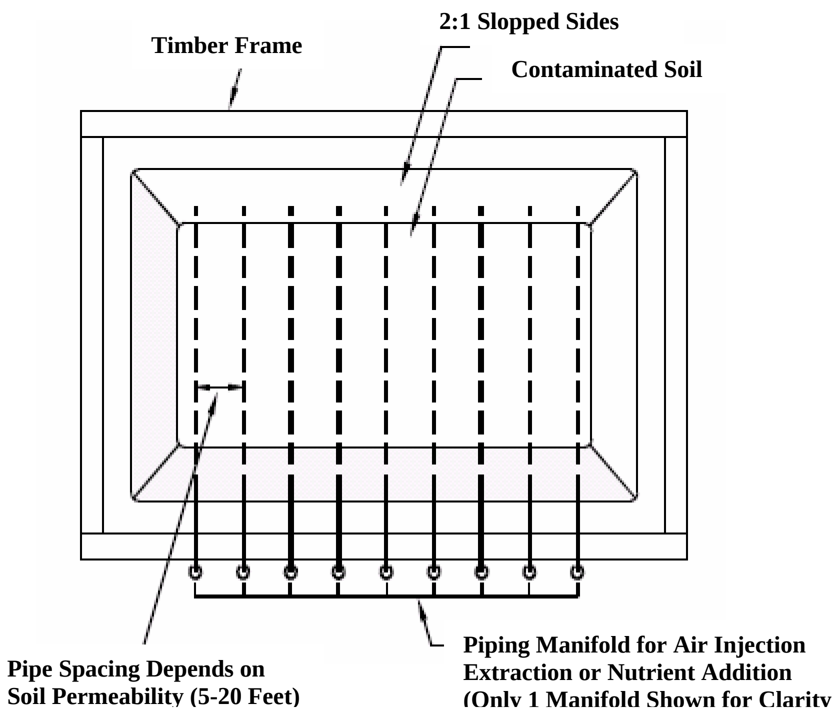
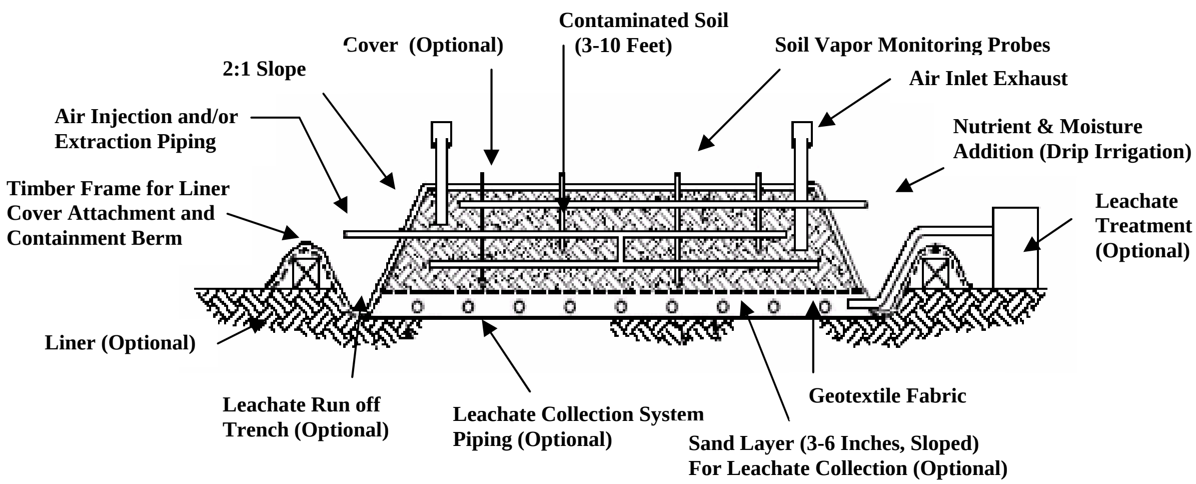
Figure 8-16 Construction Design of a Typical Biopile



PLAN VIEW
NOT TO SCALE



- ***Air Emission Controls*** (*e.g.*, covers or structural enclosures) may be required if volatile constituents are present in the biopile soils. For compliance with air quality regulations, the volatile organic emissions should be estimated based on initial concentrations of the petroleum constituents present. Vapors in extracted or injected air should be monitored during the initial phases of biopile operation for compliance with appropriate permits or regulatory limits on atmospheric discharges. If required, appropriate vapor treatment technology should be specified, including operation and monitoring parameters.

8.31.3 Remedial Progress Monitoring Plan

Regular monitoring is necessary to ensure optimization of biodegradation rates, to track constituent concentration reductions, and to monitor vapor emissions, migration of constituents into soils beneath the biopile (if unlined), and groundwater quality. If appropriate, ensure that monitoring to determine compliance with stormwater discharge or air quality permits is also proposed.

The monitoring plan for the biopile system includes monitoring of biopile soils for constituent reduction and biodegradation conditions (*e.g.*, CO_2, O_2, CH_4, H_2S), air monitoring for vapor emissions if volatile constituents are present, soil and groundwater monitoring to detect potential migration of constituents beyond the biopile area, and runoff water sampling (if applicable) for discharge permits. Make sure that the number of samples collected, sampling locations, and collection methods are in accordance with state regulations.

Soils within the biopile should be monitored at least quarterly during treatment to determine pH, moisture content, bacterial population, nutrient content, and constituent concentrations. For biopiles using air extraction or for those using air injection and off-gas collection, biodegradation conditions can be tracked by measuring oxygen and carbon dioxide concentrations in the vapor extracted from the biopile. These measurements should be taken weekly during the first 3 months of operation.
The results should be used to adjust air injection or extraction flow rates, nutrient application rates, moisture addition frequency and quantity, and pH. Optimal ranges for these parameters should be maintained to achieve maximum degradation rates.

8.31.4 Confirmation Samples

Confirmation soil samples must be collected from the biopile soils to demonstrate that petroleum hydrocarbon concentrations that remain in the soil at the UST site meet appropriate cleanup levels. The number of soil samples will depend on the size of the biopile, and should be determined in consultation with the DERR project manager. The confirmation soil samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN.

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8.32 NATURAL ATTENUATION

Note: This section has been excerpted from EPA documents. For additional details the reader is referred to the source document (EPA, 1994).

Natural attenuation, although sometimes known as passive bioremediation, intrinsic bioremediation, or intrinsic remediation actually includes this type of bioremediation, as well as other mechanisms. Natural attenuation is a passive remedial approach that depends upon natural processes to degrade and dissipate petroleum constituents in soil and groundwater. Some of the processes involved in natural attenuation of petroleum products include aerobic and anaerobic biodegradation, dispersion, volatilization, and adsorption. In general, for petroleum hydrocarbons, biodegradation is the most important natural attenuation mechanism; it is the only natural process that results in an actual reduction of petroleum constituent mass (Figure 8-17).

This section describes chemical and environmental factors that influence the rate of natural attenuation processes. Because of the complex interrelationship among these controlling factors, using specific numerical thresholds to determine whether natural attenuation will be effective is frequently not possible. A detailed site investigation is necessary to provide sufficient data on site conditions and hydrocarbon constituents present to evaluate the potential effectiveness of natural attenuation. In addition, site conditions will need to be monitored over time to confirm whether or not contaminants are being naturally degraded at reasonable rates to ensure protection of human health and the environment. Site data should clearly indicate whether concentrations of soil and groundwater contaminants are being adequately reduced without active remediation treatment. If not, more aggressive remedial alternatives should be considered.

Petroleum hydrocarbon constituents are generally biodegradable regardless of their molecular weight, as long as indigenous microorganisms have an adequate supply of nutrients and biological activity is not inhibited by toxic substances. For heavier hydrocarbons, which are less volatile and less soluble than many lighter components, biodegradation will exceed volatilization as the primary removal mechanism, even though degradation is generally slower for heavier molecular weight constituents than for lighter ones.

The essential nutrients required for biodegradation are usually naturally present in the subsurface. Aerobic biodegradation consumes oxygen, which, if not replenished, can limit the effectiveness of further aerobic biodegradation. When the geologic materials at a site are relatively porous and permeable, oxygen is naturally replenished through the soil and groundwater. When, however, the permeability is high, the possibility exists for greater downgradient migration of contaminants. Conversely, when the geologic materials have low porosity and are relatively impermeable, the potential for migration is reduced but so is the rate of oxygen replenishment. In addition, less permeable materials typically are finer grained and contain higher percentages of organic carbon. Both of these features favor adsorption and retardation of contaminant movement. In this case, contaminants may remain relatively undergraded but in close proximity to the original source.

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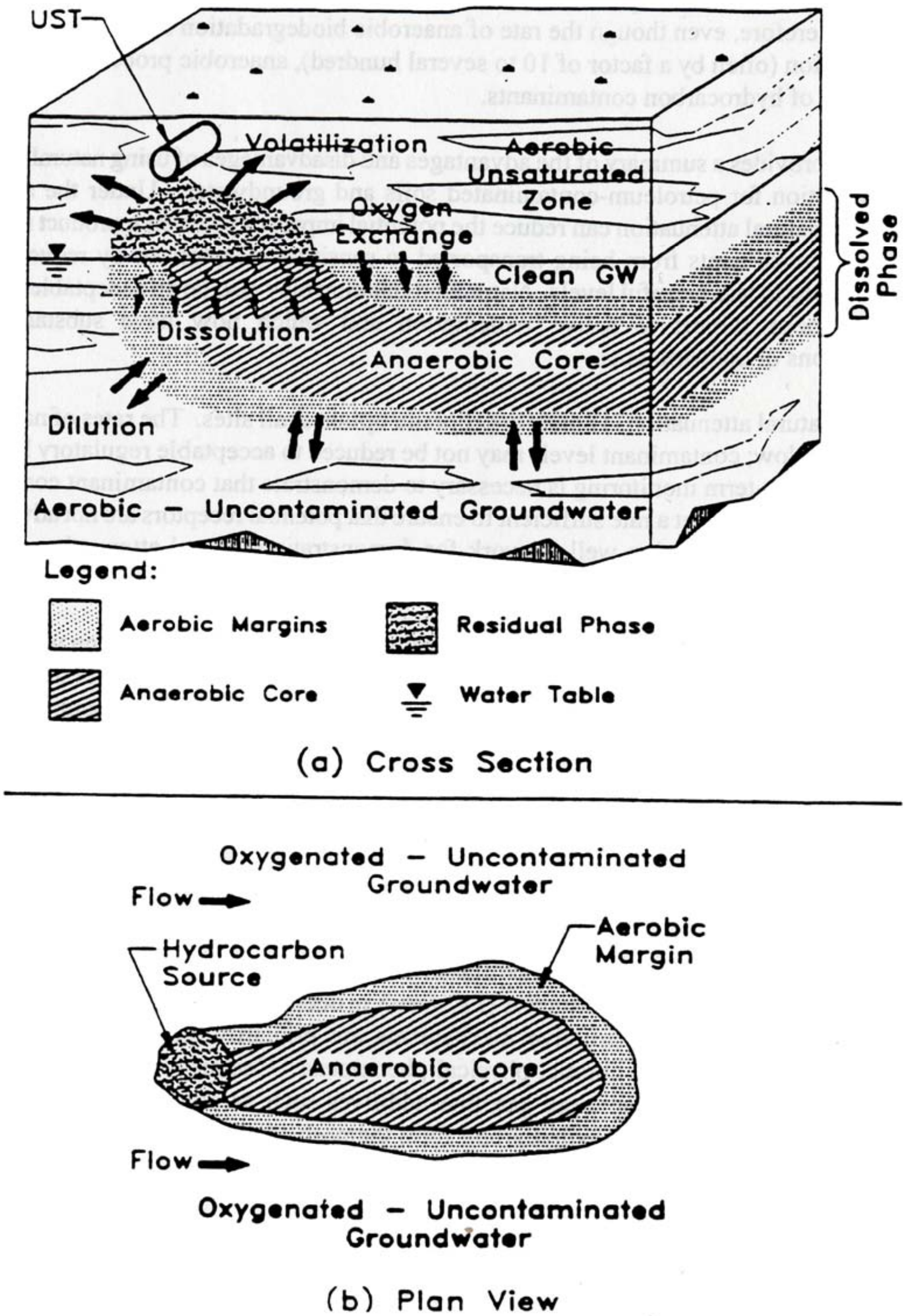
FIGURE 8-17 Typical Hydrocarbon Plume Undergoing Natural Attenuation, Including Natural Bioremediation



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Anaerobic biodegradation is also a significant attenuation process. Oxygen depletion in the subsurface is a characteristic of biodegradation of petroleum hydrocarbons and is a consequence of the rate of metabolic oxygen utilization exceeding the natural capacity for oxygen replenishment. The core of the contaminant plume is typically under anaerobic conditions and only the margins are aerobic. Therefore, even though the rate of anaerobic biodegradation is much slower than aerobic biodegradation (often by a factor of 10 to several hundred), anaerobic processes may dominate the degradation of hydrocarbon contaminants.

Table 8-20 provides a summary of the advantages and disadvantages of using natural attenuation as a remedial option for petroleum-contaminated soils and groundwater. Under the appropriate site conditions, natural attenuation can reduce the potential impact of petroleum product release either by preventing constituents from being transported to sensitive receptors or by reducing constituent concentrations to less harmful levels. Natural attenuation may also be an acceptable option for sites that have been subject to active remediation and which now have substantially reduced concentrations of contaminants.

However, natural attenuation is not an appropriate option at all sites. The rates of natural processes are typically slow; contaminant levels may not be reduced to acceptable regulatory levels for years. In addition, long-term monitoring is necessary to demonstrate that contaminant concentrations are continually decreasing at a rate sufficient to ensure that potential receptors are not adversely affected. A recommended monitoring well network for demonstrating natural attenuation is illustrated in Figure 8-18.

The policies and regulations of your state determine whether natural attenuation will be allowed as a treatment option. Before beginning an analysis of the potential effectiveness of natural attenuation, determine if your state restricts the use of this remedial option. For example, natural attenuation may not be allowed if groundwater is contaminated at levels exceeding drinking water standards (*i.e*., Maximum Contaminant Levels [MCLs]) or at concentrations that may pose risks to receptors or human health. Natural attenuation is not generally an option at sites with free product in the subsurface.

8.32.1 Natural Attenuation Mechanisms

Natural attenuation mechanisms may be classified as either destructive (*i.e.*, result in a net decrease in contaminant mass) or non-destructive (*i.e*., result in decrease in equilibrium concentrations but no net decrease in mass). Destructive mechanisms are primarily biological. The primary non-destructive mechanisms are abiotic, physical phenomena. Chemical processes are important for many compounds (including some gasoline additives such as ethylene dibromide [EDB]), but relatively insignificant for the hydrocarbon fuels themselves. For this reason, chemical processes will not be considered in the following discussion.

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TABLE 8-20
Advantages and Disadvantages of Natural Attenuation

ADVANTAGES	DISADVANTAGES
Lower costs than most active remedial alternatives.	Not effective where constituent concentrations are high (> 20,000 to 25,000 mg/Kg TPH).
Minimal disturbance to the site operations.	Not suitable under certain site conditions (e.g., impacted groundwater supply, presence of free product).
Potential use below buildings and other areas that cannot be excavated.	Some migration of constituents may occur; not suitable if receptors might be affected.
	Long period of time required to remediate heavier petroleum products.
	Longer period of time may be required to mitigate contamination than for active remedial measures.
	May not always achieve the desired cleanup levels within a reasonable length of time.

Also, although it is not likely that all environmental conditions will be within optimal ranges under natural field conditions, natural attenuation processes will still be occurring. The natural attenuation mechanisms discussed in the following section are:

- *Biological Processes*--aerobic (requires oxygen), anaerobic (must occur in the absence of oxygen), and hypoxic (can occur under conditions of low oxygen content), and
- *Physical Phenomena*--volatilization, dispersion (mechanical mixing and molecular diffusion), and sorption.

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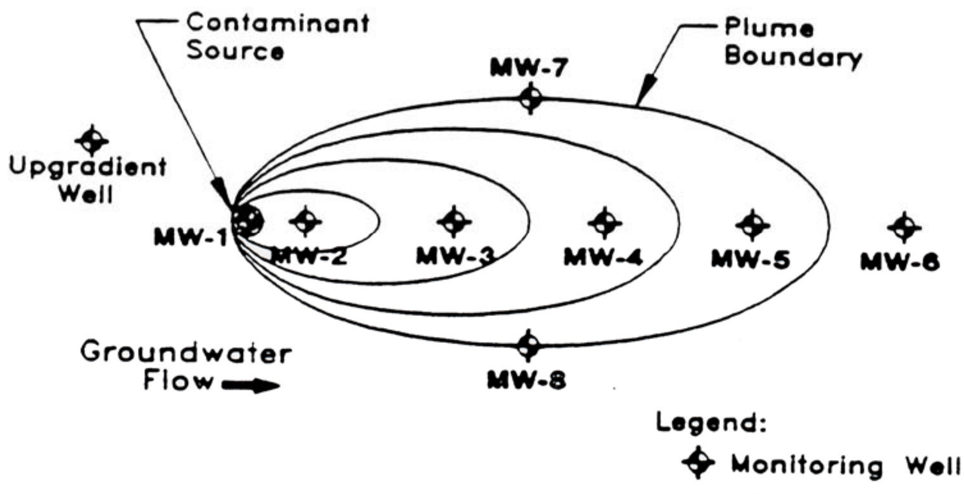
FIGURE 8-18 Recommended Monitoring Well Network for Natural Attenuation



8.32.2 Biological Processes

Aerobic biodegradation of BTEX by naturally occurring microorganisms is more rapid than anaerobic biodegradation, but both are important. The rate of oxygen depletion due to microbial metabolism typically exceeds the rate of which oxygen is naturally replenished to the subsurface. This is especially true in the core region of the hydrocarbon subsurface. This is especially true in the core region of the hydrocarbon plume dissolved in groundwater. The result is that anaerobic processes can become predominant. When oxygen is depleted, an alternative electron acceptor (*e.g.,* NO_3, SO_4^{-2}, Fe^{3+}) and a microorganisms capable of using the alternative electron acceptor must be available for biodegradation to occur. Toluene is the only BTEX component that has been shown to degrade under anaerobic conditions in the field. Conditions where oxygen is partially depleted are referred to as hypoxic [about 0.1 to 2 parts per million (ppm) oxygen]. Biodegradation of BTEX under hypoxic conditions may be possible, but it has not been demonstrated.

Anaerobic biodegradation is also a significant attenuation process. Oxygen depletion in the subsurface is a characteristic of biodegradation of petroleum hydrocarbons and is a consequence of the rate of metabolic oxygen utilization exceeding the natural capacity for oxygen replenishment. The core of a contaminant plume is typically under anaerobic conditions and only the margins are aerobic. Therefore, even though the rate of anaerobic biodegradation is much slower than aerobic biodegradation (often by a factor of 10 to several hundred), anaerobic processes may dominate the degradation of hydrocarbon contaminants. Because a variety of models are available and their appropriate use requires a high degree of technical expertise, a more detailed discussion of modeling is beyond the scope of this manual.

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8.32.3 Physical Phenomena

Physical processes such as volatilization, dispersion, and sorption also contribute to natural attenuation. Volatilization removes constituents from the groundwater or soil by transfer to the gaseous phase. In general, volatilization accounts for about 5 to 10 percent of the total mass loss of benzene at a typical site, with most of the remaining mass loss due to biodegradation (McAllister, 1994). For less volatile constituents, the expected mass loss due to volatilization is even lower. Dispersion ("spreading out" of constituents through the soil profile or groundwater unit) results in lower concentrations of constituents, but no reduction in contaminant mass. In soils, hydrocarbons disperse due to the effects of gravity and capillary forces (suction). In groundwater, hydrocarbons disperse by advection and hydrodynamic dispersion. Advection is the movement if dissolved components in flowing groundwater. Hydrodynamic dispersion is the result of mechanical mixing and molecular diffusion. If groundwater velocities are relatively high, mechanical mixing is the dominant process and diffusion is insignificant. At low velocity, these effects are reversed. Sorption (the process by which particles such as clay and organic matter "hold onto" liquids or solids) retards migration of some hydrocarbon constituents (thereby allowing more time for biodegradation before the constituents reach a receptor). Although none of these three processes results in a loss of mass, they can help to improve the rate at which natural attenuation occurs.

8.33 REMEDIAL PROGRESS MONITORING

Monitoring the progress of natural attenuation is necessary to confirm whether petroleum constituents are being degraded or displaced at acceptable rates and that potential receptors are not likely to be adversely affected.

8.33.1 Indicators of Natural Attenuation

Site characterization data can provide numerous indicators to demonstrate that natural attenuation is occurring (McAllister, 1994). Some of the necessary data may be collected as part of a standard site characterization, while other data would likely be collected specifically for the purpose of evaluating natural attenuation effectiveness. Note that sampling and analytical methods must be consistent and appropriate, and well and screen placement must be appropriate to the site conditions, or the monitoring data might not accurately reflect the rate at which natural attenuation is occurring.

A thorough evaluation of constituent mass balance can be used to demonstrate the extent and rate of natural attenuation, but this approach requires extensive monitoring data that completely define the horizontal and vertical extent of the contaminant plume. This approach has been used to investigate natural attenuation, but it is generally practical only for research. Several other indicators of natural attenuation with less extensive data requirements are described below.

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8.33.2 Constituent Plume Characteristics

In the absence of natural attenuation mechanisms, constituent concentrations would remain relatively constant within the plume, and than decrease rapidly at the edge of the plume. If natural attenuation is occurring, constituent concentrations will decrease with distance from the source along the flow path of the plume as a result of dispersion. If other natural attenuation mechanisms are occurring, the rate of which concentrations of constituents are reduced will be accelerated.

Monitoring of constituent concentrations in the groundwater over time will give the best indication of whether natural attenuation is occurring. If natural attenuation is occurring, the contaminant plume will migrate more slowly than expected based on the average groundwater velocity. Receding plumes typically occur when the source has been eliminated. Natural attenuation may also be occurring in plumes that are expanding, but at a slower than expected rate. For example, in sandy soils with relatively low organic carbon content (about 0.1 percent), BTEX constituents are expected to migrate at one-third to two-thirds of the average groundwater speed velocity (McAllister, 1994).

Higher organic carbon content would further retard constituent migration. If constituents are migrating more slowly than expected based on groundwater flow rates and retardation factors, then other natural attenuation mechanisms (primarily biodegradation) are likely reducing constituent concentrations. For stable plumes, the rate at which contaminants are being added to the system at the source is equal to the rate of attenuation. A plume may be stable for a long period of time before it begins to recede, and in some cases, if the source is not eliminated, the plume may not recede.

Occurrence of biodegradation might also be deduced by comparison of the relative migration of individual constituents. The relative migration rates of BTEX constituents, based on the chemical properties, are expected to be in the following order:

benzene > toluene, o-xylene > ethylbenzene, m-xylene, p-xylene.

If the actual migration rates do not follow this pattern, biodegradation may be responsible.

8.33.3 Dissolved Oxygen Indicators

The rate of biodegradation will depend in part on the supply of oxygen to the contaminated area. At levels of dissolved oxygen (D.O.) below 1 to 2 mg/L in the groundwater, aerobic biodegradation rates are very slow. If background D.O. levels (upgradient of the contaminant source) equal or exceed 1 to 2 mg/L, the flow of groundwater will supply D.O. to the contaminated area, and aerobic degradation is possible.

Where aerobic biodegradation is occurring, an inverse relationship between D.O. concentration and constituent concentrations can be expected (*i.e.*, D.O. levels increase as constituent levels decrease). Thus, if D.O. is significantly below background within the plume, aerobic biodegradation is probably occurring at the perimeter of the plume.

8.33.4 Geochemical Indicators

Certain geochemical characteristics can also serve as indicators that natural attenuation, particularly aerobic biodegradation, is occurring. Aerobic biodegradation of petroleum products produces carbon dioxide and organic acids, both of which tend to cause a region of lower pH and increased alkalinity within the constituent plume.

Anaerobic biodegradation may result in different geochemical changes, such as increased pH. Under anaerobic conditions, biodegradation of aromatic hydrocarbons typically causes reduction of Fe^{3+} (insoluble) to Fe^{2+} (soluble), because iron is commonly used as an electron acceptor under anaerobic conditions. Thus, soluble iron concentrations in the groundwater tend to increase immediately downgradient of a petroleum source as the D.O. is depleted, and conditions change to become anaerobic (*i.e.*, reduced). The concentration of methane increases, another indication that anaerobic biodegradation is occurring.

8.34 OXYGEN RELEASE COMPOUND®

Note: Information provided courtesy of REGENESIS bioremediation products and groundwater applications. Inclusion of this material does not imply endorsement of the DERR.

Oxygen Release Compound (ORC®) is a proprietary formulation of magnesium peroxide, which when moist releases oxygen slowly. It is used to deliver dissolved oxygen to oxygen-deficient environments to stimulate aerobic biodegradation. It should not be used when more than a sheen of free product is evident.

The laws of mass transport govern the movement of oxygen from an ORC® particle, to the environment where remediation takes place. These include Darcy's Law (advective flow) and Fick's Law (diffusion). In addition, some of the kinetic energy released when the ORC® reacts with water can facilitate dispersion. In most cases involving the distribution of oxygen in groundwater, advective flow is dominant and can be approximated using flow models. Diffusion is usually a small part of these models, but can become more important in the result as advection is diminished. A pure diffusion model will predict the distribution of oxygen in a static system. The performance of ORC® is a function of the advective flow and diffusion. A combination of both model predictions and experimental results is necessary for ORC® placement. Manufacturer supplied software is available for the design of all ORC® applications. A variety of applications are feasible with ORC® including: 1) groundwater treatment, 2) excavated tank pit treatment, 3) groundwater treatment in or near the excavated tank pit, 4) soil treatment, and 5) oxygen barrier treatment.

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8.34.1 Source Treatment Applications

Advantages and disadvantages of ORC® applications are listed in Table 8-21.

8.34.2 Groundwater Treatment

ORC® may be used in the source area of the groundwater contamination. This application has two objectives. The first is fast site closure. Since aerobic bioremediation is much faster than anaerobic bioremediation, an ORC® application results in faster site closure than natural attenuation, which generally operates under oxygen deficient conditions. ORC® treatment can also be faster, in certain cases, than engineered mechanical treatment methods. The second objective is risk reduction. Even if the source is not completely cleaned up, the application of ORC® will collapse the plume and permit compliance at a point closer to the source.

TABLE 8-21
Advantages and Disadvantages of Oxygen Release Compound®

ADVANTAGES	DISADVANTAGES
Can act as an oxygen barrier to eliminate or diminish plume concentrations downgradient of the source.	Groundwater feasibility is a function of advection and diffusion; it may not be cost effective in tight soil conditions.
Easily applied to open excavations by mixing with the soil.	Certain site conditions may require several applications and longer treatment times.
Does not require significant operation and maintenance or utility costs.	Cannot treat groundwater with more than a sheen on the surface.
Can be more cost effective than over-excavation.	Treatment is limited to biodegradable compounds in oxygen limited environments.
Has been shown to treat MTBE contamination with commingled plumes of MTBE and BTEX using microbial cometabolism.	Has not been shown to treat MTBE-only plumes.
Can treat soil/groundwater at any depth with slurry or solid injection.	

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For source treatment, ORC® may be applied using retrievable filter socks placed in completed monitoring wells, or in a water and ORC® powder slurry mixture. In this slurry form the ORC® may be back filled or injected into direct-push boreholes, or back filled into auger holes. Using any one of these methods, a saturated zone source treatment with an ORC® slurry targets dissolved phase contamination plus sorbed material within the saturated, capillary fringe, and smear zones. It is important that the entire vertical distance of these contaminant zones be covered by the ORC® for a source treatment.

8.34.3 Excavated Tank Pit Application

An ORC® excavated tank pit treatment offers a unique, one-time opportunity to provide a large treatment area across the floor of an excavated tank pit. Applying a long-lasting oxygen source into the system creates a zone of remedial activity, which protects the lower region of the pit. An ORC® excavated tank treatment can be less expensive than excavation, transportation and treatment of contamination at the bottom of the pit.

8.34.4 Groundwater Treatment In or Near the Excavated Pit

After tank removal and remedial excavation, ORC® can be used in-situ to cleanup the residual levels of hydrocarbon in the soil and at the soil/groundwater interface. In this application pure ORC® powder is physically mixed into the soil to remediate the groundwater. In order to provide accurate quantities of ORC®, the amount of TPH and BTEX should be quantified. In situations where the excavation is unstable or the construction schedule requires immediate back filling the recommended application of ORC® is between 0.1% and 1.0% by weight of ORC® to the saturated soil mass being treated. A standard starting point would be 0.3%, which would be increased if the contamination appeared to be heavy.

8.34.5 Soil Treatment

When groundwater is several feet below the bottom of the excavated pit, application of ORC® can treat spot contamination is the soil, which otherwise may desorb enough material to leach into and continually contaminate the aquifer. This application is similar to over-excavating a tank pit to provide insurance that all of the contamination has been removed.

An ORC® application may be less expensive than excavation, transportation, and disposal of the contaminated soil. For example, to treat 100 mg/Kg of sorbed TPH in the bottom 2 feet of a 40 feet x 40 feet tank pit excavation would require 960 pounds of ORC®. At $9.75 per pound (price in 1998) this ORC® treatment would cost $9,630 or, $79 per cubic yard.

8.34.6 Source Treatment Slurry Back-Fill Application

The ORC® back-fill application is used to remediate a known dissolved phase hydrocarbon contamination plus additional oxygen requirements as needed. In sites with groundwater flow, some oxygen provided by ORC® placed at the source area may move out of the target-contaminated zone and begin to treat the downgradient contamination. In this application the ORC® slurry is back-filled into direct-push or augured boreholes upon completion of drilling. A bentonite cap is typically installed over the ORC® slurry and the surface is completed normally.

8.34.7 ORC® Source Treatment Slurry Injection Application

In this application the ORC® slurry is applied under pressure into the contaminated groundwater, capillary fringe and smear zones. Borehole spacing according to the soil type is critical to ensure adequate dispersion of the oxygen, to get overlapping oxygen coverage. In general the boreholes need to be spaced less than 6 feet on center. Fifteen feet on center is about the maximum spacing that will provide overlapping zones of oxygen.

8.34.8 ORC® Source Treatment from Replacement Wells

ORC® can be used in completed monitoring wells installed in the proper area and that are screened through the vertical portion of the saturated zone, the capillary fringe, and the smear zone. In this application a mixture of ORC® and inert silica sand is contained in filter socks. After 6 months, when the oxygen is depleted, the socks should be removed from the wells. The spent ORC® filter socks may continue to be replenished until downgradient compliance is achieved and maintained.

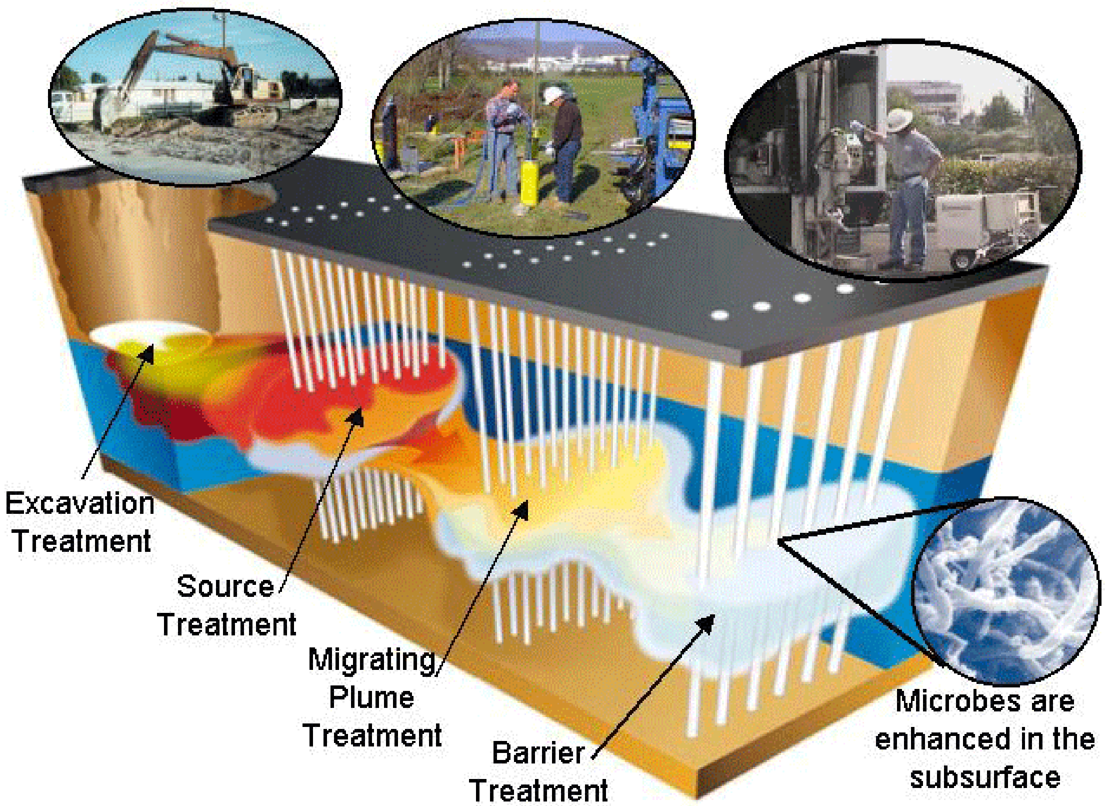
8.34.9 ORC® Oxygen Barrier Applications

The ORC® barrier treatment has the objective of reducing liability by stopping the migration of a contaminated groundwater plume beyond the property boundary or achieving compliance at a point downgradient. The ORC® is best applied in completed monitoring wells with screened intervals through the contaminated portion of the saturated zone. In this application, a mixture of ORC® and inert silica sand is contained in filter socks. After 6 months, when the oxygen is depleted, the socks may be removed from the wells.

In this application, it is assumed that there is continued source of dissolved phase hydrocarbons moving through the highly oxygenated zone provided by the ORC®. This zone is replenished by replacing the ORC® filter socks when they are depleted (Figure 8-19). The objective is to completely contain the contaminant or to reduce it so that compliance may be achieved at a point downgradient. Software is available that permits design and placement of the oxygen barrier wells in any configuration that is appropriate for the site. The dispersion of the oxygen from the ORC® is of consideration. In general to achieve overlapping oxygen coverage the wells need to be placed closer than five feet on center. Twelve feet on center is about the maximum that can provide overlapping oxygen dispersion.

In order to achieve and maintain compliance, the ORC® oxygen barrier must be recharged. As the barrier is recharged the number of socks needed should be reevaluated. This reevaluation is primarily dependent upon the continuance of the contaminant source. If this load drops off, or increases, then the number of socks may be decreased, or increased, accordingly.

FIGURE 8-19 Illustration of an ORC® Barrier Configuration.
Drawing Courtesy of Regenesis.



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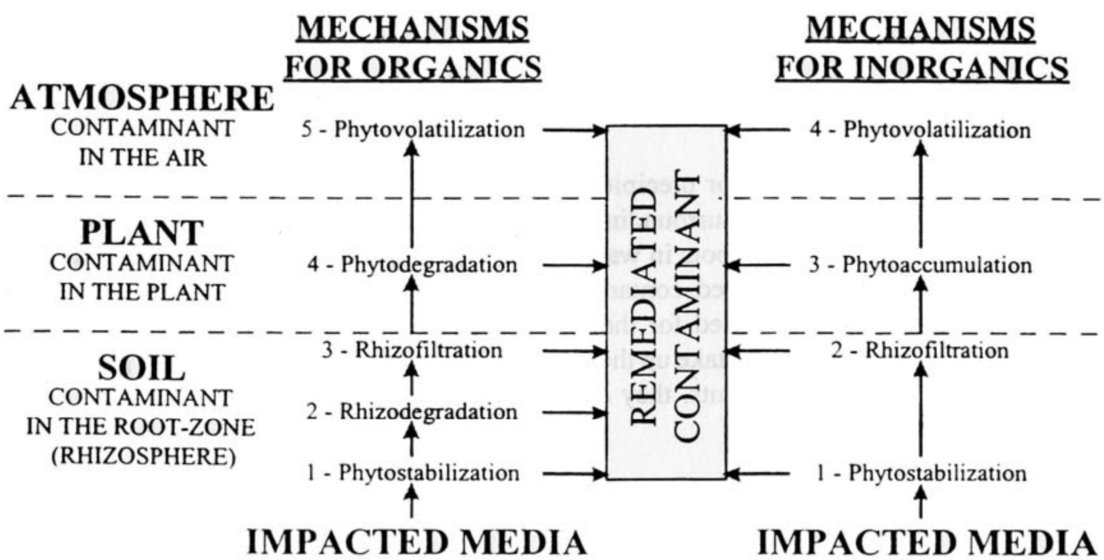
8.35 PHYTOREMEDIATION

Phytoremediation is the direct use of living plants for *in-situ* remediation of contaminated soil, sludges, sediments, and groundwater through contaminant removal, degradation, or containment. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates. Plants are used in several ways to remediate sites as described below and presented in Figure 8-20.

FIGURE 8-20

Contaminant Fates in the Soil-Plant Atmosphere Continuum



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8.36 MECHANISMS

Phytoremediation works through several mechanisms described below.

8.36.1 Phytoextraction

Phytoextraction, also called phytoaccumulation, refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants. Hyperaccumulator plants absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a site based on the type of metals present and other site conditions. After the plants have been allowed to grow for several weeks or months, they are harvested and either incinerated or composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. If plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment.

8.36.2 Rhizofiltration

Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. The plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. To acclimate the plants once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested and either incinerated or composted to recycle the contaminants.

8.36.3 Phytodegradation

Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants are degraded, used as nutrients and incorporated into the plant tissues. In some cases metabolic intermediate or end products are re-released to the environment depending on the contaminant and plant species.

8.36.4 Phytostabilization

Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and groundwater through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone (rhizosphere), and physical stabilization of soils. This process reduces the mobility of the contaminant and prevents migration to the groundwater or air. This technique can be used to re-establish a vegetative cover at sites where natural vegetation is lacking due to high metal concentration. Metal-tolerant species may be used to restore vegetation to such sites, thereby decreasing the potential migration of contamination through wind erosion, transport of exposed surface soils and leaching of soil contamination to groundwater.

8.36.5 Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with the release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water and the organic and inorganic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations. Many organic compounds transpired by a plant are subject to photodegradation.

8.36.6 Rhizodegradation

Rhizodegradation, also called phytostimulation, rhizosphere biodegradation, enhanced rhizosphere biodegradation, or plant-assisted bioremediation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere. Microorganisms (yeast, fungi, and/or bacteria) consume and degrade or transform organic substances for use as nutrient substances. Certain microorganisms can degrade organic substances such as fuels or solvents that are hazardous to humans and ecological receptors and convert them into harmless products through biodegradation. Natural substances released by the plant roots-such as sugars, alcohols, and acids-contain organic carbon that act as nutrient sources for soil microorganisms, and the additional nutrients stimulate their activity. Rhizodegradation is aided by the way plants loosen the soil and transport oxygen and water to the area. The plants also enhance biodegradation by other mechanisms such as breaking apart clods and transporting atmospheric oxygen to the root zone.

8.36.7 Applicability

Phytoremediation and plant-assisted bioremediation are most effective if soil contamination is limited to within 3 feet of the surface, and if groundwater is within 10 feet of the surface. These technologies are applicable to sites with low to moderate soil contamination over large areas, and to sites with large volumes of groundwater with low levels of contamination that have to be cleaned to low (strict) standards.

Contaminants that have been remediated in laboratory and/or field studies using phytoremediation include:

- Heavy metals (Cd, Cr(VI), Pb, Co, Ni, Se, Zn)
- Radionuclides (Cs, Sr, Ur)
- Chlorinated solvents (TCE, PCE)
- Petroleum hydrocarbons (BTEX)
- Polychlorinated biphenyls (PCBs)

- Polynuclear aromatic hydrocarbons (PAHs)
- Chlorinated pesticides
- Organophosphate insecticides (e.g., parathion)
- Explosives (TNT, DNT, TNB, RDX, HMX)
- Nutrients (nitrate, ammonium, phosphate)
- Surfactants.

Phytoremediation technology has limitations and is not applicable for all sites. Each site should undergo a site characterization and phytoremediation feasibility evaluation that should include the following concerns:

- The toxicity and bioavailability of biodegradation products is not always known.
- Mobilization of degradation by-products in groundwater or bio-accumulating in the food chain.
- The lack of research to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products manufactured by plant do not contribute toxic or harmful chemicals into the food chain.
- Scientists need to establish whether contaminants that collect in the leaves and wood of trees are released when the leaves fall in the autumn or when firewood or mulch from the trees is used.
- Pumping the water out of the ground and using it to irrigate plantations of trees may treat contaminated groundwater that is too deep to be reached by plant roots but raises concerns with the fate and transport of the contaminant.

The advantages and disadvantages of phytoremediation are presented in Table 8-22.

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TABLE 8-22
Advantages and Disadvantages of Phytoremediation

ADVANTAGES	DISADVANTAGES
Can be performed with minimal environmental disturbance.	Harvested plants may require disposal as hazardous waste.
Applicable to a broad range of contaminants, including many metals with limited alternative options.	The depth of the contaminants limits treatment. The treatment zone is determined by plant root depth. In most cases, it is limited to shallow soils, streams, and groundwater.
Possibly less secondary air/or water wastes generated than traditional methods	The success of phytoremediation may be seasonal, depending on location. Other climatic factors will also influence its effectiveness.
Organic pollutants may be degraded to CO_2 and H_2O, as opposed to transferring environmental toxicity.	If contaminant concentrations are too high, plants may die.
Cost-effective for large volumes of water having low concentrations of contaminants to low (stringent) standards.	Some phytoremediation transfers contamination across media, (e.g., from soil to air) and may create human chemical exposure concerns.
Topsoil is left in a useable condition and may be reclaimed for agricultural use.	Phytoremediation is not effective for strongly sorbed contaminants such as PCBs.
Cost effective for large areas having low to moderately contaminated surface soils.	Phytoremediation requires a large area of land for remediation.
Reduces volume of contaminated material to be landfilled or incinerated.	Animals may damage the plants and create a need to replant.
Can achieve remediation goals without using toxic chemicals.	Phytoremediation may take longer than traditional methods to reach final cleanup levels.
Reduced risk of exposure during clean up by limiting direct contact with contaminated soils.	Waste accumulation in the plants may present a problem with contaminants entering the food chain.
Plant uptake of contaminated groundwater can prevent off-site migration.	

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8.37 DESIGN

The design of a phytoremediation system varies according to the contaminants, the conditions at the site, the level of clean up required and the plants used. The design considerations include: 1) contaminant levels, 2) plant selection, 3) treatability, 4) Irrigation, nutrient requirements, and maintenance, 5) groundwater capture zone and transpiration rate, and 6) contaminant uptake rate and clean-up time required.

8.37.1 Contaminant Levels

High levels of contamination may eliminate phytoremediation as a treatment option. Plants are not able to treat all contaminants. The composition of organic compounds (structure, log K_{ow}, degree of weathering and boiling point range) and degree of adsorption are important factors in phytoremediation. In addition to knowing the contaminants and their concentrations, the depth of the contaminants must be known.

8.37.2 Plant Selection

The plant selection requirements for phytotransformation of organic compounds are: that vegetation is fast growing and hardy, easy to plant and maintain, utilizes a large quantity of water be evapotranspiration and transforms the contaminants of concern to non-toxic or less toxic products. In temperate climates, phreatophytes (*e.g.*, hybrid poplar, willow, cottonwood, aspen) are often selected because of fast growth, a deep rooting ability down to the level of groundwater, large transpiration rates, and the fact that they are native throughout most of the country.

Plants used in phytoextraction include sunflowers and Indian mustard for lead; *Thlaspi* spp. (Pennycress) for zinc, cadmium, and nickel; and sunflowers and aquatic plants for radionuclides. The two categories of aquatic plants used are emergent and submerged species. Emergent vegetation transpires water and is easier to harvest if required. Submerged species do not transpire water but provide more biomass for the uptake and sorption of contaminants.

8.37.3 Treatability

Treatability studies assess the fate of the contaminants in the plant system and are typically conducted by a plant scientist. Different concentrations of contaminants are tested with proposed plant species to predict the amount and type of material transpired and/or extracted by the plants.

8.37.4 Irrigation, Nutrient Requirements, and Maintenance

Irrigation of the plants ensures a vigorous start to the system even in drought. Hydrologic modeling may be required to estimate the rate of percolation to groundwater during irrigation conditions. Irrigation should be withdrawn if the area receives sufficient rainfall to sustain the plants. Nutrient addition is determined through soil analysis of such items as nitrogen, potassium, phosphorous, and pH. Maintenance of the phytoremediation system may include adding fertilizer, manure, sewage sludge compost, straw, or chelates. Replanting may be required due to drought, disease, insects or animals killing of the plants.

8.38 GROUNDWATER CAPTURE ZONE AND TRANSPIRATION RATE

For applications involving groundwater remediation a capture zone calculation can be used to estimate whether the phytoremediation pump (trees) can be effective at entraining the plume of contaminants. The goal is to create a water table depression where contaminants will flow to the vegetation for uptake and treatment. Organic contaminants are not taken up at the same concentration as in the soil or groundwater. Membranes at the root surface reduce the uptake rate of the contaminant.

8.38.1 Contaminant Uptake Rate and Clean-Up Time Required

Estimates of contaminant uptake and clean-up time can be calculated using first order kinetics equations provided in the Ground-Water Remediation Technologies Analysis Center Technology Evaluation Report *Phytoremediation,* by Jerald L. Schnoor.

8.38.2 Cost

Phytoremediation is very competitive with other treatment alternatives. It is aesthetically pleasing and its public acceptability is high. The cost of phytoremediation is approximately half the cost of pump and treat. It is most comparable to *in-situ* bioremediation and natural attenuation in terms of cost, however it requires longer time periods than competing technologies.

8.39 CHEMICAL OXIDATION

Note: This section has been excerpted from EPA and GWRTAC documents. For details the reader is referred to the source documents (EPA 542-R-98-008, September 1998 Field Applications of In Situ Remediation technologies: Chemical Oxidation; GWRTAC Technology Evaluation Report, TE-99-01, July 1999, In Situ Chemical Treatment; GWTRAC Technology Overview Report, TO096-06, November 1996, Ultraviolet/Oxidation Treatment).

Chemical oxidation is an innovative technology that can destroy or degrade an extensive variety of hazardous wastes in groundwater, sediment, and soil. The oxidants used are readily available, and treatment time is usually measured in months rather than years, making the process economically feasible.

Enrichment with dissolved oxygen has been shown to stimulate *in situ* biological processes, but also is used to oxidize metals. Potassium permanganate is a stable and easily handled oxidant in both solid and solution form. Hydrogen peroxide can be costly, and because of its volatility requires protective measure. Nevertheless, the sorter process may save on labor and operating costs.

In situ chemical oxidation can be applied in conjunction with other treatments such as pump-and-treat and soil vapor extraction to break down remaining compounds. It is less costly and disruptive then other traditional soil treatments such as excavation and incineration. *In situ* chemical oxidation may be used in applications where the effectiveness of bioremediation is limited by the range of contaminants and/or climate conditions.

8.39.1 Technology Description

In situ chemical oxidation is based on the delivery of chemical oxidants to contaminated media in order to either destroy the contaminants by converting them to innocuous compounds commonly found in nature. The oxidants applied in this process are typically hydrogen peroxide (H_2O_2), potassium permanganate ($KMnO_4$), ozone, or to a lesser extent, dissolved oxygen (DO).

The most common field applications have been on Fenton's Reagent whereby hydrogen peroxide is applied with an iron catalyst creating a hydroxyl free radical. This hydroxyl free radical is capable of oxidizing complex organic compounds. Residual hydrogen peroxide decomposes into water and oxygen in the subsurface and any remaining iron precipitates out. This process has a history of application in waste treatment fields.

Ultraviolet (UV)/oxidation treatment is a destructive process that oxidizes organic and explosive constituents in contaminated groundwater by the addition of strong oxidizers and irradiation with ultraviolet light. The oxidation reactions are achieved through the synergistic actions of high intensity UV light alone, or in combination with patented treatment reactor design (in some cases), ozone (O_3) and/or hydrogen peroxide. Hydroxyl radicals are generated that destroy most organic chemical compounds. If complete mineralization is achieved in the reaction, the final products of the process are carbon dioxide, water, and salts.

The volume and chemical composition of individual treatments are based on the contaminant levels and volume, subsurface characteristics, and pre-application laboratory test results. The methods for delivery of the chemical may vary. The oxidant can be injected through a well or injector head directly into the subsurface, mixed with a catalyst and injected, or combined with an extract from the site and then injected and recirculated.

In situ chemical oxidation is being used for groundwater, sediment, and soil remediation. It can be applied to a variety of soil types and sizes (silt and clay). It is used to treat volatile organic chemicals including dichloroethene, trichloroethene, tetrachloroethene, and BTEX as well as semi-volatile organic chemicals including pesticides, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls.

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8.39.2 Amenability to Chemical Treatment

The chemical reactions employed in *in situ* chemical reactions depend on the sensitivity of the environmental contaminants to this chemical reaction. To assess the efficiency of a chemical treatment process to a certain contaminant, detailed studies need to be conducted. A three-step process may be followed. First, a laboratory screening study in water without natural matrix present may be conducted to test the ability of a chemical in degrading or immobilizing a contaminant of interest. The optimum conditions, such as pH, temperature, and chemical loading, for treatment of the contaminant can be determined during this study. Second, a batch study with natural matrices present may be conducted to investigate the effect of natural matrix on the treatability of the contaminant with the proposed chemical. Third, a column study may be conducted to evaluate the effect of diffusion on treatability and determine the rate-limiting steps for the chemical treatment.

8.39.3 Engineering Aspects of Chemical Injection

The feasibility of delivery of chemicals to the contaminated region is the key for successful *in situ* remediation of contaminants via chemical injection. Several conventional delivery systems, namely vertical wells, well points, horizontal or inclined wells, infiltration galleries, treatment fence, etc. have been field demonstrated to be capable of delivering chemicals into subsurface environments. For soils of low permeability, innovative technologies such as deep soil mixing and hydraulic fracturing provide better solutions for the delivery.

Successful delivery of chemicals to the contaminated region relies on careful engineering design of the system and proper construction of the needed delivery equipment. An injection system for the delivery of hydrogen peroxide was constructed of Teflon® and is similar to devices used for jet grout injection. Two major components of the injection system are a rod and a jet tip perpendicular to the axis of the rod. By rotating the rod about its axis, and thereby rotating the tip, the hydrogen peroxide can be injected in a plane perpendicular to the rod.

For soils of low permeability, deep soil mixing technology is applied. This technology uses special augers in series, equipped with mixing paddles that mix soil as they rotate. Drilling over 30.5 meters has been achieved. Treatment solutions can be injected into an air stream such that it enters the mixed zone as a fine mist.

Hydraulic fracturing uses pumped water or air under high pressure to deliver reagent to a low-permeability subsurface. A series of horizontally stacked fractures 12 to 15 meters in diameter can create an effective reactive zone to intercept and treat downward migrating contaminants.

A summary of advantages and disadvantages is shown below in Table 8-24.

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TABLE 8-24
Advantages and Disadvantages of Chemical Oxidation

ADVANTAGES	DISADVANTAGES
Chemical oxidation processes destroy contaminants in contrast to transferring them to another medium.	Free radical scavengers can inhibit contaminant destruction efficiency. Excessive dosages of chemical additives may also act as a scavenger.
Can be used *in situ* by delivering the chemicals to contaminated media.	UV/oxidation treatment requires low turbidity and suspended solids concentrations in the groundwater.
Aggressive treatment process and applicable to a wide variety of chemicals including refractive chemical substances.	Costs may be higher than some applications because of energy requirements.
	Handling and storage of oxidizers require special safety precautions.
	Possible air emission problems with ozone as the oxidant.

8.40 *IN SITU* FLUSHING

Note: This section has been excerpted from GWRTAC documents. For details the reader is referred to the source documents: (GWTRAC TO-97-02, June 1997, In Situ Flushing; GWRTAC TE-96-02, December 1996, Surfactants/Cosolvents).

In situ flushing is the injection or infiltration of an aqueous solution into a zone of contaminated soil/groundwater, followed by downgradient extraction of groundwater and elutriate (flushing solution mixed with the contaminants) and aboveground treatment and discharge or re-injection. Flushing solutions include plain water sometimes augmented by surfactants, cosolvents, or other facilitators. *In situ* flushing enhances conventional pump and treat technology through increasing the efficiency of a flushing pore volume, or accelerating natural flushing action. The technology is potentially applicable to a very broad range of contaminants, and is not limiting in terms of contaminant depth or location within the hydrogeologic regime, although successful implementation is highly site-specific.

Important site-related parameters include variations in hydraulic conductivity, degree of heterogeneity, and soil organic content. Some of the contaminant related factors include solubility and octanol/water partitioning coefficient.

The goal of surfactant flushing is to decrease the required flushing volume by mobilizing and/or solubilizing nonaqueous liquid phases and/or solubilizing sorbed contaminants. These phenomena occur because the surfactant may:

1) lower NAPL-water interfacial tension, thereby decrease capillary forces within the porous media

2) create a Winsor type III middle phase microemulsion

3) solubilize individual contaminant molecules in surfactant micelles or single phase microemulsion systems (with added cosurfactants, usually alcohols).

8.41 PUMP-AND-TREAT TECHNOLOGIES

Note: This section has been excerpted from EPA documents. For detail, the reader is referred to the source documents (EPA, 1989; 1995).

Conventional pump-and-treat technologies are among the most widely used systems for the remediation of contaminated groundwater. Within recent years it has become recognized that these systems can require prolonged periods of time to make significant reductions in the quantity of contaminants associated with both the liquid and solid phases which constitute the subsurface matrix.

Groundwater extraction technology is based on two fundamental assumptions. First, it is assumed that a well system can produce groundwater flow patterns that will permit the wells to withdraw all of the contaminated groundwater from the aquifer. Second, it is assumed that the contaminants will come out of the aquifer with the water. In an ideal hydrogeologic system with simple pre-existing flow patterns, homogeneous aquifer properties, and with mobile contaminants present only in aqueous solution, groundwater extraction can work quite well. However, most real-world sites are more complex than this, and most departures from the ideal conditions described above tend to reduce the potential effectiveness of groundwater extraction.

A common method for aquifer remediation is to withdraw the contaminated water from the aquifer and treat it on site. The treated water may than be returned to the aquifer, discharged to surface water, or transferred to a public water treatment plant. However, at many sites pump-and-treat technology will require decades of costly operation to achieve the desired levels of cleanup. Extended periods of remediation are highly undesirable because the operation and maintenance costs associated with the remediation can be large, and, in many cases, otherwise valuable land cannot be used for any economic purpose.

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A major concern in pump-and-treat operations is that contaminant concentrations within the extraction wells will decline at a progressively slower rate as pumping continues. When the rate of decline becomes small and the contaminant concentrations are still above the target cleanup levels, an extraction well is said to exhibit "tailing". Contaminant concentrations may have dropped several orders of magnitude, but they remain above the target cleanup level despite a considerable period of pumping. A great uncertainty in pump-and-treat operations is the time required for these tailing concentrations to decrease below the target clean-up levels.

In heterogeneous porous media, groundwater in higher permeability layers has greater velocities than water within the lower permeability zones. The higher permeability pathways are not necessarily sand or gravel nor are the lower permeability zones necessarily silts or clays; it is sufficient if one region possesses greater hydraulic conductivity relative to the adjacent materials. During pump-and-treat remediation, contaminants in the high permeability layers are removed more quickly than from the lower permeability layers.

Advantages and disadvantages of pump and treat are listed in Table 8-25. Figure 8-21 provides an illustration of a typical pump-and-treat system.

TABLE 8-25
Advantages and Disadvantages of Pump-and-Treat Technologies

ADVANTAGES	DISADVANTAGES
Widespread use, relatively easy technology.	Large amounts of water generated which must be treated before disposal.
Contaminant concentrations can be quickly reduced.	Cleanup levels may be difficult to achieve.
	Expensive and time consuming.

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8.42 TREATMENT OF GROUNDWATER

Once groundwater has been removed from the subsurface, the water generally must be treated in some manner prior to discharge or reinjection; or disposed of properly. Some commonly used methods for treatment of groundwater include: air stripping, carbon adsorption, oil/water separation, biofiltration, and chemical/UV oxidation.

8.42.1 Air Stripping

Air stripping involves pumping water to the top of a tower or column that may be filled with packing materials, or to a layered tray configuration with multiple air passage holes. As the water percolates through the packing material or across the tray, air is forced counter-currently to the water to drive off the volatile organic compounds (VOCs). VOCs having large Henry's Law constants are more readily stripped from groundwater than VOCs having low Henry's Law constants. MBTEXN compounds have relatively large Henry's Law constants, and are therefore readily stripped from water. MTBE can be removed by air stripping, however higher air pressures and longer stripping times are required. The effluent water can be reinjected into the aquifer or discharged, provided MBTEXN/TPH concentrations meet clean-up standards. The Division of Air Quality air emission discharge regulations are applicable to air stripper emissions as described in R307-401 in Chapter 9. Air strippers are prone to plugging and fouling due to high concentrations of suspended solids, iron, magnesium, and calcium, which become oxidized in the air stripper and precipitate from solution. Air stripper designs should incorporate chemical recirculation or chemical flow through systems for stripper cleaning.

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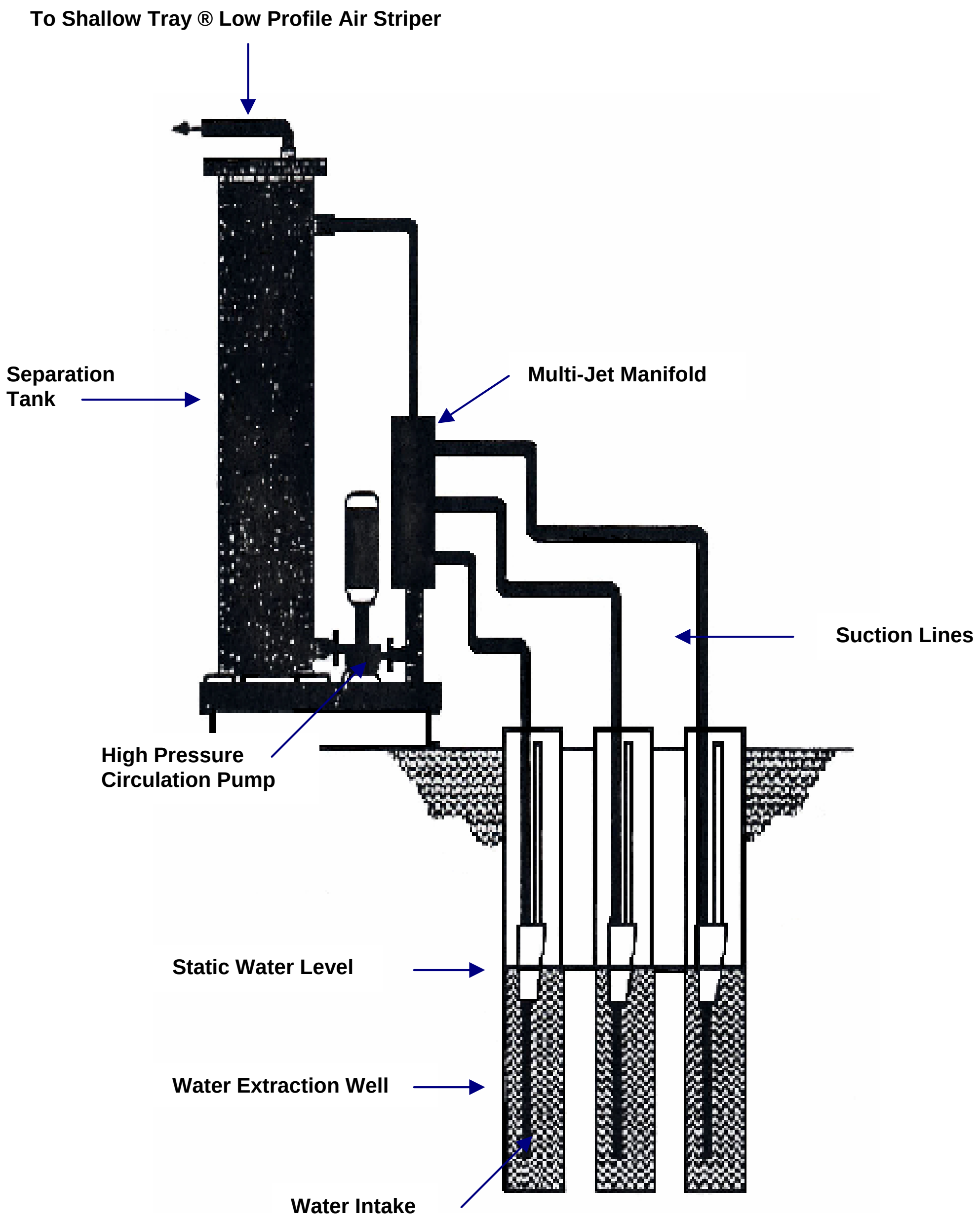
FIGURE 8-21. Typical Pump-and-Treat System with Air-Stripping Tower
Drawing Courtesy of North East Environmental Products, Inc.



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8.42.2 Carbon Adsorption

Carbon Adsorption involves pumping groundwater through beds or canister containing granular activated carbon (GAC). Low concentrations of MBTEXN may be more effectively removed by adsorption onto GAC than by air stripping. The groundwater may be reinjected or discharged after treatment through carbon adsorption. The GAC may require disposal as hazardous waste. A disadvantage of GAC units is that at high concentrations of MBTEXN, the carbon will become spent quickly, necessitating frequent expensive replacement and disposal.

8.42.3 Oil/Water Separation

Oil/water separation involves a mechanical device designed to separate large quantities of free-phase petroleum product from groundwater that has been pumped to the surface. An oil skimmer removes the free-phase petroleum product. The effluent water may require treatment as discussed above.

8.42.4 Biofiltration

Biofiltration utilizes naturally occurring microorganisms to clean contaminated air and odor emissions. The biofilter passes air through a series of interlocking, stacked trays filled with a compost-based medium containing microorganisms. A typical system consists of a humidifier, process blower, and stacked tray biofilter. The biofilter may require post-treatment polishing with GAC canisters to achieve complete removal of volatile compounds.

8.42.5 Chemical/UV Oxidation

Chemical/UV oxidation utilizes hydroxyl radical generating chemicals and/or ultra violet light to destroy organic compounds in groundwater.

8.43 GROUNDWATER MONITORING

Periodic monitoring of groundwater is typically required by the DERR from the time groundwater contamination is first reported to the DERR, through the subsurface investigation and corrective action phases. Quarterly sampling and analysis is the most common period, although the interval may be lengthened or shortened depending on site-specific conditions. Groundwater samples should be analyzed for the same parameters as the closure samples, typically TPH and MBTEXN. Groundwater monitoring results will indicate how well the treatment is progressing, and will form the basis for determining when corrective action cleanup goals have been achieved.

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9.1 UNDERGROUND UTILITIES AND BLUE STAKES

Besides being the law, utility clearance prior to drilling or excavation benefits the consultants, excavators or drillers, and the utility companies. Avoiding a "dig-in" of a utility line prevents death and injury, costly damage to public and private property, delays in projects, wasted time, possible legal action, and loss or interruption of services vital to public safety.

"Dig Safely." That is the slogan of the one-call Blue Stakes utility clearance program in Utah. The Blue Stakes program is a computerized notification system which establishes a communication link between those who dig underground (excavators) and those who operate underground facilities (operators). The notification center is funded by a state non-profit corporation. Members, some of whom are mandated by law, are operators engaged in 1) communications; 2) cable TV; 3) gas/oil/steam distribution, transmission, and gathering; 4) electric power; and 5) water/sewer.

Utah law (*Damage to Underground Utility Facilities,* Title 54, Chapter 8a), requires that the person or firm disturbing the earth's surface notify the operators of the underground facilities that there is planned work in the area near those lines. A copy of the Utah law can be located at: **http://www.bluestakes.org**. Excavators could be required to pay repair costs when underground lines are damaged as a result of digging.

The free Blue Stakes service notifies all members with underground facilities on public property in the area where an excavation (which by definition includes drilling) is to take place. Members mark facilities in the area of excavation, and in some cases may inform excavators that they have no facilities in the area of work. Once staked, the marks are valid for 14 days and must be updated if that time expires.

A private utility locator company may be warranted to mark utilities on private property. A private locator company can utilize induction or direct conduction to locate buried utility lines. Companies with geophysical capabilities can use techniques like ground penetrating radar to locate buried objects, such as USTs and large concrete irrigation piping.

The Blue Stakes program requires that you call (800-662-4111 or 801-532-5000) at least 2 days, but not more than 10 days, before work is to commence. The Blue Stakes operator will request the following information:

- County where the job is located;
- City, or closest town;
- Location, including street address, lot number, legal description, or public land survey grid location (township/range/section);
- Nearest street intersection;
- Type of work;
- The caller's name;
- The caller's company name and address;

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- The caller's telephone number;
- Name of company or individual for whom the work is being done; and
- The scheduled date and time of work.

The Blue Stakes operator will respond with a date and time that the location will be cleared and will provide a Location Request Number. In addition the caller may request a list of the members who will be notified. A list of member utilities is located at: **http://www.bluestakes.org**. It is important to record which utilities are notified because not every utility in Utah is required to participate in the program. Non-member utilities in the area should be notified by the environmental consultant.

The Blue Stakes *Excavators' Guide* is located at: **http://www.bluestakes.org**. The *Excavators' Guide* is designed to be used as a reference tool when planning an excavation and interacting with Blue Stakes. Blue Stakes may require the caller to mark the proposed excavation with white paint so that it is not confused with the standard utility marking color codes.

- **White – proposed excavation or drilling location;**
- **Red – electric power lines, cables, conduit, and lighting cables;**
- **Yellow – gas, oil, steam, petroleum, or gaseous materials;**
- **Orange – communication, CATV, alarm or signal lines, cables, or conduit;**
- **Blue – water, irrigation, and slurry lines;**
- **Green – sewers and drain lines; and**
- **Pink – temporary survey markings.**

When using powered digging equipment, use the 2-foot by 2-foot Rule: Stop powered digging 2 feet before reaching the line marked by Blue Stakes. Cautious digging can proceed by hand shovel (or insulated object) within 2 feet of the line. Carefully clear soil away from rigid objects within 4 feet of the Blue Stakes lines.

Finally, if a utility is damaged by excavation, call the utility company immediately to discuss repairs. Blue Stakes does not handle repairs to utilities.

For more information on Blue Stakes of Utah call toll free at 800-662-4111 or visit their website at: **http://www.bluestakes.org**.

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9.2 UDOT REQUIREMENTS

For invasive work on sidewalks and in roads, a right-of-way (ROW) permit is usually required, either by the local jurisdiction or the Utah Department of Transportation (UDOT). The local agency or UDOT should be contacted for site-specific requirements that can include payment of fees, limitations on scheduling, acquisition of a bond, submittal of a letter to justify the need for well locations, agreement to raise monuments when the ROW is repaved in the future, and/or well abandonment.

9.2.1 UDOT ROW Encroachment Permits

UDOT ROW encroachment permit requirements may vary in each of the four regions or three districts. The regions and districts coordinate the construction, road maintenance, snow removal, encroachment permits, and many other functions within their respective jurisdictions. Any work conducted within a UDOT ROW requires submittal and approval of a ROW encroachment permit application. The ROW permit application must be submitted to the appropriate region and/or district dependent upon the location of the project. The ROW encroachment permit is issued when the application is approved by the UDOT and local jurisdiction. The Utah Department of Transportation has divided the state into four regions, with Region Four sub-divided into three districts. The regions and districts coordinate the construction, road maintenance, snow removal, encroachment permits, and many other functions within their respective jurisdictions. Most questions people have are more appropriately directed to the region or district with jurisdiction over the location in question. A list of UDOT contacts with addresses and telephone numbers can be located at: **http://www.dot.state.ut.us**.

Application requirements for a UDOT ROW encroachment permit vary depending on region and/or district. However, ROW encroachment permit applications typically include:

- A location map showing the exact location of the proposed development;
- A topographic map showing existing features;
- A county plat of the area;
- State ROW details (*e.g.*, access connections, utilities, etc.);
- A traffic control plan;
- Written approval from the local jurisdiction; and
- Nominal fee starting at $20 for each permit.

General requirements may include a 3-year performance bond of $10,000 or the value of work performed if that value exceeds $10,000. ROW encroachment permit applications may require a 1- to 3-week review period at which time UDOT will then indicate the extent of additional requirements.

9.2.2 Traffic Control

A traffic control plan is an integral component of a UDOT ROW encroachment permit application. The traffic control plan is designed to provide continuity of function (movement of traffic, pedestrians, access to properties and utilities, etc.) during times when the normal function of the roadway is interrupted by environmental work. The US Department of Transportation, Federal Highway Administration has published Part IV, Standards and Guides for Traffic Controls for Street and Highway Construction, Maintenance, Utility, and Incident Management Operations (1993). This provides an excellent resource for traffic control plan preparation. Additionally, several traffic safety equipment providers in Utah will prepare a traffic control plan as part of an agreement to purchase or rent their equipment.

9.3 GROUNDWATER MONITORING WELL RULES, PERMITS, AND ABANDONMENT

The US EPA has delegated authority to UDEQ to administer its own water quality regulatory programs, such as surface water discharge, and underground injection. In addition, the Utah Department of Natural Resources (DNR) Division of Water Rights (DWR) administers a system to approve and record wells greater than or equal to 30 feet in depth.

9.3.1 Monitoring Wells

The Utah DNR DWR has established Administrative Rules for Water Well Drillers, UAC R655-4, which applies to wells equal to or greater than 30 feet total depth below the natural ground surface. Rule R655-4 is located at: **http://www.rules.utah.gov/publicat/code/r655/r655-004.htm**. UAC R655-4-11 describes the requirements for monitoring well installation. In general wells drilled to 30 feet or greater in depth must be drilled by a currently licensed water well driller, prevent cross-contamination, and prevent infiltration of surface water into the subsurface. There are no specific regulations that govern wells less than 30 feet total depth; however, it is good practice to follow the techniques in the Water Well Rules as a guideline for drilling and abandonment.

To gain approval for a monitoring well from the State Engineer, the owner or applicant must submit a request for non-production well construction for wells deeper than 30 feet. The request form is located on the Utah Division of Water Rights website at: **http://www.waterrights.utah.gov/wrinfo/forms**. The form details the location, wells planned, well construction, and the name of the well driller. After the State Engineer assigns an authorization number, the driller will submit a start card indicating the intention to drill wells. Specific requirements for monitoring well construction are listed in UAC R655-4-11.

Wells to depths of 30 feet or greater below grade also must be abandoned in accordance with UAC R655-4-12 under the direct supervision of a licensed well driller. The intention of this requirement is to prevent the annular space surround the well casing from becoming a conduit

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for possible contamination of the [potential] groundwater supply. It is desirable to remove the well casing during well abandonment, and to place impermeable well abandonment materials progressively upward from the bottom of the well during casing removal. Wells shall be sealed with cement grout, neat cement, bentonite products, concrete, or clay slurry, and the screened interval of wells shall be pressure grouted.

9.3.2 Underground Injection Control

The Underground Injection Control (UIC) Program for Class I, III, IV, and V injection wells is administered by the Utah Division of Water Quality. The UIC Program is responsible for protecting underground sources of drinking water (USDWs)[1] by prohibiting underground injections that would allow movement of fluid containing any contaminant into a USDW if the presence of that contaminant may cause a violation of any primary drinking water regulation (40 CFR Part 141) and Utah Primary Drinking Water Standards R309-200-5), or which may adversely affect the health of persons, or may cause a violation of any ground water quality rule (R317-6).

Aquifer Remediation-Related Wells are a subclass (5X26) of Class V injection wells used to prevent, control, or remediate contamination in permeable materials of the subsurface environment that contain or are capable of containing ground water.[2] The UIC Program grants authorization-by-rule (ABR) status to Aquifer Remediation-Related Wells provided certain conditions are met. Owners/operators of all Class V injection wells must submit inventory information (R317-7-6.4(C)) before injection occurs. Injection associated with an aquifer remediation project must be limited and controlled such that the injection does not cause the exceedance of MCLs outside the zone of active remediation. Injection of hazardous waste is not permitted. Injection of hazardous waste into or above a formation that within a 2-mile radius of the well contains a USDW is considered a Class IV injection activity and is banned unless it is being conducted under the authority of CERCLA and certain qualifying criteria are met.

Information on the UIC program and a copy of the UIC Inventory Information Form can be found at the following website: http://www.waterquality.utah.gov/UIC/index.htm.

[1] As defined in UAC R317-7-2.57 and 40CFR144.3;An Underground Source of Drinking Water (USDW) means an aquifer or its portion:
- (a) (1) Which supplies any public water system; or
  - (2) Which contains a sufficient quantity of ground water to supply a public water system; and
    - (i) Currently supplies drinking water for human consumption; or
    - (ii) Containsc fewer than 10,000 mg/l total dissolved solids; and
- (b) Which is not an exempted aquifer.

[2] Report to Congress: Class V Injection Wells; Current Inventory; Effects on Ground Water; Technical Recommendations; EPA 570/9-87-006; September 1987; p 4-334.

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9.4 DISPOSAL OF CONTAMINATED/TREATED GROUNDWATER TO THE SANITARY SEWER (POTW)

An owner/operator may plan to dispose of water from a LUST site waste water treatment system to a sanitary sewer. A discharge permit from the DWQ must be obtained if the municipality or sewer district does not have a state-approved pre-treatment program or authority to use its own permits. Requirements imposed by publicly owned treatment works (POTW) are site- and sewer-district-specific for pretreatment and discharge concentration limits of petroleum-impacted groundwater. Waste waters discharged to the sanitary sewer are subject to compliance with "The Water Quality Act of 1987," all applicable Federal General Pretreatment Regulations (40 CFR 403), State Pretreatment Requirements (UAC R317-8-8), and any local discharge limitations developed by the POTW.

The local sanitary sewer district must be contacted before any treated or untreated waters are discharged to the sanitary sewer. The lead time needed to obtain approval for discharge to a sanitary sewer will be dependent upon the local jurisdiction and its respective approval process. Documentation of the notification and any permits or approvals obtained must be submitted to the DERR.

9.5 STORM DRAIN AND RECEIVING STREAM DISCHARGE REGULATIONS (UPDES PERMITS)

If an owner/operator of a LUST site knows that groundwater has been impacted by petroleum LNAPL or dissolved product, or that surface waters have been contaminated, the Department of Water Quality (DWQ) must be notified immediately.

Any required discharge permits, such as the Utah Pollution Discharge Elimination System (UPDES) permit, must be obtained prior to initiating corrective action or abatement measures that involve the discharge of pollutants from any point source into waters of the State. "Waters of the State" means all streams, lakes, ponds, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, storm sewers, and all other bodies or accumulations or water, surface and underground, natural or artificial, public or private, which are contained within, flow through, or border upon this State or any portion thereof. Some exceptions apply. UPDES rules and regulations are found in UAC R317-8.

The General Permit for Discharge of Treated Groundwater, General Permit No. UTG790000, was established under UAC R317-8-2.5 to standardize, streamline, and expedite the permitting process for the numerous discharges statewide of treated groundwater contaminated with petroleum products from LUST sites. The April 2005 revision of the General Permit, which allows for additional site-specific requirements for compliance, can be obtained from DWQ. The DWQ's website has contact information and some permit forms online at: **http://www.waterquality.utah.gov**.

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To be eligible for coverage under the General Permit, an applicant must file a Notice of Intent [to discharge] application. The current requirements include the traditional parameters of BTEX, naphthalene (if diesel fuel), pH, oil and grease, possibly total lead, total suspended solids, total toxic organics (TTO), and biomonitoring (fish toxicity), which reflect typical concerns with petroleum products.

If other compounds are identified in the TTO analyses, the General Permit will be amended with site-specific requirements after 1) DWQ has conducted a waste load analysis, and 2) the applicant demonstrates the ability to treat groundwater to the prescribed concentrations. Based upon the TTO analyses, DWQ will perform waste load analysis using concentration data for the additional detected compounds of concern, such as MTBE or tetrachloroethylene. The waste load analysis considers the specific receiving stream and its sensitivity to pollutants. DWQ will establish discharge concentration limits for the additional detected compounds of concern. Once the applicant demonstrates that the Best Available Control Technology (BACT) will achieve the prescribed limits, the General Permit application can be approved.

Upon approval, groundwater treatment may involve separation of LNAPL using an oil/water separator, air stripping, treating the water with granular activated carbon, and/or some other acceptable technology.

Discharge compliance with the General Permit requires on-going monitoring of water quality. The details of the monitoring schedule for petroleum contamination only are listed in the *Statement of Basis for the General UST Permit* (2000).

The UPDES fee is $1,800 for a General Permit and can be prorated over the project duration up to a maximum of 5 years.

9.5.1 Local Construction Permits and Notifications

Facilities treating waste water may need construction permits, unless they discharge into a municipal sanitary sewer system. Such construction permits may require as much as 60 days to 6 months for approval, and do not expire. Also, construction for excavation, *e.g.*, as with installation of a remediation system, may require a local construction permit. In general the public safety must be protected during construction and excavation work, and surface conditions must be restored after the construction activity. Local permits may require an inspection by the local official. Each local jurisdiction will have specific requirements for paying fees, posting bonds, controlling traffic, and obtaining and complying with construction permits.

During preparation of the Closure Plan, the owner/operator must notify the local health and fire departments. In addition, they and DERR must be notified at least 72 hours prior to starting closure activities.

Additionally, the owner/operator is responsible for notifying and obtaining approval from the DERR, the DAQ, and local health and fire departments prior to treatment of petroleum-contaminated soils from LUST sites. If any free product is to be stored on-site, the local fire department must be notified.

9.6 AIR PERMITS AND APPROVALS

The UDEQ Division of Air Quality (DAQ) must be notified prior to any release of petroleum vapors from free product removal or soil or groundwater treatment, so a determination can be made as to whether or not an air permit is required. Documentation of the notification and any permits or approvals obtained must be submitted to the DERR.

DAQ requirements are contained in UAC R307-401-15, *De minimis Emissions from Air Strippers and Soil Venting Projects*, and in UAC R307-401-16, *De minimis emissions from Soil Aeration Projects*. The requirements for a Permit, including a Notice of Intent (NOI) and Approval Order are listed in UAC R307-401. UAC R307-401 can be found at: http://www.rules.utah.gov/publicat/code.htm. A copy of Form 16 for Soil/Groundwater Hydrocarbon Remediation can be found on DAQ's website at: **http://www.airquality.utah.gov/Permits/Permitting_Forms.htm#NewSourceReview**.

An owner or operator of an air stripper or soil venting system will not be required to obtain an approval order under R307-401 to conduct remediation of contaminated groundwater or soil, if the owner or operator submits written documentation of the following to the DAQ prior to beginning the remediation project:

(a) the estimated total air emissions of volatile organic compounds from a given project are less than the de minimis emissions listed in UAC R307-401-9(1)(c), and

(b) the level of any one hazardous air pollutant or any combination of hazardous air pollutants is below the levels listed in UAC R307-410-4(1)(d).

After beginning the soil remediation project, the owner or operator shall submit emissions information to the DAQ to verify that the emission rates of the volatile organic compounds and hazardous air pollutants in (1) are not exceeded. Emissions estimates of volatile organic compounds and hazardous air pollutants shall be based on test data obtained in accordance with the test method in the EPA document SW-846, Method 8020 or Method 8021 or other test or monitoring method approved by the DAQ. Results of the test and calculated annual quantity of emissions of volatile organic compounds and hazardous air pollutants shall be submitted to the DAQ within one month of sampling. The test samples shall be drawn on intervals of no less than 28 days and no more than 31 days (*i.e.*, monthly) for the first quarter, quarterly for the first year, and semi-annually thereafter or as determined necessary by the DAQ.

The following control devices do not require an approval order under UAC R307-401 when used in relation to an air stripper or soil venting project applicable to this rule:

(a) thermodestruction unit with a rated input capacity of less than 5 million British thermal units (BTU) per hour using no other auxiliary fuel than natural gas or liquefied petroleum gas (LPG), or
(b) carbon adsorption unit.

9.7 SOIL AERATION

An owner or operator of a soil remediation project is not required to obtain an approval order from the DAQ under UAC R307-401 when soil aeration is used to conduct a soil remediation, if the owner or operator submits written documentation of the following to the DAQ prior to beginning the remediation project:

(1) the estimated total air emissions of volatile organic compounds, using an appropriate sampling method, from a given project are less than the de minimis emissions listed in UAC R307-401-9(1)(c);

(2) the levels of any one hazardous air pollutant or any combination of hazardous air pollutants are less than the levels in UAC R307-410-4(1)(d); and

(3) the location of the remediation and where the remediated material originated.

An owner/operator of a soil aeration project must follow the DERR "Guidelines for the Disposition and Treatment of Petroleum Contaminated Soils from Underground Storage Tank Sites." A copy of the guidelines can be found on the DERR's website at: **http://www.undergroundtanks.utah.gov/remediation.htm**.

9.8 CONTAMINATED SOIL AND WATER DISPOSAL FACILITIES AND TRANSPORTERS

Table 9-1 is included to list known disposal facilities and waste transporters in the Utah region. The list shows the materials accepted by each of the facilities. This list is intended to be a guide. Specific requirements for each facility or transporter should be verified by the waste generator and UST Consultant, such as certain waste restrictions and analytical needs.

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Table 9-1 Utah Disposal Facilities and Transporters

Facility Information	Services Available
AET Environmental 3653 South 700 West, Unit B Salt Lake City, Utah 84119 801-281-3507 http://aetenvironmental.com	• Disposal of petroleum contaminated soil and water, tank rinsate, used oil, activated carbon, and hazardous waste • Transportation • Landfill
E.T. Technologies, Inc. 6030 West California Avenue Salt Lake City, Utah 84104 801-973-2065	• Disposal of petroleum contaminated soil and activated carbon • Transportation • Landfarm
Pacific West 1515 West 2200 South, Suite C Salt Lake City, Utah 84119 801-972-2727	• Disposal of petroleum contaminated soil • Transportation
Ashland Chemical Environmental Services P.O. Box 160367 Clearfield, Utah 84016 800-637-7922 http://ashland.com/	• Disposal of petroleum contaminated soil and water, tank rinsate, used oil, activated carbon, and hazardous waste • Transportation • Landfill
Clean Harbors Grassy Mountain 801-323-8900 http://www.cleanharbors.com/	• Disposal of petroleum contaminated soil, activated carbon, and hazardous waste • Transportation • Landfill
Clean Harbors Aragonite Facility 801-323-8100 http://www.cleanharbors.com/	• Disposal of petroleum contaminated soil and water, tank rinsate, used oil, activated carbon, and hazardous waste • Transportation
ECDC Environmental, L.C. 1111 West Highway 123 P.O. Box 69 East Carbon, Utah 84520 800-444-4451	• Disposal of petroleum contaminated soil and water, tank rinsate, used oil, and activated carbon • Transportation • Landfill
V.J. Environmental 155 North 500 West Salt Lake City, Utah 84116 801-595-8151	• Disposal of petroleum contaminated water, tank rinsate, and used oil • Transportation
National Tank and Monitoring 4152 West 8370 South West Jordan, Utah 84088 801-280-3324 http://www.nationaltank.com/	• Disposal of petroleum contaminated soil and water, and tank rinsate • Transportation
Thermo Fluids, Inc 3545 West 500 South Salt Lake City, Utah 84104 801-296-6611 http://www.thermofluids.com/	• Disposal of petroleum contaminated soil and water, tank rinsate, and used oil • Transportation
Emerald Services 2450 South 800 West Salt Lake City, Utah 84119 801-973-4131 http://www.emeraldnw.com/	• Disposal of petroleum contaminated soil and water, tank rinsate, and used oil • Transportation

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9.9 LANDFILLS

Excavated soil with petroleum contamination can be transported to a local landfill in most instances for use as daily cover. Local landfill disposal usually requires little to no analytical documentation. Specific requirements for each landfill should be verified by the waste generator and UST Consultant.

A list of active landfills can be found on the Division of Solid and Hazardous Waste's website at: **http://www.hazardouswaste.utah.gov/SWBranch/SWSection/SolidWasteSection.htm**.

9.10 E.T. TECHNOLOGIES, INC.

One alternative to a city or county landfill (Table 9-1) is E.T. Technologies, Inc. (ET) Soils Regeneration Site in Salt Lake City, Utah. ET is a nonhazardous waste, bioremediation landfarm located adjacent to the Salt Lake County Landfill. ET uses a soil and waste blending ratio based on Federal regulations, biodegradation, and plant toxicity factors. With the proper profile data, the ET facility can accept petroleum wastes including soil and water from LUST sites. The Class 7 nonhazardous waste profile form, the nonhazardous waste manifest, and the list analytical requirements can be obtained by contacting ET. The processed soil is used as daily cover, final cover, and topsoil in the operations at the Salt Lake County Landfill.

9.11 ABOVEGROUND STORAGE TANKS

The DERR has traditionally regulated only petroleum USTs. In 1996 the DERR and DWQ formally recognized the similarity of managing petroleum releases from USTs and aboveground storage tanks (ASTs). DERR and DWQ entered into an agreement to clarify their respective roles and to streamline the administration of petroleum releases from ASTs. The following Memo of Understanding describes the process developed to standardize the evaluation criteria for oversight.

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MEMORANDUM OF UNDERSTANDING BETWEEN THE DIVISION OF WATER QUALITY AND THE DIVISION OF ENVIRONMENTAL RESPONSE AND REMEDIATION REGARDING PETROLEUM PRODUCT RELEASES TO THE ENVIRONMENT FROM SOURCES OTHER THAN LEAKING UNDERGROUND STORAGE TANKS

9.12 INTRODUCTION

The Division of Environmental Response and Remediation (DERR) and the Division of Water Quality (DWQ) have specific regulatory responsibilities pertaining to petroleum releases that impact or may potentially impact ground water. The DERR has responsibility for all activities involving petroleum releases from "regulated" leaking underground storage tanks through the Leaking Underground Storage Tank (LUST) program. The DWQ through its Ground Water Quality Protection program has responsibility for releases of petroleum products from facilities that impact or have the potential to impact ground water whether or not these facilities are regulated by DERR. Historically, the DWQ has assumed most of the regulatory responsibility for petroleum releases that impact ground water when the source of the contamination is not regulated by another agency.

The purpose of this Memorandum of Understanding (MOU) is to establish a framework of policy and procedure by which the LUST program can assume regulatory oversite for petroleum releases from underground heating oil tanks and above ground storage tanks (ASTs). This MOU will make more efficient use of Department resources by consolidating and clarifying the roles of each Division to facilitate the effective evaluation and remediation of petroleum releases. A further purpose of this agreement is to simplify the regulatory framework for the regulated community, and to ensure that releases of petroleum from LUST's, underground heating oil tanks and AST's can be evaluated and subject to the same standards and procedures.

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9.13 POLICY

WE THE UNDERSIGNED DO HEREBY AGREE TO THE FOLLOWING POLICIES:

A. The DERR LUST program will assume regulatory oversite of all reported petroleum releases from underground heating oil tanks and ASTs (not regulated by other agencies) and other petroleum releases that present a direct and immediate threat to public health or the environment.

B. The DWQ will assume regulatory oversite of all other reported petroleum releases, including other underground storage tanks not regulated by the DERR LUST program.

C. The DERR will be responsible for receiving all reports of petroleum releases. The DERR will complete a Release Report (attachment A) and evaluate the reported information to determine the source of the release.

1. If the source of the petroleum release is not from a LUST, underground heating oil tank, or AST, the DERR will transfer the Release Report to the DWQ's Groundwater Protection Section Manager. The DWQ will then provide regulatory oversite of the release, using their existing regulations and procedures.

2. When a petroleum release affects or has the potential to affect waters of the State and presents a direct and immediate threat to public health or the environment, the DERR will notify the DWQ of the release and coordinate activities, as necessary. The DWQ and DERR will make an immediate decision as to the most effective method to regulate the release and abate the emergency.

3. The DERR will provide regulatory oversight of investigations and remediation of petroleum releases from underground heating oil tanks and AST's. The DERR will use LUST existing policies, guidelines, standards and procedures when providing oversight activities. The facility owner will be sent an initial letter by the DERR's LUST program indicating LUST requirements which have been interpreted by the Executive Secretary of the Water Quality Board to meet the intent of the Water Quality Act and the Ground Water Quality Protection Regulations. If at any time during the oversight process an owner of an underground heating oil tank release or AST release does not comply with the LUST requirements, the case file will be transferred to the DWQ for possible compliance actions.

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4. If the DWQ receives a report of a petroleum release from a regulated LUST, underground heating oil tank, or AST, a Release Report will be completed by the DWQ and transferred to the DERR LUST Remedial Assistance Section Manager.

D. The DWQ will continue to manage petroleum releases that have the potential to impact ground water from other sources such as tanker trucks, railroad tankers, and transportation pipelines. The DWQ will utilize and apply cleanup criteria pertaining to petroleum releases that are developed and utilized by the DERR LUST program.

E. All underground heating oil tank releases or AST releases currently being managed by the DWQ will continue to be managed by the DWQ until the sites meet DWQ's applicable closure criteria.

Effective: December 11, 2000

Brad T Johnson, Director
Division of Environmental Response and Remediation

Walter L. Baker, Director
Division of Water Quality

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