EPA/625/R-02/002
January 2002

Technical Approaches to Characterizing and Redeveloping Brownfields Sites:

Municipal Landfills and Illegal Dumps

Site Profile

Technology Transfer and Support Division
National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

Notice

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described here under Contract No. 68-C7-0011 to Science Applications International Corporation (SAIC). It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems, remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director

Acknowledgments

This document was prepared by Science Applications International Corporation (SAIC) for the U.S. Environmental Protection Agency's National Risk Management Research Laboratory Technology Transfer and Support Division (TTSD) in the Office of Research and Development. Susan Schock of TTSD served as Work Assignment Manager. Tena Meadows O'Rear served as SAIC's Project Manager. Participating in this effort were Arvin Wu, Joel Wolf, and Karyn Sper. Reviewers of this document include Eletha Brady-Roberts - NCEA Cincinnati, Emery Bayley - ECOSS Seattle, Washington, Jan Brodmerkl of the Army Corps of Engineers, Alison Benjamin - Southwest Detroit Environmental Vision, Michigan., and Association of State and Territorial Solid Waste Mangerment Officials (ASTSWMO).

Appreciation is given to EPA's Office of Special Programs for guidance on the Brownfields Initiative.

Contents

Chapter 1
Introduction

Purpose

EPA has developed a set of technical guides, including this document, to assist communities, states, municipalities, and the private sector to better address brownfields sites. Currently, these three guides in the series are available:

- *Technical Approaches to Characterizing and Cleaning up Iron and Steel Mill Sites under the Brownfields Initiative*, EPA/625/R-98/007, December 1998.
- *Technical Approaches to Characterizing and Cleaning up Automotive Repair Sites under the Brownfields Initiative*, EPA/625/R-98/008, December 1999.
- *Technical Approaches to Characterizing and Cleaning Metal Finishing Sites under the Brownfields Initiative*, EPA/625/R-98/006, December, 1999.

A supplementary guide contains information on cost-estimating tools and resources for brownfields sites (*Cost Estimating Tools and Resources for Addressing Sites Under the Brownfields Initiative*, EPA/625/R-99-001, January 1999).

EPA has since developed a general guide to provide decision-makers, such as city planners, private sector developers, and others, with a better understanding of the common technical issues involved in assessing and cleaning up brownfield sites.[1] The general guide will be supplemented with site specific profiles that provide further information on specific types of brownfields sites. An understanding of key industrial processes once used at a brownfields site can help the planner identify likely areas of contamination and management approaches. This overview also points to information sources on specific processes or technologies.

The purpose of this guide is to provide decision-makers with:

- An background understanding of common industrial processes formerly used at this type of brownfields site and the general relationship between such processes and potential releases of contaminants to the environment.

- Information on the types of contaminants likely to be present at landfill and illegal dump brownfields sites.

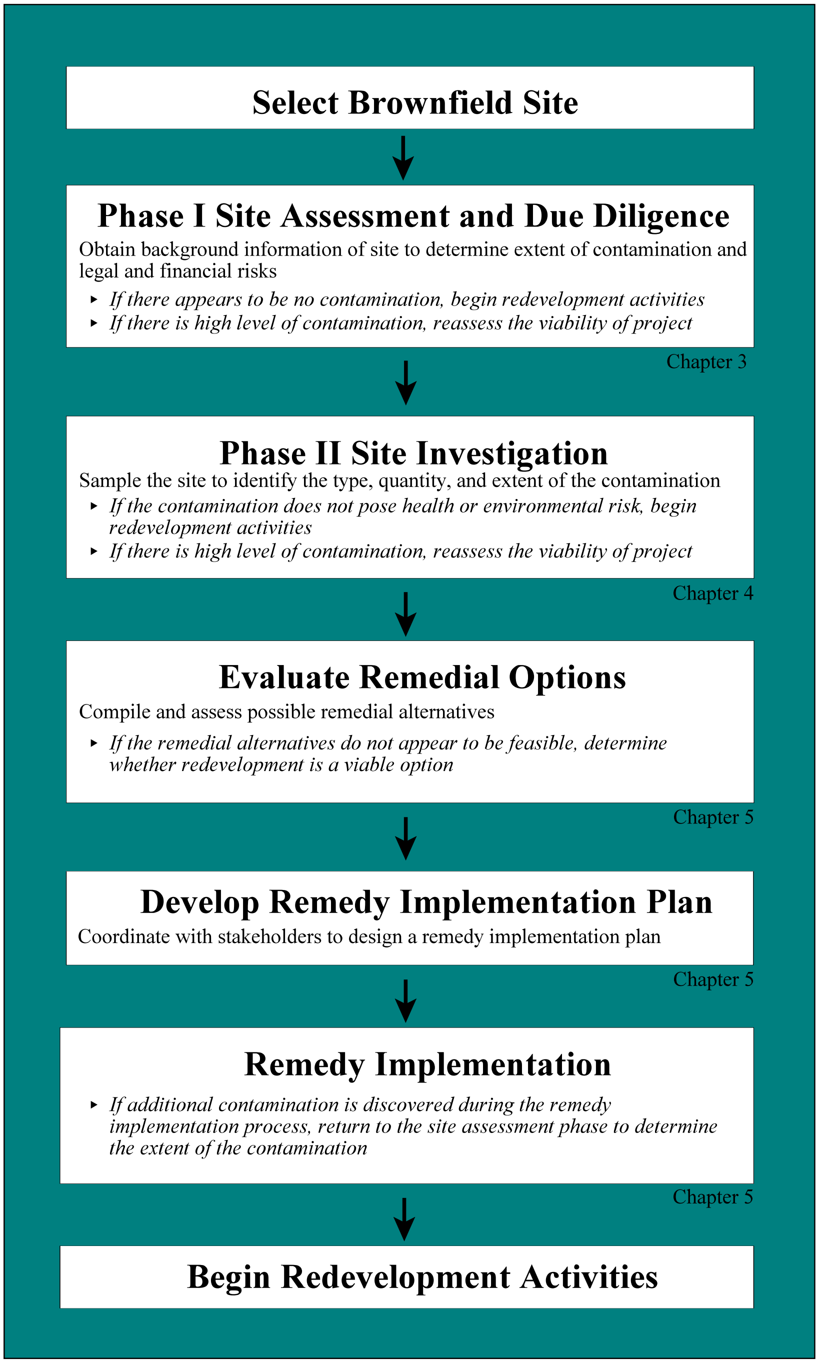
- A discussion of the common steps involved in brownfields redevelopment: Phase I site assessment, due diligence, Phase II site investigation, remedial alternative evaluation, remedy implementation plan development, and remedy implementation.

Background

Many communities across the country have brownfields sites, which the U.S. Environmental Protection Agency (EPA) defines as abandoned, idle, and under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination. Concerns about liability, cost, and potential health risks associated with brownfields sites may prompt businesses to migrate to "greenfields" outside the city. Left behind are communities burdened with environmental contamination, declining property values, and increased unemployment.

---

[1] Because parts of this document are technical in nature, planners may want to refer to additional EPA guides for further information. *The Tool Kit of Technology Information Resources for Brownfields Sites*, published by EPA's Technology Innovation Office (TIO), contains a comprehensive list of relevant technical guidance documents (available from NTIS, No. PB97144828). EPA's *Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup*, also by EPA's TIO, provides an introduction to site assessment and cleanup (EPA Order No. EPA/542/B-97/002).



Select Brownfield Site

Phase I Site Assessment and Due Diligence

Obtain background information of site to determine extent of contamination and legal and financial risks

- *If there appears to be no contamination, begin redevelopment activities*
- *If there is high level of contamination, reassess the viability of project*

Chapter 3

Phase II Site Investigation

Sample the site to identify the type, quantity, and extent of the contamination

- *If the contamination does not pose health or environmental risk, begin redevelopment activities*
- *If there is high level of contamination, reassess the viability of project*

Chapter 4

Evaluate Remedial Options

Compile and assess possible remedial alternatives

- *If the remedial alternatives do not appear to be feasible, determine whether redevelopment is a viable option*

Chapter 5

Develop Remedy Implementation Plan

Coordinate with stakeholders to design a remedy implementation plan

Chapter 5

Remedy Implementation

- *If additional contamination is discovered during the remedy implementation process, return to the site assessment phase to determine the extent of the contamination*

Chapter 5

Begin Redevelopment Activities

Exhibit 1-1. Flow Chart of the Brownfields Redevelopment Process

The EPA established the Brownfields Economic Redevelopment Initiative to enable states, site planners, and other community stakeholders to work together in a timely manner to prevent, assess, safely clean up, and sustainably reuse brownfields sites.

The cornerstone of EPA's Brownfields Initiative is the Brownfields Pilot Program. Under this program, EPA has funded more than 200 brownfields assessment pilot projects in states, cities, towns, counties, and tribal lands across the country. The pilots, each funded at up to $200,000 over two years, are bringing together community groups, investors, lenders, developers, and other affected parties to address the issues associated with assessing and cleaning up contaminated brownfields sites and returning them to appropriate, productive use. In addition to the hundreds of brownfields sites being addressed by these pilots, many states have established voluntary cleanup programs to encourage municipalities and private sector organizations to assess, clean up, and redevelop brownfields sites.

Typical Brownfield Redevelopment Process

The typical brownfields redevelopment process begins with a Phase I site assessment and due diligence, as shown in Exhibit 1-1. The site assessment and due diligence process provides an initial screening to determine the extent of the contamination and possible legal and financial risks. If the site assessment and due diligence process reveals no apparent contamination and no significant health or environmental risks, redevelopment activities may begin immediately. If the site seems to contain unacceptably high levels of contamination, a reassessment of the project's viability may be appropriate.

A Phase II site investigation samples the site to provide a comprehensive understanding of the contamination. If this investigation reveals no significant sources of contamination, redevelopment activities may commence. Again, if the sampling reveals unacceptably high levels of contamination, the viability of the project should be reassessed. Should the Phase II site investigation reveal a manageable level of contamination, the next step is to evaluate possible remedial alternatives. If no feasible remedial alternatives are found, the project viability would have to be reassessed. Otherwise, the next step would be to select an appropriate remedy and develop a remedy implementation plan. Following remedy implementation, if additional contamination is discovered, the entire process is repeated.

This document is organized as follows:

- Chapter 2 – Municipal Landfills and Illegal Dumps
- Chapter 3 – Phase I Site Assessment and Due Diligence
- Chapter 4 – Phase II Site Investigation
- Chapter 5 – Contaminant Management
- Chapter 6 – Conclusion
- Appendix A – Acronyms
- Appendix B – Glossary
- Appendix C – Testing Technologies
- Appendix D – Cleanup Technologies
- Appendix E – Works Cited

Chapter 2
Municipal Landfills & Illegal Dumps

Introduction

By definition, a municipal solid waste landfill is a discrete area of land or an excavation that receives household waste, and that is not a land application unit, surface impoundment, injection well, or waste pile, as those terms are defined in law. Household waste includes any solid waste, including garbage, trash, and septic tank waste, derived from houses, apartments, hotels, motels, campgrounds, and picnic grounds. Subtitle D of RCRA defines other types of wastes a municipal solid waste landfill may accept, such as commercial solid waste, nonhazardous sludge, small quantity generator waste, and industrial solid waste. (EPA ,1993)

Landfills come in all shapes and sizes and can impact the environment in many different ways. Some dump sites may be as small as a few barrels of waste oil, while the largest industrial waste landfill may cover 100 acres or more. The range of effects that dump sites and landfills can manifest upon the environment are just as diverse as the various forms the sites may take. This chapter will frequently characterize solid waste contaminated brownfields and outline typical remediation strategies that can be used to redevelop these sites.

Landfills and Open Dumps in America

The modern day American landfill was preceded by the open and unregulated town dump. In these dumps wastes were left uncovered and untreated, leaving the refuse open to the full effects of the elements. Often, neither the existence nor the use of the dump was authorized, and there was no supervision. There was little or no effort made to compact or cover the waste and no regard was given to pollution control measures or aesthetics. Frequently, these open dumps were also burning dumps. Fire could occur spontaneously, but more often, the fire was purposely set in an attempt to reduce the volume at a dump or destroy the food that attracts rodents and insects. The most common air pollution resulting from burning dumps was highly visible clouds of particulate matter and incompletely burned gases, as well as the smell of smoldering garbage (EPA, 1971).

Sanitary landfills began to emerge in the 1930s with systematic deposition, compaction, and burial of refuse, but open dumps still persisted into the 1960s and 1970s (US Army, 1978). The primary difference between a dump and a sanitary landfill was that a sanitary landfill was covered with several inches of soil every evening. The purpose of the soil was to reduce odors and reduce the access of vermin to the waste. It was not until 1993 and Subtitle D of the Resource Conservation and Recovery Act (RCRA) that there were federal regulations governing the construction and operation of sanitary landfills.

Cape Charles, Virginia
A Brownfields Success Story:

Cape Charles' Sustainable Technology Park Authority in conjunction with a grant from EPA's Brownfield Assessment Pilot assessed an abandoned 25-acre town dump in the middle of a planned eco-industrial park in the heart of Cape Charles. The overall site will contain a conference and training center. Two businesses are locating on the site: Energy to Recovery, a research and development company that plans to hire 50 local residents and Solar Building Systems, Inc., a company that assembles solar panels and has already hired 30 local residents. One half of the land is natural habitat and will eventually have walkways and trails.

In the example just given, and in many other examples from Brownfields Pilot sites, it has been shown that the redevelopment of a dump site can be very positive for the community. The developer must consider however, the variety of situations which may be encountered when such a site is under redevelopment. Il

Landfill and Dump Site Characteristics

There are two major sources of contaminants in municipal landfills and dumpsites; leachate and landfill gas (LFG). Each is composed of different contaminants and each poses its own set of management burdens for the development of a brownfield. Taken together, they can affect the soils, ground and surface waters, and air in and around the sites of the landfills, many times years after the landfill has been closed. In addition to these, there are buried materials which may also contribute to contamination.

Leachate

Leachate is the liquid that results from rain, snow, dew, and natural moisture which percolates through the waste in a landfill or dump. While migrating through the waste, the liquid dissolves salts, picks up organic constituents, and leaches heavy metals, such as iron, mercury, lead, and zinc from cans, batteries, paints, pesticides, cleaning fluids, and inks. The organic strength of landfill leachate can be greater than 20 to 100 times the strength of raw sewage. This “landfill liquor” is potentially a potent polluter of soil and groundwater. The majority of open dumps and old sanitary landfills do not have liners or proper drainage systems to divert the leachate. Both pose the problem that the leached material could be absorbed into the ground and then possibly move into groundwater, surface water, or aquifer systems. (Heimlich, Undated)

A 1977 EPA study looked at three municipal landfill sites to determine the effects of the disposal facilities on surrounding soils and groundwater. Groundwater samples from up and down the groundwater flow gradient and below the landfill were taken. At all three of the sites, changes in chemical composition of the groundwater could be related to the position of the borings with respect to the landfill. Water quality below and down the groundwater flow gradients from the landfills showed elevated nitrate, total organic carbon, and cyanide levels. The percolation of the leachate did not alter the permeability of the soil beneath the refuse, nor was there evidence that the sub-landfill soils sealed themselves. Borings directly below the landfill showed decreasing constituents as sample depth increased; therefore, the source of the contamination may be the refuse and leachate from the landfill.

Landfill Gases

Methane (CH_4) is the principal gas produced from the decomposition of the organic solid waste (about 50% by volume) with carbon dioxide, nitrogen, andoxygen, and “non-methane organic compounds” (NMOCs) making up the remainder. (Ewall, 1999) Landfill gases are released either by aerobic and anaerobic decomposition of refuse or by the volatilization of existing compounds.

Initially, there is a high percentage of carbon dioxide as a result of aerobic decomposition. Aerobic decomposition continues to occur until the oxygen in the air initially present in the compacted waste is depleted. From that point on, anaerobic decomposition will occur.

Methane emissions result from the anaerobic decomposition of organic landfill materials such as yard waste, household garbage, food waste, and paper. Landfills are the largest anthropogenic source of methane, and municipal solid waste landfills account for approximately 93 percent of total landfill emissions. (EPA 1999) Methane production typically begins one or two years after waste placement in a landfill and may last from ten to sixty years. Explosions and fires at old dumps and landfills are often the result of methane build-up at a building on or adjacent to the landfill property. (Heimlich, Undated) In many cases, the use of landfill gas as an energy source is not economically feasible because of the low quality of the methane gas and its rate of production when compared with natural pipeline gas. (Lee and Jones-Lee, Undated)

The "landfill smell" that many people recognize from older dump sites is the result of landfill gases. Emissions of potentially carcinogenic organic chemicals have been detected from landfills. Benzene and vinyl chloride have been detected at landfills sites in California, Wisconsin, and New Jersey. Problems in sampling procedures make it difficult to determine if there is evidence of migration of the VOCs off-site into the ambient air. (Tchobanoglous et al, 1977)

Landfill and Dump Site Remediation Strategies

Site Investigation

The first step in any successful brownfield remediation is an accurate assessment of the character and scope of the problem. The following technologies are ones typically used to assess the state of contamination in and around landfills and dump sites:

- **Direct Push and Drilling Techniques**

  This sampling technique involves the use of drills and hydraulic presses to remove core samples of soil in and around landfills and dump sites. These samples are then brought to off-site laboratories for analysis. Labs can test for the presence of contaminants in the soil. This technique, whereby soil is analyzed off-site rather than on, provides much greater accuracy and provides managers with much more accurate information on the extent of site contamination.

- **Groundwater Sampling**

  Groundwater sampling is a very important aspect of the initial site investigation. The large majority of compliance and pollution problems associated with landfill brownfields have to do with contaminated groundwater. Contaminated groundwater is an especially dangerous problem in rural areas where most people rely on wells for their drinking water. Site managers should plan on carrying out extensive groundwater sampling before any development can commence.

- **Fugitive Gas Sampling**

  This investigative technique involves the use of gas sampling devices to determine the volume and type of landfill gas emissions at potential brownfields. This is very important for sites where building of any significance is to take place, as fugitive gas emissions are most dangerous in situations where the former landfill will be disturbed by excavation.

Site Remediation

Remediation of former landfill sites is somewhat different from remediation at other contaminated brownfields. For one, landfills differ from other brownfields in the sheer volume of contamination. No other brownfield has as much TOTAL contamination as a former landfill does, whether measured by volume or area. Also, site contamination is almost always spread throughout the entire site and cannot be remediated economically with most treatment technologies (i.e., you cannot possibly treat all of the contaminated soil at a municipal landfill). The final remediation strategy for a site will depend mostly then on the size of the landfill or dump site and the costs of the proposed remediation strategies.

- **Landfill Capping**

  Landfill capping is by far the most common method of site remediation. There are many types of landfill caps on the market, ranging from the ultra-sophisticated, ultra-expensive to the simplest coverings of plastic and canvas. Landfill caps are designed to do just what their name says, they 'cap' the landfill so that contaminants contained within are not released into the environment. They are most effective when the landfill or dump site in question has a viable bedliner that is still functioning and where most of the waste is above the water table.(CPEO, 2000) In these situations, a cap functions to keep water from entering the waste matrix, thus reducing leachate contamination. Caps usually are formed of a combination of compacted clay and soil in combination with a semi-permeable membrane (either plastic or some other composite). The most sophisticated caps are called RCRA "C" or "D" caps, but caps of all types can be created by contractors with the unique needs of each site in mind. It is estimated that C-type caps cost around 175 thousand dollars per acre while D-type caps cost as much as 225 thousand dollars per acre. (FRTR, 2000)

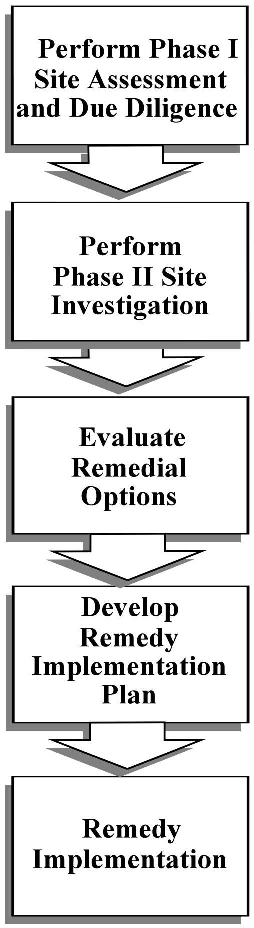
- **Landfill Gas Collection**

This type of pollution control actually evolved as a means to make money off of omnipresent landfill gas. Scientists learned early on that LFG was over 50% methane, the main component of natural gas. Today, the technology exists to 'harvest' the gas and (after filtering and cleaning it) burn that gas to make electricity. A side effect of this process is that landfill gas that once was released directly into the atmosphere, can now be collected, lessening the environmental and aesthetic impact of the gas.(EREN, 2000) A number of successful electric utilities have already been constructed on retired and active landfills throughout the US. (Ewall, 1999)

Conclusion

Landfills and illegal dump sites pose a significant risk to human and environmental health. Simply based on the number of sites throughout the country, landfills are one of the largest sources of potential pollution in communities of all types. Yet as pressure for new land rises, especially in urban and suburban areas, these landfill 'brownfields' are becoming valuable parcels of land and cost-effective and safe remediation of any contaminants on-site becomes a first priority. This chapter outlines the history of landfills and illegal dump sites, describes probable contaminants associated with these sites, and offers suggestions for successful remediation programs, with the ultimate purpose being to educate developers and community planners on the most important aspects of brownfield redevelopment.

Chapter 3
Site Assessment



Site assessment and due diligence provide initial information regarding the feasibility of a brownfields redevelopment project. A site assessment evaluates the health and environmental risks of a site and the due diligence process examines the legal and financial risks. These two assessments help the planner build a conceptual framework of the site, which will develop into the foundation for the next steps in the redevelopment process.

Site assessment and due diligence are necessary to fully address issues regarding the environmental liabilities associated with property ownership. Several federal and state programs exist to minimize owner liability at brownfields sites and facilitate cleanup and redevelopment. Planners and decision-makers should contact their state environmental or regional EPA office for further information.

The Phase I site assessment is generally performed by an environmental professional. Cost for this service depends upon size and location of the site, and . A site assessment typically identifies:

- Potential contaminants that remain in and around a site;
- Likely pathways that the contaminants may move; and
- Potential risks to the environment and human health that exist along the migration pathways.

Due diligence typically identifies:

- Potential legal and regulatory requirements and risks;
- Preliminary cost estimates for property purchase, engineering, taxation and risk management; and
- Market viability of redevelopment project.

This chapter begins with background information on the role of the EPA and state government in brownfields redevelopment. The remainder of the chapter provides a description of the components of site assessment and the due diligence process.

Role of EPA and State Government

A brownfields redevelopment project is a partnership between planners and decision-makers (both in the private and public sector), state and local officials, and the local community. State environmental agencies are often key decision-makers and a primary source of information for brownfields projects. In most cases, planners and decision-makers need to work closely with state program managers to determine their particular state's requirements for brownfields development. Planners may also need to meet additional federal requirements. While state roles in brownfields programs vary widely, key state functions include:

- Overseeing the brownfields site assessment and cleanup process, including the management of voluntary cleanup programs;
- Providing guidance on contaminant screening levels; and
- Serving as a source of site information, as well as legal and technical guidance.

The EPA works closely with state and local governments to develop state Voluntary Cleanup Programs (VCP) to encourage, assist, and expedite brownfields redevelopment. The purpose of a state VCP is to streamline brownfields redevelopment, reduce transaction costs, and provide liability protection for past contamination. Planners and decision-makers should be aware that state cleanup requirements vary significantly; brownfields managers from state agencies should be able to clarify how their state requirements relate to federal requirements.

EPA encourages all states to have their VCPs approved via a Memorandum of Agreement (MOA), whereby EPA transfers control over a brownfields site to that state (Federal Register 97-23831). Under such an arrangement, the EPA does not anticipate becoming involved with private cleanup efforts that are approved by federally recognized state VCPs (unless the agency determines that a given cleanup poses an imminent and substantial threat to public health, welfare or the environment). EPA may, however, provide states with technical assistance to support state VCP efforts.

To receive federal certification, state VCPs must:

- *Provide for meaningful community involvement.* This requirement is intended to ensure that the public is informed of and, if interested, involved in brownfields planning. While states have discretion regarding how they provide such opportunities, at a minimum they must notify the public of a proposed contaminant management plan by directly contacting local governments and community groups and publishing or airing legal notices in local media.
- *Ensure that voluntary response actions protect human health and the environment.* Examples of ways to determine protectiveness include: conducting site-specific risk assessments to determine background contaminant concentrations; determining maximum contaminant levels for groundwater; and determining the human health risk range for known or suspected carcinogens. Even if the state VCP does not require the state to monitor a site after approving the final voluntary contaminant management plan, the state may still reserve the right to revoke the cleanup certification if there is an unsatisfactory change in the site's use or additional contamination is discovered.

Houston, Texas
A Brownfields Success Story:

Browning Ferris Industries, the site owner, has partnered with EnCap Golf LLC to develop a 450-acre golf course on a former landfill located near the Astrodome. The facility will include two 18-hole golf courses, a full-service clubhouse, a well-equipped practice & training facility, and a pitch & putt area. The new golf course is slated to open for business in late 2000.

Houston Mayor's Office of Environmental Policy. Brownfields Redevelopment Program. www.epa.gov/earth1r6/6sf/pdffiles/houston.pdf

- *Provide resources needed to ensure that voluntary response actions* are conducted in an appropriate and timely manner. State VCPs must have adequate financial, legal, and technical resources to ensure that voluntary cleanups meet these goals. Most state VCPs are intended to be self-sustaining. Generally, state VCPs obtain their funding in one of two ways: planners pay an hourly oversight charge to the state environmental agency, in addition to all cleanup costs; or planners pay an application fee that can be applied against oversight costs.

- *Provide mechanisms for the written approval of voluntary response action plans* and certify the completion of the response in writing for submission to the EPA and the voluntary party.

- *Ensure safe completion of voluntary response actions* through oversight and enforcement of the cleanup process.

- *Oversee the completion of the cleanup and long-term site monitoring*. In the event that the use of the site changes or is found to have additional contamination, states must demonstrate their ability to enforce cleanup efforts via the removal of cleanup certification or other means.

Performing A Phase I Site Assessment

The purpose of a Phase I site assessment is to identify the type, quantity, and extent of potential contamination at a brownfields site. Financial institutions typically require a site assessment prior to lending money to potential property buyers to protect the institution's role as mortgage holder. In addition, parties involved in the transfer, foreclosure, leasing, or marketing of properties recommend some form of site evaluation. A site investigation should include:[2]

- A review of readily available records, such as former site use, building plans, records of any prior contamination events;
- A site visit to observe the areas used for various industrial processes and the condition of the property;
- Interviews with knowledgeable people, such as site owners, operators, and occupants; neighbors; local government officials; and
- A report that includes an assessment of the likelihood that contaminants are present at the site.

A site assessment should be conducted by an environmental professional, and may take three to four weeks to complete. Information on how to review records, conduct site visits and interviews, and develop a report during a site assessment is provided below. Exhibit 3-1 shows a flow chart representing the site assessment process.

Review Records

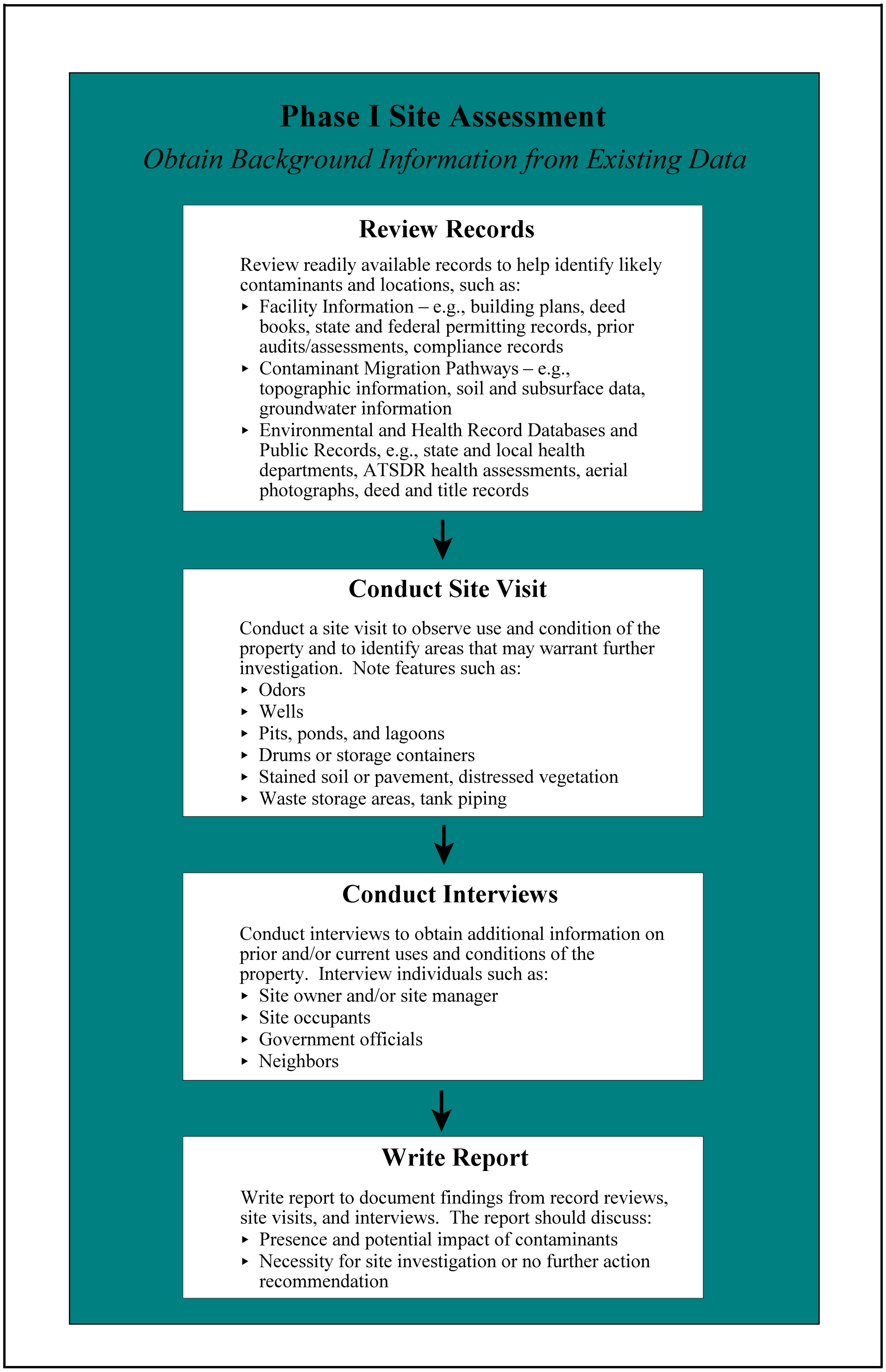
A review of readily available records helps identify likely contaminants and their locations. This review provides a general overview of the brownfields site, likely contaminant pathways, and related health and environmental concerns.

Facility Information

Facility records are often the best source of information on former site activities. If past owners are not initially known, a local records office should have deed books that contain ownership history. Generally, records pertaining specifically to the site in question are adequate for site assessment review purposes. In some cases, however, records of adjacent properties may also need to be reviewed to assess the possibility of contaminants migrating from or to the site, based on geologic or hydrogeologic conditions. If the brownfields property resides in a low-lying area, in close proximity to other industrial facilities or formerly industrialized sites, or downgradient from current or former industrialized sites, an investigation of adjacent properties is warranted.

---

[2] The elements of a site assessment presented here are based in part on ASTM Standards 1527 and 1528.



Phase I Site Assessment

Obtain Background Information from Existing Data

Review Records

Review readily available records to help identify likely contaminants and locations, such as:

- Facility Information – e.g., building plans, deed books, state and federal permitting records, prior audits/assessments, compliance records
- Contaminant Migration Pathways – e.g., topographic information, soil and subsurface data, groundwater information
- Environmental and Health Record Databases and Public Records, e.g., state and local health departments, ATSDR health assessments, aerial photographs, deed and title records

Conduct Site Visit

Conduct a site visit to observe use and condition of the property and to identify areas that may warrant further investigation. Note features such as:

- Odors
- Wells
- Pits, ponds, and lagoons
- Drums or storage containers
- Stained soil or pavement, distressed vegetation
- Waste storage areas, tank piping

Conduct Interviews

Conduct interviews to obtain additional information on prior and/or current uses and conditions of the property. Interview individuals such as:

- Site owner and/or site manager
- Site occupants
- Government officials
- Neighbors

Write Report

Write report to document findings from record reviews, site visits, and interviews. The report should discuss:

- Presence and potential impact of contaminants
- Necessity for site investigation or no further action recommendation

Exhibit 3-1. Flow Chart of the Site Assessment Process.

In addition to facility records, American Society for Testing and Materials (ASTM) Standard 1527 identifies other useful sources of information such as historical aerial photographs, fire insurance maps, property tax files, recorded land title records, topographic maps, local street directories, building department records, zoning/land use records, maps and newspaper archives (ASTM, 1997).

State and federal environmental offices are also potential sources of information. These offices may provide information such as facility maps that identify activities and disposal areas, lists of stored pollutants, and the types and levels of pollutants released. State and federal offices can provide the following types of facility level data:

- The state offices responsible for industrial waste management and hazardous waste should have a record of any emergency removal actions at the site (e.g., the removal of leaking drums that posed an "imminent threat" to local residents); any Resource Conservation and Recovery Act (RCRA) permits issued at the site; notices of violations issued; and any environmental investigations.

- The state office responsible for discharges of wastewater to water bodies under the National Pollutant Discharge Elimination System (NPDES) program will have a record of any permits issued for discharges into surface water at or near the site. The local publicly owned treatment works (POTW) will have records for permits issued for indirect discharges into sewers (e.g., floor drain discharges into sanitary drains).

- The state office responsible for underground storage tanks may also have records of tanks located at the site, as well as records of any past releases.

- The state office responsible for air emissions may be able to provide information on potential air pollutants associated with particular types of onsite contamination.

- EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) of potentially contaminated sites should have a record of any previously reported contamination at or near the site. For information, contact the Superfund Hotline (800-424-9346).

- EPA Regional Offices can provide records of sites that have released hazardous substances. Information is available from the Federal National Priorities List (NPL); lists of treatment, storage, and disposal (TSD) facilities subject to corrective action under the Resource Conservation and Recovery Act (RCRA); RCRA generators; and the Emergency Response Notification System (ERNS). Contact EPA Regional Offices for more information.

- State environmental records and local library archives may indicate permit violations or significant contamination releases from or near the site.

- Residents who were former employees may be able to provide information on waste management practices. These reports should be substantiated.

- Local fire departments may have responded to emergency events at the facility. Fire departments or city halls may have fire insurance maps[3] or other historical maps or data that indicate the location of hazardous waste storage areas at the site.

---

[3] Fire insurance maps show, for a specific property, the locations of such items as UST's, buildings, and areas where chemicals have been used for certain industrial processes.

- Local waste haulers may have records of the facility's disposal of hazardous or other wastes.

- Utility records.

- Local building permits.

Requests for federal regulatory information are governed by the Freedom of Information Act (FOIA), and the fulfilling of such requests generally takes a minimum of four to eight weeks. Similar freedom of information legislation does not uniformly exist on the state level; one can expect a minimum waiting period of four weeks to receive requested information (ASTM, 1997).

Identifying Contaminant Migration Pathways

Offsite migration of contaminants may pose a risk to human health and the environment. A site assessment should gather as much readily available information on the physical characteristics of the site as possible. Migration pathways, such as through soil, groundwater, and air, depend on site-specific characteristics such as geology and the physical characteristics of the individual contaminants (e.g., mobility, solubility, and density). Information on the physical characteristics of the general area can play an important role in identifying potential migration pathways and focusing environmental sampling activities, if needed.

Topographic, soil and subsurface, and groundwater data are particularly important:

Topographic Data. Topographic information helps determine whether the site may be subject to contamination from or the source of contamination to adjoining properties. Topographic information will help identify low-lying areas of the facility where rain and snowmelt (and any contaminants in them) may collect and contribute both water and contaminants to the underlying aquifer or surface runoff to nearby areas. The U.S. Geological Survey (USGS) of the Department of the Interior has topographic maps for nearly every part of the country. These maps are inexpensive and available through the following address:

USGS Information Services
Box 25286
Denver, CO 80225
[http://www.mapping.usgs.gov/esic/to_order.hmtl]

Soil and Subsurface Data. Soil and subsurface soil characteristics determine how contaminants move in the environment. For example, clay soils limit downward movement of pollutants into underlying groundwater but facilitate surface runoff. Sandy soils, on the other hand, can promote rapid infiltration into the water table while inhibiting surface runoff. Soil information can be obtained through a number of sources:

- The Natural Resource Conservation Service and Cooperative Extension Service offices of the U.S. Department of Agriculture (USDA) are also likely to have soil maps.
- Local planning agencies should have soil maps to support land use planning activities. These maps provide a general description of the soil types present within a county (or sometimes a smaller administrative unit, such as a township).
- Well-water companies are likely to be familiar with local subsurface conditions, and local water districts and state water divisions may have well-logging and water testing information.
- Local health departments may be familiar with subsurface conditions because of their interest in septic drain fields.
- Local construction contractors are likely to be familiar with subsurface conditions from their work with foundations.

Soil characteristics can vary widely within a relatively small area, and it is common to find that the top layer of soil in urban areas is composed of fill materials, not native soils. Geotechnical survey reports are often required by local authorities prior to construction. While the purpose of such surveys is to test soils for compaction, bedrock, and water table, general information gleaned from such reports can support the environmental site assessment process. Though local soil maps and other general soil information can be used for screening purposes such as in a site assessment, site-specific information will be needed in the event that cleanup is necessary.

Groundwater Data. Planners should obtain general groundwater information about the site area, including:

- State classifications of underlying aquifers;
- Depth to the groundwater tables;
- Groundwater flow direction and rate;
- Location of nearby drinking water and agricultural wells; and
- Groundwater recharge zones in the vicinity of the site.

This information can be obtained from several local sources, including water authorities, well drilling companies, health departments, and Agricultural Extension and Natural Resource Conservation Service offices.

Identifying Potential Environmental and Human Health Concerns

Identifying possible environmental and human health risks early in the process can influence decisions regarding the viability of a site for cleanup and the choice of cleanup methods used. A visual inspection of the area will usually suffice to identify onsite or nearby wetlands and water bodies that may be particularly sensitive to releases of contaminants during characterization or cleanup activities. Planners should also review available information from state and local environmental agencies to ascertain the proximity of residential dwellings, industrial/commercial activities, or wetlands/water bodies, and to identify people, animals, or plants that might receive migrating contamination; any particularly sensitive populations in the area (e.g., children; endangered species); and whether any major contamination events have occurred previously in the area (e.g., drinking water problems; groundwater contamination). Such general environmental information may be obtained by contacting the U.S. Army Corps of Engineers, state environmental agencies, local planning and conservation authorities, the U.S. Geological Survey, and the USDA Natural Resource Conservation Service. State and local agencies and organizations can usually provide information on local fauna and the habitats of any sensitive and/or endangered species.

For human health information, planners can contact:

- *State and local health assessment organizations*. Organizations such as health departments, should have data on the quality of local well water used as a drinking water source as well as any human health risk studies that have been conducted. In addition, these groups may have other relevant information, such as how certain types of contaminants might pose a health risk during site characterization. Information on exposures to particular contaminants and associated health risks can also be found in health profile documents developed by the Agency for Toxic Substances and Disease Registry (ATSDR). In addition, ATSDR may have conducted a health consultation or health assessment in the area if an environmental contamination event occurred in the past. Such an event and assessment should have been identified in the site assessment records review of prior contamination incidents at the site. For information, contact ATSDR's Division of Toxicology (404-639-6300).

- *Local water and health departments.* During the site visit (described below), when visually inspecting the area around the facility, planners should identify any residential dwellings or commercial activities near the facility and evaluate whether people there may come into contact with contamination along one of the migration pathways. Where groundwater contamination may pose a problem, planners should identify any nearby waterways or aquifers that may be impacted by groundwater discharge of contaminated water, including any drinking water wells downgradient of the site, such as a municipal well field. Local water departments will have a count of well connections to the public water supply. Planners should also pay particular attention to information on private wells in the area downgradient of the facility because they may be vulnerable to contaminants migrating offsite even when the public municipal drinking water supply is not vulnerable. Local health departments often have information on the locations of private wells.

Both groundwater pathways and surface water pathways should be evaluated because contaminants in groundwater can eventually migrate to surface waters and contaminants in surface waters can migrate to groundwater.

Conducting a Site Visit

In addition to collecting and reviewing available records, a site visit can provide important information about the uses and conditions of the property and identify areas that warrant further investigation (ASTM, 1997). During a visual inspection, the following should be noted:

- Current or past uses of abutting properties that may affect the property being evaluated;
- Evidence of hazardous substances migrating on- or off-site;
- Odors;
- Wells;
- Pits, ponds, or lagoons;
- Surface pools of liquids;
- Drums or storage containers;
- Stained soil or pavements;
- Corrosion;
- Stressed vegetation;
- Solid waste;
- Drains, sewers, sumps, or pathways for off-site migration; and
- Roads, water supplies, and sewage systems.

Conducting Interviews

Interviewing the site owner, site occupants, and local officials can help identify and clarify the prior and current uses and conditions of the property. They may also provide information on other documents or references regarding the property. Such documents include environmental audit reports, environmental permits, registrations for storage tanks, material safety data sheets, community right-to-know plans, safety plans, government agency notices or correspondence, hazardous waste generator reports or notices, geotechnical studies, or any proceedings involving the property (ASTM, 1997). Personnel from the following local government agencies should be interviewed: the fire department, health agency, and the agency with authority for hazardous waste disposal or other environmental matters. Interviews can be conducted in person, by telephone, or in writing.

ASTM Standard 1528 provides a questionnaire that may be appropriate for use in interviews for certain sites. ASTM suggests that this questionnaire be posed to the current property owner, any major occupant of the property (or at least 10 percent of the occupants of the property if no major occupant exists), or "any occupant likely to be using, treating, generating, storing, or disposing of hazardous substances or petroleum products on or from the property" (ASTM, 1996). A user's guide accompanies the ASTM questionnaire to assist the investigator in conducting interviews, as well as researching records and making site visits.

Developing a Report

Toward the end of the site assessment, planners should develop a report that includes all of the important information obtained during record reviews, the site visit, and interviews. Documentation, such as references and important exhibits, should be included, as well as the credentials of the environmental professional who conducted the environmental site assessment. The report should include all information regarding the presence or likely presence of hazardous substances or petroleum products on the property and any conditions that indicate an existing, past, or potential release of such substances into property structures or into the ground, groundwater, or surface water of the property (ASTM, 1997). The report should include the environmental professional's opinion of the impact of the presence or likely presence of any contaminants, and a findings and conclusion section that either indicates that the environmental site assessment revealed no evidence of contaminants in connection with the property, or discusses what evidence of contamination was found (ASTM, 1997).

Additional sections of the report might include a recommendations section for a site investigation, if appropriate. Some states or financial institutions may require information on specific substances such as lead in drinking water or asbestos.

Due Diligence

The purpose of the due diligence process is to determine the financial viability and extent of legal risk related to a particular brownfields project. The concept of financial viability can be explored from two perspectives, the marketability of the intended redevelopment use and the accuracy of the financial analysis for redevelopment work. Legal risk is determined through a legal liability analysis. Exhibit 3-3 represents the three-stage due diligence process.

Market Analysis

To gain an understanding of the marketability of any given project, it is critical to relate envisioned use(s) of a redeveloped brownfields site to the state and local communities in which it is located. Knowing the role of the projected use of the redevelopment project in the larger picture of economic and social trends helps the planner determine the likelihood of the project's success. For example, many metropolitan areas are adopting a profile of economic activity that parallels the profile of the Detroit area dominated by the auto manufacturing industry. New York, Northern Virginia and Washington, for example, are becoming known as telecommunications hubs. (Brownfields Redevelopment: A Guidebook for Local Governments & Communities, International City/County Management Association, 1997) Ohio is asserting itself as a plastics research and development center, and even smaller communities, such as Frederick, Maryland, a growing center for biomedical research and technology are marketing themselves with a specific economic niche in mind.

The benefits of co-locating similar and/or complementary business activities can be seen in business and industrial parks, where collaboration occurs in such areas as facility use, joint business ventures, employee support services such as on-site childcare, waste recycling and disposal, and others. For the brownfields redevelopment planner, this contextual information provides opportunities for creative thinking and direction for collaborative planning related to various possible uses for a particular site and their likelihood of success.

The long-term zoning plan of the jurisdiction in which the brownfields site is located provides an important source of information. Location of existing and planned transportation systems is a key question for any redevelopment activity. Observing the site's proximity to other amenities will flesh out the picture of the attraction potential for any given use.

Conduct Due Diligence

Minimize the Legal and Financial Risk of a Brownfields Project

Market Analysis

Determine the market viability of the project by:

- Developing and analyzing the community profile to assess public consensus for the market viability of the project
- Identifying economic trends that may influence the project at various levels or scales
- Determining possible marketting strategies
- Defining the target market
- Observing proximity to amenities for location attractions and value
- Assessing historic characteristics of the site that may influence the project

Financial Analysis

Assess the financial risks of the prooject by:

- Estimating cost of engineering, zoning, environmental consultant, legal ownership, taxation, and risk management
- Estimating property values before and after project
- Determining affordability, financing potential and services
- Identifying lending institutions and other funding mechanisms
- Understanding projected investment return and strategy

Legal Liability Analysis

Minimize the legal liability of the project by:

- Reviewing the municipal planning and zoning ordinances to determine requirements, options, limitations on uses, and need for variances
- Clarifying property ownership and owner cooperation
- Assessing the political climate of the community and the political context of the stakeholders
- Reviewing federal and local environmental requirements to assess not only risks, but ongoing regulatory/permitting requirements
- Evaluating need and availability for environmental insurance policies that can be streamlined to satisfy a wide range of issues
- Ensuring that historical liability insurance policies have been retained
- Evaluating federal and local financial and/or tax incentives
- Understanding tax implications (deductibility or capitalization) of environmental remediation costs

Exhibit 3-2. Flow Chart of the Due Diligence Process

Assessing the historic characteristics of the site that may influence the project is an important consideration at the neighborhood level. Gaining an understanding of the historic significance of a particular building might lead the community developer toward rehabilitation, rather than new construction on the site. Sensitivity regarding local affinities toward existing structures can go far to win a community's support of a redevelopment project.

Understanding what exists and what is planned provides part of the marketability picture. Particularly for smaller brownfields projects, knowing what is missing from the local community fabric can be an equally important aspect of the market analysis. Whether the "hub" of the area's economic life is light industry or an office complex or a recreational facility, numerous other services are needed to support the fabric of community. Restaurants and delicatessens, for instance, complement many larger, more central attractions, as do many other retail, service and recreational endeavors. A survey of local residents will inform the planner of local needs.

Financial Analysis

The goal of a financial analysis is to assess the financial risks of the redevelopment project. A Phase I Site Assessment will give the planner some indication of the possible extent of environmental contamination to the site. Financial information continues to unfold with a Phase II Site Investigation. The process of establishing remedial goals and screening remedial alternatives requires an understanding of associated costs. Throughout these processes increasingly specific cost information informs the planner's decision-making process. The planner's financial analysis should, therefore, serve as an ongoing "conversation" with development plans, providing an informed basis for the planner to determine whether or not to pursue the project. Ultimately the plan for remediation and use should contain as few financial unknowns as possible.

While costs related to the environmental aspects of the project need to be considered throughout the process, other cost information is also critical, including the price of purchase and establishment of legal ownership of the site, planning costs, engineering and architectural costs, hurdling zoning issues, environmental consultation, taxation, infrastructure upgrades, and legal consultation and insurance to help mitigate and manage associated risks.

In a property development initiative, where "time is money," scheduling is a critical factor influencing the financial feasibility of any development project. The timeframe over which to project costs, the expected turnaround time for attaining necessary permit approvals, and the schedule for site assessment, site investigation and actual cleanup of the site, are some aspects of the overall schedule of the project. Throughout the life of the project, the questions of, "how much will it cost," and, "how long will it take," must be tracked as key interacting variables.

Financing brownfields redevelopment projects presents unique difficulties. Many property purchase transactions use the proposed purchase as collateral for financing, depending upon an appraiser's estimate of the property's current and projected value. In the case of a brownfields site, however, a lending institution is likely to hesitate or simply close the door on such an arrangement due to the uncertain value and limited resale potential of the property. Another problem that the developer may face in seeking financing is that banks fear the risk of additional contamination that might be discovered later in the development process, such as an underground plume of groundwater contamination that travels unexpectedly into a neighboring property. Finally, though recent legislative changes may soften these concerns, many banks fear that their connection with a brownfields project will put them in the "chain of title" and make them potentially liable for cleanup costs (Brownfields Redevelopment: A Guidebook for Local Governments & Communities, International City/County Management Association, 1997).

A local appraiser can assist with estimation of property values before and after completion of the project, as well as evaluation of resale potential.

Some of the more notable brownfields redevelopment successes have been financed through consortiums of lenders who agree to spread the risk. Public/private financing partnerships may also be organized to finance brownfields redevelopment through grants, loans, loan guarantees, or bonds. Examples of projects employing unique revenue streams, financing avenues, and tax incentives related to brownfields redevelopment are available in Lessons from the Field, Unlocking Economic Potential with an Environmental Key, by Edith Perrer, Northeast Midwest Institute, 1997. Certain states, such as New Jersey, have placed a high priority on brownfields redevelopment, and are dedicating significant state funding to support such initiatives. By contacting the appropriate state department of environmental protection, developers can learn about opportunities related to their particular proposal.

Legal Liability Analysis

The purpose of legal analysis is to minimize the legal liability associated with the redevelopment process. The application and parameters of zoning ordinances, as well as options and limitations on use need to be clear to the developer. The need for a zoning variance and the political climate regarding granting of variances can be generally ascertained through discussions with the local real estate community. Legal counsel can help the developer clarify property ownership, and any legal encumbrances on the property, e.g. rights-of-way, easements. An environmental attorney can also assist the planner/developer to identify applicable regulatory and permitting requirements, as well as offer general predictions regarding the time frames for attaining these milestones throughout the development process. All of the above legal concerns are relevant to any land purchase.

Special legal concerns arise from the process of redeveloping a brownfields site. Those concerns include reviewing federal and local environmental requirements to assess not only risks, but ongoing regulatory/permitting requirements. In recent years, several changes have occurred in the law defining liability related to brownfields site contamination and cleanup. New legislation has generally been directed to mitigating the strict assignment of liability established by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or "Superfund"), enacted by Congress in 1980. While CERCLA has had numerous positive effects, it also represents barriers to redeveloping brownfields, most importantly the unknown liability costs related to uncertainty over the extent of contamination present at a site. Several successful CERCLA liability defenses have evolved and the EPA has reformed its administrative policy in support of increased brownfields redevelopment. In addition to legislative attempts to deal with the disincentives created by CERCLA, most states have developed Voluntary Cleanup or similar Programs with liability assurances documented in agreements with the EPA (Brownfields Redevelopment: A Guidebook for Local Governments & Communities, International City/County Management Association, 1997).

Another opportunity for risk protection for the developer is environmental insurance. Evaluation of the need and availability of environmental insurance policies that can be streamlined to satisfy a wide range of issues should be part of the analysis of legal liability. Understanding whether historical insurance policies have been retained, as well as the applicability of such policies, is also a dimension of the legal analysis.

Understanding tax implications, including deductibility or capitalization of environmental remediation costs, is a feature of legal liability analysis. Also, federal, state or local tax or other financial incentives may be available to support the developer's financing capacity.

Understanding the appropriateness of institutional controls is important in process of Brownfields Redevelopment. The use of zoning restrictions, deed restrictions may be important to ensure the future uses of the land are planned with full knowledge of the history of the site.

Conclusion

If the Phase I site assessment and due diligence adequately informs state and local officials, planners, community representatives, and other stakeholders that no contamination exists at the site, or that contamination is so minimal that it does not pose a health or environmental risk, those involved may decide that adequate site assessment has been accomplished and the process of redevelopment may proceed.

In some cases where evidence of contamination exists, stakeholders may decide that enough information is available from the site assessment and due diligence to characterize the site and determine an appropriate approach for site cleanup of the contamination. In other cases, stakeholders may decide that additional testing is warranted, and a Phase II site investigation should be conducted, as described in the next chapter.

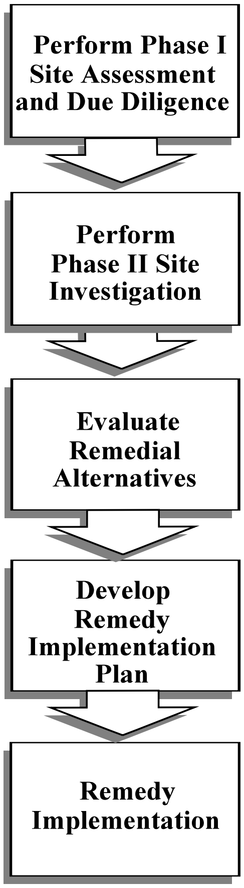
Chapter 4
Phase II Site Investigation

Background

Data collected during the Phase I site assessment may conclude that contaminant(s) exist at the site and/or that further study is necessary to determine the extent of contaminants. The purpose of a Phase II site investigation is to give planners and decision-makers objective and credible data about the contamination at a brownfields site to help them develop an appropriate contaminant management strategy. A site investigation is typically conducted by an environmental professional. This process evaluates the following types of data:

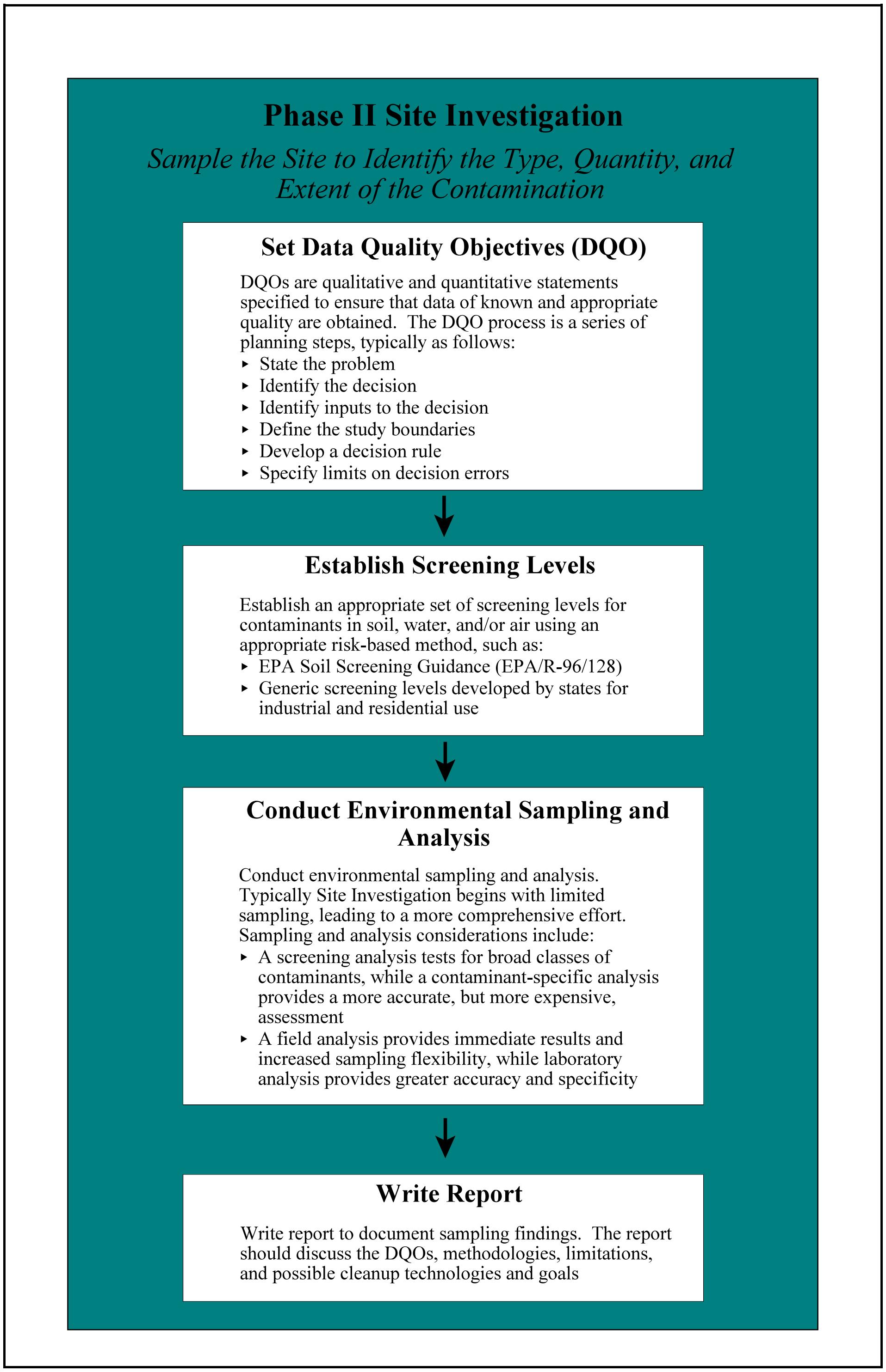
- Types of contamination present;
- Cleanup and reuse goals;
- Length of time required to reach cleanup goals;
- Post-treatment care needed; and
- Costs.

A site investigation involves setting appropriate data quality goals based upon brownfields redevelopment goals, using appropriate screening levels for the contaminants, and conducting environmental sampling and analysis.



Data gathering in a site investigation may typically include soil, water, and air sampling to identify the types, quantity, and extent of contamination in these various environmental media. The types of data used in a site investigation can vary from compiling existing site data (if adequate), to conducting limited sampling of the site, to mounting an extensive contaminant-specific or site-specific sampling effort. Planners should use knowledge of past facility operations whenever possible to focus the site evaluation on those process areas where pollutants were stored, handled, used, or disposed. These will be the areas where potential contamination will be most readily identified. Generally, to minimize costs, a site investigation begins with limited sampling (assuming readily available data does not adequately characterize the type and extent of contamination on the site) and proceed to more comprehensive sampling if needed (e.g., if the initial sampling could not identify the geographical limits of contamination). Exhibit 4-1 shows a flow chart of the site investigation process.

Various environmental companies provide site investigation services. Additional information regarding selection of a site investigation service can be found in *Assessing Contractor Capabilities for Streamlined Site Investigations* (EPA/542-R-00-001, January 2000).



Phase II Site Investigation

Sample the Site to Identify the Type, Quantity, and Extent of the Contamination

Set Data Quality Objectives (DQO)

DQOs are qualitative and quantitative statements specified to ensure that data of known and appropriate quality are obtained. The DQO process is a series of planning steps, typically as follows:

- State the problem
- Identify the decision
- Identify inputs to the decision
- Define the study boundaries
- Develop a decision rule
- Specify limits on decision errors

Establish Screening Levels

Establish an appropriate set of screening levels for contaminants in soil, water, and/or air using an appropriate risk-based method, such as:

- EPA Soil Screening Guidance (EPA/R-96/128)
- Generic screening levels developed by states for industrial and residential use

Conduct Environmental Sampling and Analysis

Conduct environmental sampling and analysis. Typically Site Investigation begins with limited sampling, leading to a more comprehensive effort. Sampling and analysis considerations include:

- A screening analysis tests for broad classes of contaminants, while a contaminant-specific analysis provides a more accurate, but more expensive, assessment
- A field analysis provides immediate results and increased sampling flexibility, while laboratory analysis provides greater accuracy and specificity

Write Report

Write report to document sampling findings. The report should discuss the DQOs, methodologies, limitations, and possible cleanup technologies and goals

Exhibit 4-1. Flow Chart of the Site Investigation Process

This chapter provides a general approach to site evaluation; planners and decision-makers should expand and refine this approach for site-specific use at their own facilities.

Setting Data Quality Objectives

While it is not easy, and probably impossible, to completely characterize the contamination at a site, decisions still have to be made. EPA's Data Quality Objectives (DQO) process provides a framework to make decisions under circumstances of data uncertainty. The DQO process uses a systematic approach that defines the purpose, scope, and quality requirements for the data collection effort. The DQO process consists of the following seven steps (EPA 2000):

- *State the problem.* Summarize the contamination problem that will require new environmental data, and identify the resources available to resolve the problem and to develop the conceptual site model.
- *Identify the decision* that requires new environmental data to address the contamination problem.
- *Identify the inputs to the decision.* Identify the information needed to support the decision and specify which inputs require new environmental measurements.
- *Define the study boundaries.* Specify the spatial and temporal aspect of the environmental media that the data must represent to support the decision.
- *Develop a decision rule.* Develop a logical "if ...then ..." statement that defines the conditions that would cause the decision-maker to choose among alternative actions.
- *Specify limits on decision errors.* Specify the decision maker's acceptable limits on decision errors, which are used to establish performance goals for limiting uncertainty in the data.
- *Optimize the design for obtaining data.* Identify the most resource-effective sampling and analysis design for generating data that are expected to satisfy the DQOs.

Please refer to *Data Quality Objectives Process for Hazardous Waste Site Investigations* (EPA 2000) for more detailed information on the DQO process.

Establish Screening Levels

During the initial stages of a site investigation, planners should establish an appropriate set of screening levels for contaminants in soil, water, and/or air. Screening levels are risk-based benchmarks that represent concentrations of chemicals in environmental media that do not pose an unacceptable risk. Sample analyses of soils, water, and air at the facility can be compared with these benchmarks. If onsite contaminant levels exceed the screening levels, further investigation will be needed to determine if and to what extent cleanup is appropriate. If contaminant concentrations are below the screening level, for the intended use, no action is required.

Some states have developed generic screening levels (e.g., for industrial and residential use), and EPA's *Soil Screening Guidance* (EPA/540/R-96/128) includes generic screening levels for many contaminants. Generic screening levels may not account for site-specific factors that affect the concentration or migration of contaminants. Alternatively, screening levels can be developed using site-specific factors. While site-specific screening levels can more effectively incorporate elements unique to the site, developing site-specific standards is a time- and resource-intensive process. Planners should contact their state environmental offices and/or EPA regional offices for assistance in using screening levels and in developing site-specific screening levels.

Risk-based screening levels are based on calculations and models that determine the likelihood that exposure of a particular organism or plant to a particular level of a contaminant would result in a certain adverse effect. Risk-based screening levels have been developed for tap water, ambient air, fish, and soil. Some states or EPA regions also use regional background levels (or ranges) of contaminants in soil and Maximum Contaminant Levels (MCLs) in water established under the Safe Drinking Water Act as screening levels for some chemicals. In addition, some states and/or EPA regional offices have developed equations for converting soil screening levels to comparative levels for the analysis of air and groundwater.

When a contaminant concentration exceeds a screening level, further site assessment activities (such as sampling the site at strategic locations and/or performing more detailed analysis) are needed to determine whether: (1) the concentration of the contaminant is relatively low and/or the extent of contamination is small and does not warrant cleanup for that particular chemical, or (2) the concentration or extent of contamination is high, and that site cleanup is needed (See Chapter 5, Contaminant Management, for more information.)

Using EPA's soil screening guidance for an initial brownfields investigation may be beneficial if no industrial screening levels are available or if the site may be used for residential purposes. However, it should be noted that EPA's soil screening guidance was designed for high-risk, Tier I sites, rather than brownfields, and conservatively assumes that future reuse will be residential. Using this guidance for a non-residential land use project could result in overly conservative screening levels.

In addition to screening levels, EPA regional offices and some states have developed cleanup levels, known as corrective action levels. If contaminant concentrations are above corrective action levels, a cleanup action must be pursued. Screening levels should not be confused with corrective action levels; Chapter 5, Contaminant Management, provides more information on corrective action levels.

Conduct Environmental Sampling and Data Analysis

Environmental sampling and data analysis are integral parts of a site investigation process. Many different technologies are available to perform these activities, as discussed below.

Levels of Sampling and Analysis

There are two levels of sampling and analysis: screening and contaminant-specific. Planners are likely to use both levels at different stages of the site investigation.

- *Screening.* Screening sampling and analysis use relatively low-cost technologies to take a limited number of samples at the most likely points of contamination and analyze them for a limited number of parameters. Screening analyses often test only for broad classes of contaminants, such as total petroleum hydrocarbons, rather than for specific contaminants, such as benzene or toluene. Screening is used to narrow the range of areas of potential contamination and reduce the number of samples requiring further, more costly, analysis. Screening is generally performed on site, with a small percentage of samples (e.g., generally 10 percent) submitted to a state-approved laboratory for a full organic and inorganic screening analysis to validate or clarify the results obtained.

  Some geophysical methods are used in site assessments because they are noninvasive (i.e., do not disturb environmental media as sampling does). Geophysical methods are commonly used to detect underground objects that might exist at a site, such as USTs, dry wells, and drums. The two most common and cost-effective technologies used in geophysical surveys are ground-penetrating radar and electromagnetics. Table C-1 in Appendix C contains an overview of geophysical methods. For more information on screening (including geophysical) methods, please refer to *Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide* (EPA/625/R-93003a).

- *Contaminant-specific.* For a more in-depth understanding of contamination at a site (e.g., when screening data are not detailed enough), it may be necessary to analyze samples for specific contaminants. With contaminant-specific sampling and analysis, the number of parameters analyzed is much greater than for screening-level sampling, and analysis includes more accurate, higher-cost field and laboratory methods. Samples are sent to a state-approved laboratory to be tested under rigorous protocols to ensure high-quality results. Such analyses may take several weeks. For some contaminants, innovative field technologies are as capable, or nearly as capable, of achieving the accuracy of laboratory technologies, which allows for a rapid turnaround of the results. The principal benefit of contaminant-specific analysis is the high quality and specificity of the analytical results.

Elizabeth, New Jersey
A Brownfields Success Story:

ONEJ Corporation, the New Jersey Department of Environmental Protection, and the New Jersey Economic Development Authority worked together to cleanup a 166-acre landfill site that is now the Jersey Gardens Mall. The mall has resulted in $219 million in private investments and an estimated $4 to $5 million in new annual tax revenues. The mall can also be credited with creating .....

New Jersey Brownfields Program. Office of State Planning. New Jersey Brownfields A New Opportunity, June 2000.

Increasing the Certainty of Sampling Results

Statistical Sampling Plan. Statistical sampling plans use statistical principles to determine the number of samples needed to accurately represent the contamination present. With the statistical sampling method, samples are usually analyzed with highly accurate laboratory or field technologies, which increase costs and take additional time. Using this approach, planners can consult with regulators and determine in advance specific measures of allowable uncertainty (e.g., an 80 percent level of confidence with a 25 percent allowable error).

Use of Lower-cost Technologies with Higher Detection Limits to Collect a Greater Number of Samples. This approach provides a more comprehensive picture of contamination at the site, but with less detail regarding the specific contamination. Such an approach would not be recommended to identify the extent of contamination by a specific contaminant, such as benzene, but may be an excellent approach for defining the extent of contamination by total organic compounds with a strong degree of certainty.

Site Investigation Technologies

This section discusses the differences between using field and laboratory technologies and provides an overview of applicable site investigation technologies. In recent years, several innovative technologies that have been field-tested and applied to hazardous waste problems have emerged. In many cases, innovative technologies may cost less than conventional techniques and can successfully provide the needed data. Operating conditions may affect the cost and effectiveness of individual technologies.

Field versus Laboratory Analysis

The principal advantages of performing field sampling and field analysis are that results are immediately available and more samples can be taken during the same sampling event; also, sampling locations can be adjusted immediately to clarify the first round of sampling results, if warranted. This approach may reduce costs associated with conducting additional sampling events after receipt of laboratory analysis. Field assessment methods have improved significantly over recent years; however, while many field technologies may be comparable to laboratory technologies, some field technologies may not detect contamination at levels as low as laboratory methods, and may not be contaminant-specific. To validate the field results or to gain more information on specific contaminants, a small percentage of the samples can be sent for laboratory analysis. The choice of sampling and analytical procedures should be based on Data Quality Objectives established earlier in the process, which determine the quality (e.g., precision, level of detection) of the data needed to adequately evaluate site conditions and identify appropriate cleanup technologies.

Sample Collection Technologies

Sample collection technologies vary widely, depending on the medium being sampled and the type of analysis required, based on the Data Quality Objectives (see the section on this subject earlier in this document). For example, soil samples are generally collected using spoons, scoops, and shovels, while subsurface sampling is more complex. The selection of a subsurface sample collection technology depends on the subsurface conditions (e.g., consolidated materials, bedrock), the required sampling depth and level of analysis, and the extent of sampling anticipated. If subsequent sampling efforts are likely, installing semipermanent well casings with a well-drilling rig may be appropriate. If limited sampling is expected, direct push methods, such as cone penetrometers, may be more cost-effective. The types of contaminants will also play a key role in the selection of sampling methods, devices, containers, and preservation techniques.

Groundwater contamination should be assessed in all areas, particularly where solvents or acids have been used. Solvents can be very mobile in subsurface soils; and acids, such as those used in finishing operations, increase the mobility of metal compounds. Groundwater samples should be taken at and below the water table in the surficial aquifer. Cone penetrometer technology is a cost-effective approach for collecting these samples. The samples then can be screened for contaminants using field methods such as:

- pH meters to screen for the presence of acids;
- Colormetric tubes to screen for volatile organics; and
- X-ray fluorescence to screen for metals.

Tables C-2 through C-4 in Appendix C list more information on various sample collection technologies, including a comparison of detection limits and costs.

The following chapter describes various contaminant management strategies that are available to the developer.

Chapter 5
Site Cleanup

Background

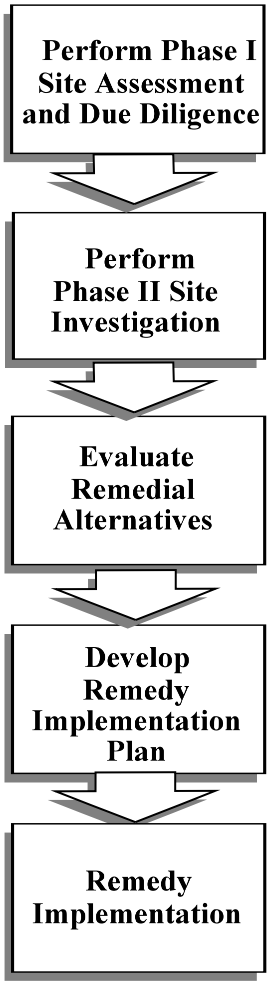
The purpose of this chapter is to help planners and decision-makers select an appropriate remedial alternative. This section contains information on developing a contaminant management plan and discusses various contaminant management options, from institutional controls and containment strategies, through cleanup technologies. Finally, this chapter provides an overview of post-construction issues that planners and decision-makers need to consider when selecting alternatives.

The principal factors that will influence the selection of a cleanup technology include:

- Types of contamination present;
- Cleanup and reuse goals;
- Length of time required to reach cleanup goals;
- Post-treatment care needed; and
- Budget.

The selection of appropriate remedy options often involves tradeoffs, particularly between time and cost. A companion document, *Cost Estimating Tools and Resources for Addressing Sites Under the Brownfields Initiative* (EPA/625/R-99/001 April 1999), provides information on cost factors and developing cost estimates. In general, the more intensive the cleanup approach, the more quickly the contamination will be mitigated and the more costly the effort. In the case of brownfields cleanup, both time and cost can be major concerns, considering the planner's desire to return the facility to reuse as quickly as possible. Thus, the planner may wish to explore a number of options and weigh carefully the costs and benefits of each.

Selection of remedial alternatives is also likely to involve the input of remediation professionals.



The overview of technologies cited in this chapter provides the planner with a framework for seeking, interpreting, and evaluating professional input.

The intended use of the brownfields site will drive the level of cleanup needed to make the site safe for redevelopment and reuse. Brownfields sites are by definition not Superfund sites; that is, brownfields sites usually have lower levels of contamination present and, therefore, generally require less extensive cleanup efforts than

Superfund sites. Nevertheless, all potential pathways of exposure, based on the intended reuse of the site, must be addressed in the site assessment and cleanup; if no pathways of exposure exist, less cleanup (or possibly none) may be required.

Some regional EPA and state offices have developed corrective action levels (CALs) for different chemicals, which may serve as guidelines or legal requirements for cleanups. It is important to understand that screening levels (discussed in "Performing a Phase II Site Assessment" above) are different from cleanup (or corrective action) levels. Screening levels indicate whether further site investigation is warranted for a particular contaminant. CALs indicate whether cleanup action is needed and how extensive it needs to be. Planners should check with their state environmental office for guidance and/or requirements for CALs.

Evaluate Remedial Alternatives

If the site investigation shows that there is an unacceptable level of contamination, the problem will have to be remedied. Exhibit 5-1 shows a flow chart of the remedial alternative evaluation process.

Establishing Remedial Goals

The first step in evaluating remedial alternatives is to articulate the remedial goals. Remedial goals relate very specifically to the intended use of the redeveloped site. A property to be used for a plastics factory may not need to be cleaned up to the same level as a site that will be used a school. Future land use holds the key to practical brownfields redevelopment plans. Knowledge of federal, state, local or tribal requirements helps to ensure realistic assumptions. Community surroundings, as seen through a visual inspection will help provide a context for future land uses, though many large brownfields redevelopment projects have provided the catalyst to overall neighborhood refurbishment. Available funding and timeframe for the project are also very significant factors in defining remedial goals.

Developing a List of Options

Developing a list of remedial options may begin with a literature search of existing technologies, many of which are listed in Exhibit D-1 of this document. Analysis of technical information on technology applicability requires a professional remediation specialist. However, general information is provided below for the community planner/developer in order to support informed interaction with the remediation professional.

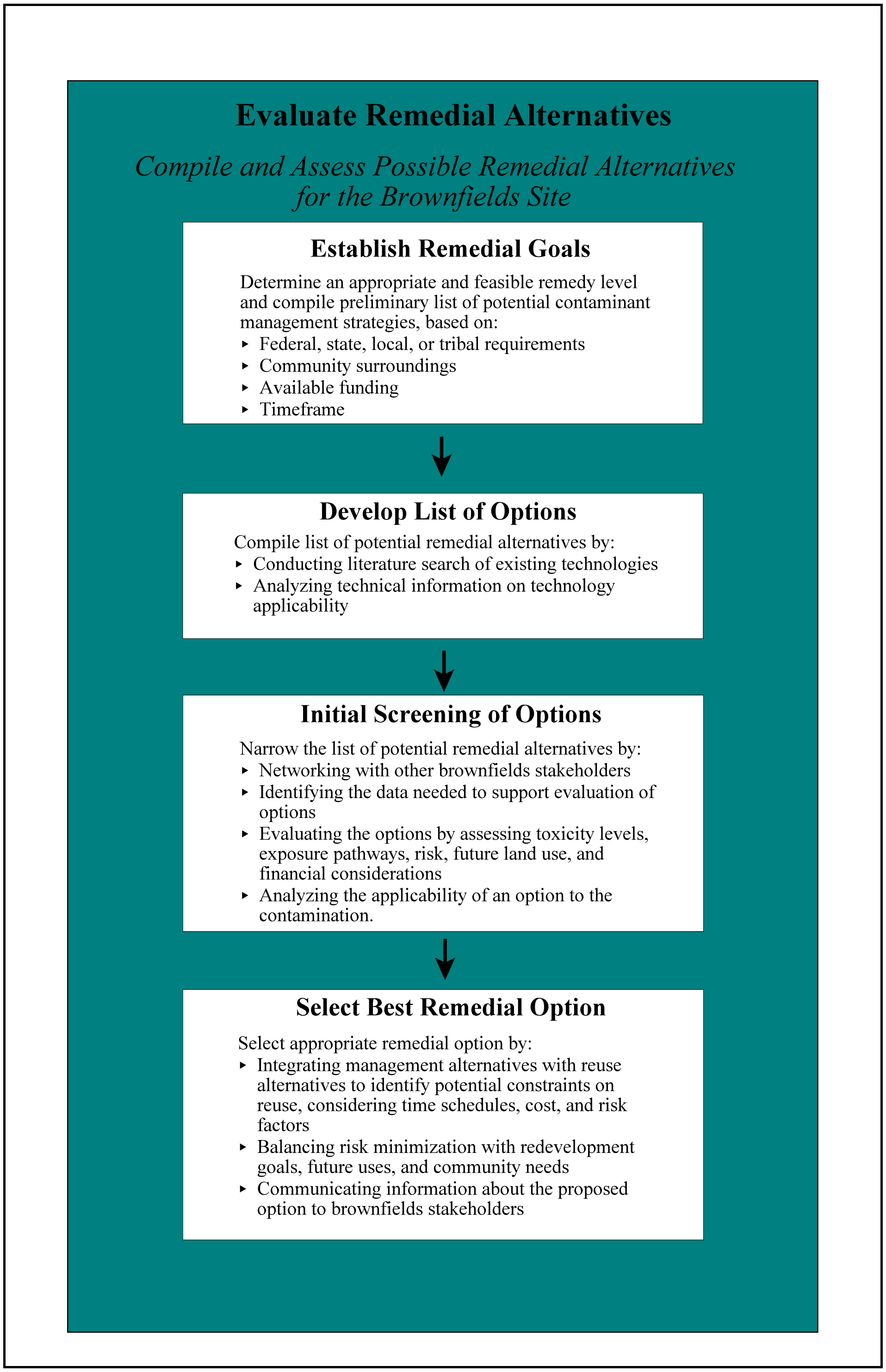
Remedial alternatives fall under three categories, institutional controls, containment technologies, and cleanup technologies. In many cases, the final remedial strategy will involve aspects of all three approaches.

Institutional Controls

Institutional controls are mechanisms that help control the current and future use of, and access to, a site. They are established, in the case of brownfields, to protect people from possible contamination. Institutional controls can range from a security fence prohibiting access to certain portions of the site to deed restrictions imposed on the future use of the facility. If the overall management approach does not include the complete cleanup of the facility (i.e., the complete removal or destruction of onsite contamination), a deed restriction will likely be required that clearly states that hazardous waste is being left in place within the site boundaries. Many state brownfields programs include institutional controls.

Containment Technologies

The purpose of containment is to reduce the potential for offsite migration of contaminants and possible subsequent exposure to people and the environment. Containment technologies include engineered barriers such as caps and liners for landfills, slurry walls, and hydraulic containment. Often, soils contaminated with metals can be solidified by mixing them with cement-like materials, and the resulting stabilized material can be stored on site in a landfill. Like institutional controls, containment technologies do not remove the contamination, but rather mitigate potential risk by limiting access to it.



Evaluate Remedial Alternatives

Compile and Assess Possible Remedial Alternatives for the Brownfields Site

Establish Remedial Goals

Determine an appropriate and feasible remedy level and compile preliminary list of potential contaminant management strategies, based on:

- Federal, state, local, or tribal requirements
- Community surroundings
- Available funding
- Timeframe

Develop List of Options

Compile list of potential remedial alternatives by:

- Conducting literature search of existing technologies
- Analyzing technical information on technology applicability

Initial Screening of Options

Narrow the list of potential remedial alternatives by:

- Networking with other brownfields stakeholders
- Identifying the data needed to support evaluation of options
- Evaluating the options by assessing toxicity levels, exposure pathways, risk, future land use, and financial considerations
- Analyzing the applicability of an option to the contamination.

Select Best Remedial Option

Select appropriate remedial option by:

- Integrating management alternatives with reuse alternatives to identify potential constraints on reuse, considering time schedules, cost, and risk factors
- Balancing risk minimization with redevelopment goals, future uses, and community needs
- Communicating information about the proposed option to brownfields stakeholders

Exhibit 5-1. Flow Chart of the Remedial Alternative Evaluation Process

For example, if contamination is found underneath the floor slab at a facility, leaving the contaminated materials in place and repairing any damage to the floor slab may be justified. The likelihood that such an approach will be acceptable to regulators depends on whether potential risk can be mitigated and managed effectively over the long term. In determining whether containment is feasible, planners should consider:

- *Depth to groundwater*. Planners should be prepared to prove to regulators that groundwater levels will not rise and contact contaminated soils.
- *Soil types*. If contaminants are left in place, native soils will be an important consideration. Sandy or gravelly soils are highly porous, which enable contaminants to migrate easily. Clay and fine silty soils provide a much better barrier.
- *Surface water control*. Planners should be prepared to prove to regulators that stormwater cannot infiltrate the floor slab and flush the contaminants downward.
- *Volatilization of organic contaminants*. Regulators are likely to require that air monitors be placed inside the building to monitor the level of organics that may be escaping upward through the floor and drains.

Cleanup Technologies

Cleanup technologies may be required to remove or destroy onsite contamination if regulators are unwilling to accept the levels of contamination present or if the types of contamination are not conducive to the use of institutional controls or containment technologies. Cleanup technologies fall broadly into two categories--ex situ and in situ, as described below.

- *Ex Situ*. An ex situ technology treats contaminated materials after they have been removed and transported to another location. After treatment, if the remaining materials, or residuals, meet cleanup goals, they can be returned to the site. If the residuals do not yet meet cleanup goals, they can be subjected to further treatment, contained on site, or moved to another location for storage or further treatment. A cost-effective approach to cleaning up a brownfields site may be the partial treatment of contaminated soils or groundwater, followed by containment, storage, or further treatment off site.

- *In Situ*. In situ technologies treat contamination in place and are often innovative technologies. Examples of in situ technologies include bioremediation, soil flushing, oxygen-releasing compounds, air sparging, and treatment walls. In some cases, in situ technologies are feasible, cost-effective choices for the types of contamination that are likely at brownfields sites. Planners, however, do need to be aware that cleanup with in situ technologies is likely to take longer than with ex situ technologies. Several innovative technologies are available to address soils and groundwater contaminated with organics, such as solvents and some PAHs, which are common problems at brownfields sites.

Maintenance requirements associated with in situ technologies depend on the technology used and vary widely in both effort and cost. For example, containment technologies such as caps and liners will require regular maintenance, such as maintaining the vegetative cover and performing periodic inspections to ensure the long-term integrity of the cover system. Groundwater treatment systems will require varying levels of post-cleanup care and verification testing. If an in situ system is in use at the site, it will require regular operations support and periodic maintenance to ensure that the system is operating as designed.

Table D-1 in Appendix D presents a comprehensive list of various cleanup technologies that may be appropriate, based on their capital and operating costs, for use at brownfields sites. In addition to more conventional technologies, a number of innovative technology options are listed.

Screening and Selection of Best Remedial Option

When screening management approaches at brownfields sites, planners and decision-makers should consider the following:

- Cleanup approaches can be formulated for specific contaminant types; however, different contaminant types are likely to be found together at brownfields sites, and some contaminants can interfere with certain cleanup techniques directed at other contaminant types.
- The large site areas typical of some brownfields can be a great asset during cleanup because they facilitate the use of land-based cleanup techniques such as landfilling, landfarming, solidification, and composting.
- Consolidating similar contaminant materials at one location and implementing a single, large-volume cleanup approach is often more effective than using several similar approaches in different areas of the site. At iron and steel sites for example, metals contamination from the blast furnace, the ironmaking area, and the finishing shops can be consolidated and cleaned up using solidification/stabilization techniques, with the residual placed in an appropriately designed landfill with an engineered cap. Planners should investigate the likelihood that such consolidation may require prior regulatory approval.
- Some mixed contamination may require multicomponent treatment trains for cleanup. A cost-effective solution might be to combine consolidation and treatment technologies with containment where appropriate. For example, soil washing techniques can be used to treat a mixed soil matrix contaminated with metals compounds (which may need further stabilization) and PAHs; the soil can then be placed in a landfill. Any remaining contaminated soils may be subjected to chemical dehalogenation to destroy the polycyclic aromatic hydrocarbon (PAH) contamination.
- Groundwater contamination may contain multiple constituents, including solvents, metals, and PAHs. If this is the case, no in situ technologies can address all contaminants; instead, groundwater must be extracted and treated. The treatment train is likely to be comprised of a chemical precipitation unit to remove the metals compounds and an air stripper to remove the organic contaminants.

Selection of the best remedial option results from integrating management alternatives with reuse alternatives to identify potential constraints on reuse. Time schedules, cost, and risk factors must be considered. Risk minimization is balanced against redevelopment goals, future uses, and community needs. The process of weighing alternatives rarely results in a plan without compromises in one or several directions.

Components of the Presumptive Remedy: Source Containment

- Landfill cap;
- Source area ground-water control to obtain plume;
- Leachate collection and treatment; and/or
- Institutional controls to supplement engineering

USEPA, 1993.

Develop Remedy Implementation Plan

The remedy implementation plan, as developed by a professional environmental engineer, describes the approach that will be used to contain and clean up contamination. In developing this plan, planners and decision-makers should incorporate stakeholder concerns and consider a range of possible options, with the intent of identifying the most cost-effective approaches for cleaning up the site, considering time and cost concerns. The remedy implementation plan should include the following elements:

- A clear delineation of environmental concerns at the site. Areas should be discussed separately if the management approach for one area is different than that for other areas of the site. Clear documentation of existing conditions at the site and a summarized assessment of the nature and scope of contamination should be included.
- A recommended management approach for each environmental concern that takes into account expected land reuse plans and the adequacy of the technology selected.
- A cost estimate that reflects both expected capital and operating/maintenance costs.
- Post-construction maintenance requirements for the recommended approach.
- A discussion of the assumptions made to support the recommended management approach, as well as the limitations of the approach.

Planners and decision-makers can use the framework developed during the initial site evaluation (see the section on "Site Assessment") and the controls and technologies described below to compare the effectiveness of the least costly approaches for meeting the required management goals established in the Data Quality Objectives. These goals should be established at levels that are consistent with the expected reuse plans. Exhibit 5-2 shows the remedy implementation plan development process.

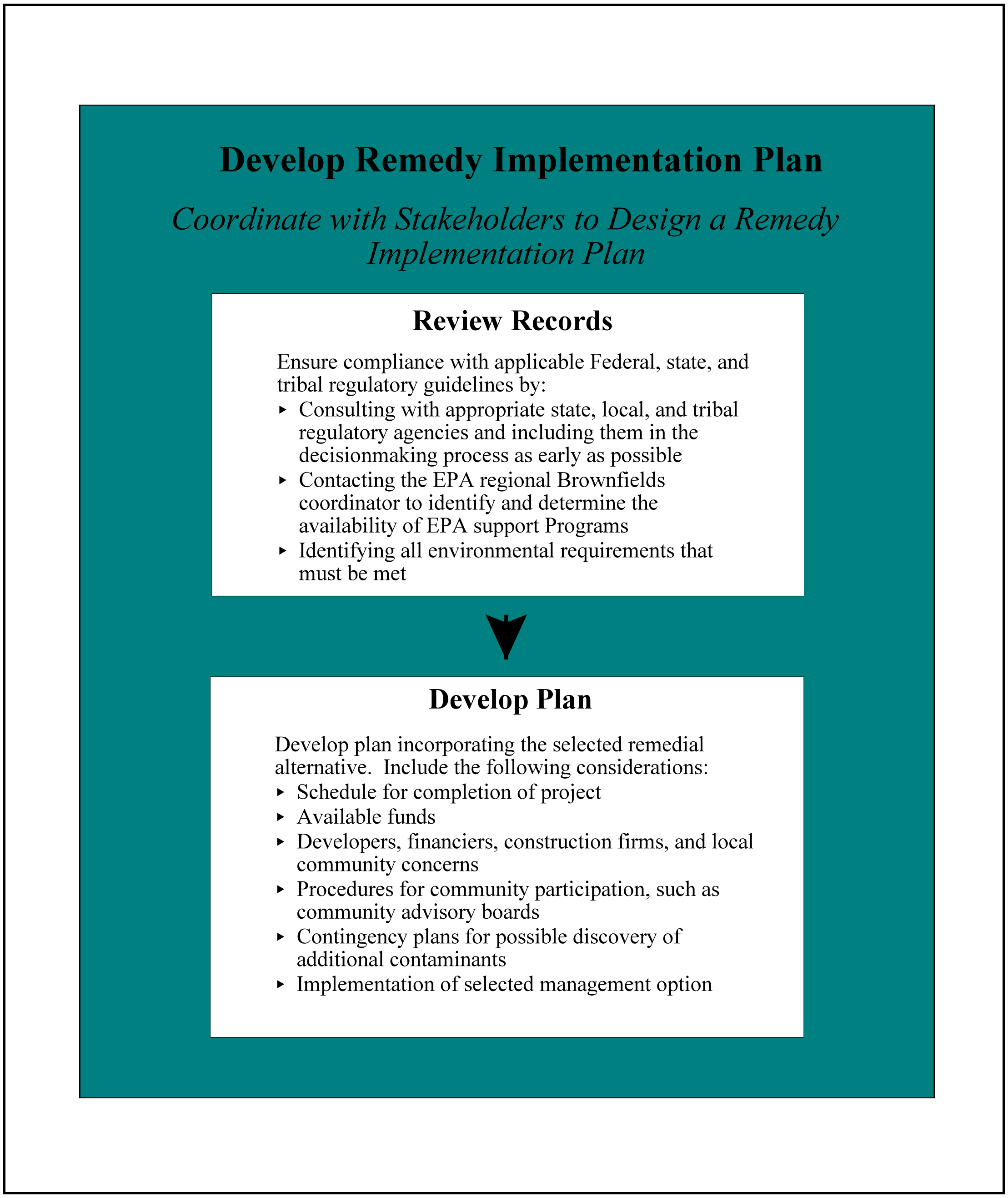
A remedy implementation plan should involve stakeholders in the community in the development of the plan. Some examples of various stakeholders are:

- Industry;
- City, county, state and federal governments;
- Community groups, residents and leaders;
- Developers and other private businesses;
- Banks and lenders;
- Environmental groups;
- Educational institutes;
- Community development organizations;
- Environmental justice advocates;
- Communities of color and low-income; and
- Environmental regulatory agencies.

Community-based organizations represent a wide range of issues, from environmental concerns to housing issues to economic development. These groups can often be helpful in educating planners and decision-makers in the community about local brownfields sites, which can contribute to successful brownfields site assessment and cleanup activities. In addition, state voluntary cleanup programs require that local communities be adequately informed about brownfields cleanup activities. Planners can contact the local Chamber of Commerce, local philanthropic organizations, local service organizations, and neighborhood committees for community input. Representatives from EPA regional offices and state and local environmental groups may be able to supply relevant information and identify other appropriate community organizations. Involving the local community in brownfields projects is a key component in the success of such projects.

Remedy Implementation

Many of the management technologies that leave contamination onsite, either in containment systems or because of the long periods required to reach management goals, will require long-term maintenance and possibly operation. If waste is left onsite, regulators will likely require long-term monitoring of applicable media (e.g., soil, water, and/or air) to ensure that the management approach selected is continuing to function as planned (e.g., residual contamination, if any, remains at acceptable levels and is not migrating). If long-term monitoring is required (e.g., by the state) periodic sampling, analysis, and reporting requirements will also be involved. Planners and decision-makers should be aware of these requirements and provide for them in cleanup budgets. Post-construction sampling, analysis, and reporting costs can be substantial and therefore need to be addressed in cleanup budgets.



Develop Remedy Implementation Plan

Coordinate with Stakeholders to Design a Remedy Implementation Plan

Review Records

Ensure compliance with applicable Federal, state, and tribal regulatory guidelines by:

- Consulting with appropriate state, local, and tribal regulatory agencies and including them in the decisionmaking process as early as possible
- Contacting the EPA regional Brownfields coordinator to identify and determine the availability of EPA support Programs
- Identifying all environmental requirements that must be met

Develop Plan

Develop plan incorporating the selected remedial alternative. Include the following considerations:

- Schedule for completion of project
- Available funds
- Developers, financiers, construction firms, and local community concerns
- Procedures for community participation, such as community advisory boards
- Contingency plans for possible discovery of additional contaminants
- Implementation of selected management option

Exhibit 5-2. Flow Chart of the Remedy Implementation Plan Development Process

Chapter 6
Conclusion

Brownfields redevelopment contributes to the revitalization of communities across the U.S. Reuse of these abandoned, contaminated sites spurs economic growth, builds community pride, protects public health, and helps maintain our nation's "greenfields," often at a relatively low cost. This document in conjunction with the Generic Guide provide an overview of the technical methods that can be used to achieve successful site assessment and cleanup, which are two key components in the brownfields redevelopment process.

This landfill site profile provides the technical information necessary to conduct a successful brownfields redevelopment. However, each site is unique and the specific cleanup activities will be dictated by the site assessment, future use of the site, budget and time frame.

To avoid problems throughout the process it is important that stakeholders are involved from the beginning. Consultation with state and local environmental officials and community leaders, as well as careful planning early in the project, will allow planners to develop the most appropriate site assessment and cleanup approaches. Planners should also determine early on if they are likely to require the assistance of environmental engineers. A site assessment strategy should be agreeable to all stakeholders and should address:

- The type and extent of any contamination present at the site;
- The types of data needed to adequately assess the site;
- Appropriate sampling and analytical methods for characterizing contamination; and
- An acceptable level of data uncertainty .

When used appropriately, the process described in this document will help to ensure that a good strategy is developed and implemented effectively.

Once the site has been assessed and stakeholders agree that cleanup is needed, planners will need to consider the cleanup options. Many different types of cleanup technologies are available. The guidance provided in this document on selecting appropriate methods directs planners to base cleanup initiatives on site- and project-specific conditions. The type and extent of cleanup will depend in large part on the type and level of contamination present, reuse goals, and the budget available. Certain cleanup technologies are used onsite, while others require offsite treatment. Also, in certain circumstances, containment of contamination onsite and the use of institutional controls may be important components of the cleanup effort. Finally, planners will need to include budgetary provisions and plans for post-cleanup and post-construction care if it is required at the brownfields site. By developing a technically sound site assessment and cleanup approach that is based on site-specific conditions and addresses the concerns of all project stakeholders, planners can achieve brownfield redevelopment and reuse goals effectively and safely.

Appendix A
Acronyms

ASTM	American Society for Testing and Materials
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
DQO	Data Quality Objective
EPA	U.S. Environmental Protection Agency
NPDES	National Pollutant Discharge Elimination System
O&M	Operations and Maintenance
ORD	Office of Research and Development
OSWER	Office of Solid Waste and Emergency Response
PAH	Polyaromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCP	Pentachlorophenol
RCRA	Resource Conservation and Recovery Act
SVE	Soil Vapor Extraction
SVOC	Semi-Volatile Organic Compound
TCE	Trichloroethylene
TIO	Technology Innovation Office
TPH	Total Petroleum Hydrocarbon
UST	Underground Storage Tank
VCP	Voluntary Cleanup Program
VOC	Volatile Organic Compound

Appendix B
Glossary

Air Sparging In air sparging, air is injected into the ground below a contaminated area, forming bubbles that rise and carry trapped and dissolved contaminants to the surface where they are captured by a soil vapor extraction system. Air sparging may be a good choice of treatment technology at sites contaminated with solvents and other volatile organic compounds (VOCs). See also Volatile Organic Compound.

Air Stripping Air stripping is a treatment method that removes or "strips" VOCs from contaminated groundwater or surface water as air is forced through the water, causing the compounds to evaporate. See also Volatile Organic Compound.

American Society for Testing and Materials (ASTM) The ASTM sets standards for many services, including methods of sampling and testing of hazardous waste, and media contaminated with hazardous waste.

Aquifer An aquifer is an underground rock formation composed of such materials as sand, soil, or gravel that can store groundwater and supply it to wells and springs.

Aromatics Aromatics are organic compounds that contain 6-carbon ring structures, such as creosote, toluene, and phenol, that often are found at dry cleaning and electronic assembly sites.

Baseline Risk Assessment A baseline risk assessment is an assessment conducted before cleanup activities begin at a site to identify and evaluate the threat to human health and the environment. After cleanup has been completed, the information obtained during a baseline risk assessment can be used to determine whether the cleanup levels were reached.

Bedrock Bedrock is the rock that underlies the soil; it can be permeable or non-permeable. See also Confining Layer and Creosote.

Bioremediation Bioremediation refers to treatment processes that use microorganisms (usually naturally occurring) such as bacteria, yeast, or fungi to break down hazardous substances into less toxic or nontoxic substances. Bioremediation can be used to clean up contaminated soil and water. In situ bioremediation treats the contaminated soil or groundwater in the location in which it is found. For ex situ bioremediation processes, contaminated soil must be excavated or groundwater pumped before they can be treated.

Bioventing Bioventing is an in situ cleanup technology that combines soil vapor extraction methods with bioremediation. It uses vapor extraction wells that induce air flow in the subsurface through air injection or through the use of a vacuum. Bioventing can be effective in cleaning up releases of petroleum products, such as gasoline, jet fuels, kerosene, and diesel fuel. See also Bioremediation.

Borehole A borehole is a hole cut into the ground by means of a drilling rig.

Borehole Geophysics Borehole geophysics are nuclear or electric technologies used to identify the physical characteristics of geologic formations that are intersected by a borehole.

Brownfields Brownfields sites are abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination.

BTEX BTEX is the term used for benzene, toluene, ethylbenzene, and xylene--volatile aromatic compounds typically found in petroleum products, such as gasoline and diesel fuel.

Cadmium Cadmium is a heavy metal that accumulates in the environment. See also Heavy Metal.

Carbon Adsorption Carbon adsorption is a treatment method that removes contaminants from groundwater or surface water as the water is forced through tanks containing activated carbon.

Chemical Dehalogenation Chemical dehalogenation is a chemical process that removes halogens (usually chlorine) from a chemical contaminant, rendering the contaminant less hazardous. The chemical dehalogenation process can be applied to common halogenated contaminants such as polychlorinated biphenyls (PCBs), dioxins (DDT), and certain chlorinated pesticides, which may be present in soil and oils. The treatment time is short, energy requirements are moderate, and operation and maintenance costs are relatively low. This technology can be brought to the site, eliminating the need to transport hazardous wastes. See also Polychlorinated Biphenyl.

Cleanup Cleanup is the term used for actions taken to deal with a release or threat of release of a hazardous substance that could affect humans and/or the environment.

Colorimetric Colorimetric refers to chemical reaction-based indicators that are used to produce compound reactions to individual compounds, or classes of compounds. The reactions, such as visible color changes or other easily noted indications, are used to detect and quantify contaminants.

Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) CERCLIS is a database that serves as the official inventory of Superfund hazardous waste sites. CERCLIS also contains information about all aspects of hazardous waste sites, from initial discovery to deletion from the National Priorities List (NPL). The database also maintains information about planned and actual site activities and financial information entered by EPA regional offices. CERCLIS records the targets and accomplishments of the Superfund program and is used to report that information to the EPA Administrator, Congress, and the public. See also National Priorities List and Superfund.

Confining Layer A confining layer is a geological formation characterized by low permeability that inhibits the flow of water. See also Bedrock and Permeability.

Contaminant A contaminant is any physical, chemical, biological, or radiological substance or matter present in any media at concentrations that may result in adverse effects on air, water, or soil.

Data Quality Objective (DQO) DQOs are qualitative and quantitative statements specified to ensure that data of known and appropriate quality are obtained. The DQO process is a series of planning steps, typically conducted during site assessment and investigation, that is designed to ensure that the type, quantity, and quality of environmental data used in decision-making are appropriate. The DQO process involves a logical, step-by-step procedure for determining which of the complex issues affecting a site are the most relevant to planning a site investigation before any data are collected.

Disposal Disposal is the final placement or destruction of toxic, radioactive or other wastes; surplus or banned pesticides or other chemicals; polluted soils; and drums containing hazardous materials from removal actions or accidental release. Disposal may be accomplished through the use of approved secure landfills, surface impoundments, land farming, deep well injection, ocean dumping, or incineration.

Dual-Phase Extraction Dual-phase extraction is a technology that extracts contaminants simultaneously from soils in saturated and unsaturated zones by applying soil vapor extraction techniques to contaminants trapped in saturated zone soils.

Electromagnetic (EM) Geophysics EM geophysics refers to technologies used to detect spatial (lateral and vertical) differences in subsurface electromagnetic characteristics. The data collected provide information about subsurface environments.

Electromagnetic (EM) Induction EM induction is a geophysical technology used to induce a magnetic field beneath the earth's surface, which in turn causes a secondary magnetic field to form around nearby objects that have conductive properties, such as ferrous and nonferrous metals. The secondary magnetic field is then used to detect and measure buried debris.

Emergency Removal An emergency removal is an action initiated in response to a release of a hazardous substance that requires on-site activity within hours of a determination that action is appropriate.

Emerging Technology An emerging technology is an innovative technology that currently is undergoing bench-scale testing. During bench-scale testing, a small version of the technology is built and tested in a laboratory. If the technology is successful during bench-scale testing, it is demonstrated on a small scale at field sites. If the technology is successful at the field demonstrations, it often will be used full scale at contaminated waste sites. The technology is continually improved as it is used and evaluated at different sites. See also Established Technology and Innovative Technology.

Engineered Control An engineered control, such as barriers placed between contamination and the rest of a site, is a method of managing environmental and health risks. Engineered controls can be used to limit exposure pathways.

Established Technology An established technology is a technology for which cost and performance information is readily available. Only after a technology has been used at many different sites and the results fully documented is that technology considered established. The most frequently used established technologies are incineration, solidification and stabilization, and pump-and-treat technologies for groundwater. See also Emerging Technology and Innovative Technology.

Exposure Pathway An exposure pathway is the route of contaminants from the source of contamination to potential contact with a medium (air, soil, surface water, or groundwater) that represents a potential threat to human health or the environment. Determining whether exposure pathways exist is an essential step in conducting a baseline risk assessment. See also Baseline Risk Assessment.

Ex Situ The term ex situ or "moved from its original place," means excavated or removed.

Filtration Filtration is a treatment process that removes solid matter from water by passing the water through a porous medium, such as sand or a manufactured filter.

Flame Ionization Detector (FID) An FID is an instrument often used in conjunction with gas chromatography to measure the change of signal as analytes are ionized by a hydrogen-air flame. It also is used to detect phenols, phthalates, polyaromatic hydrocarbons (PAH), VOCs, and petroleum hydrocarbons. See also Polyaromatic Hydrocarbons and Volatile Organic Compounds.

Fourier Transform Infrared Spectroscopy A Fourier transform infrared spectroscope is an analytical air monitoring tool that uses a laser system chemically to identify contaminants.

Fumigant A fumigant is a pesticide that is vaporized to kill pests. They often are used in buildings and greenhouses.

Furan Furan is a colorless, volatile liquid compound used in the synthesis of organic compounds, especially nylon.

Gas Chromatography Gas chromatography is a technology used for investigating and assessing soil, water, and soil gas contamination at a site. It is used for the analysis of VOCs and semivolatile organic compounds (SVOC). The technique identifies and quantifies organic compounds on the basis of molecular weight, characteristic fragmentation patterns, and retention time. Recent advances in gas chromatography considered innovative are portable, weather-proof units that have self-contained power supplies.

Ground-Penetrating Radar (GPR) GPR is a technology that emits pulses of electromagnetic energy into the ground to measure its reflection and refraction by subsurface layers and other features, such as buried debris.

Groundwater Groundwater is the water found beneath the earth's surface that fills pores between such materials as sand, soil, or gravel and that often supplies wells and springs. See also Aquifer.

Hazardous Substance A hazardous substance is any material that poses a threat to public health or the environment. Typical hazardous substances are materials that are toxic, corrosive, ignitable, explosive, or chemically reactive. If a certain quantity of a hazardous substance, as established by EPA, is spilled into the water or otherwise emitted into the environment, the release must be reported. Under certain federal legislation, the term excludes petroleum, crude oil, natural gas, natural gas liquids, or synthetic gas usable for fuel.

Heavy Metal Heavy metal refers to a group of toxic metals including arsenic, chromium, copper, lead, mercury, silver, and zinc. Heavy metals often are present at industrial sites at which operations have included battery recycling and metal plating.

High-Frequency Electromagnetic (EM) Sounding High-frequency EM sounding, the technology used for non-intrusive geophysical exploration, projects high-frequency electromagnetic radiation into subsurface layers to detect the reflection and refraction of the radiation by various layers of soil. Unlike ground-penetrating radar, which uses pulses, the technology uses continuous waves of radiation. See also Ground-Penetrating Radar.

Hydrocarbon A hydrocarbon is an organic compound containing only hydrogen and carbon, often occurring in petroleum, natural gas, and coal.

Hydrogeology Hydrogeology is the study of groundwater, including its origin, occurrence, movement, and quality.

Hydrology Hydrology is the science that deals with the properties, movement, and effects of water found on the earth's surface, in the soil and rocks beneath the surface, and in the atmosphere.

Ignitability Ignitable wastes can create fires under certain conditions. Examples include liquids, such as solvents that readily catch fire, and friction-sensitive substances.

Immunoassay Immunoassay is an innovative technology used to measure compound-specific reactions (generally colorimetric) to individual compounds or classes of compounds. The reactions are used to detect and quantify contaminants. The technology is available in field-portable test kits.

Incineration Incineration is a treatment technology that involves the burning of certain types of solid, liquid, or gaseous materials under controlled conditions to destroy hazardous waste.

Infrared Monitor An infrared monitor is a device used to monitor the heat signature of an object, as well as to sample air. It may be used to detect buried objects in soil.

Inorganic Compound An inorganic compound is a compound that generally does not contain carbon atoms (although carbonate and bicarbonate compounds are notable exceptions), tends to be soluble in water, and tends to react on an ionic rather than on a molecular basis. Examples of inorganic compounds include various acids, potassium hydroxide, and metals.

Innovative Technology An innovative technology is a process that has been tested and used as a treatment for hazardous waste or other contaminated materials, but lacks a long history of full-scale use and information about its cost and how well it works sufficient to support prediction of its performance under a variety of operating conditions. An innovative technology is one that is undergoing pilot-scale treatability studies that are usually conducted in the field or the laboratory; require installation of the technology; and provide performance, cost, and design objectives for the technology. Innovative technologies are being used under many Federal and state cleanup programs to treat hazardous wastes that have been improperly released. For example, innovative technologies are being selected to manage contamination (primarily petroleum) at some leaking underground storage sites. See also Emerging Technology and Established Technology.

In Situ The term in situ, "in its original place," or "on-site", means unexcavated and unmoved. In situ soil flushing and natural attenuation are examples of in situ treatment methods by which contaminated sites are treated without digging up or removing the contaminants.

In Situ Oxidation In situ oxidation is an innovative treatment technology that oxidizes contaminants that are dissolved in groundwater and converts them into insoluble compounds.

In Situ Soil Flushing In situ soil flushing is an innovative treatment technology that floods contaminated soils beneath the ground surface with a solution that moves the contaminants to an area from which they can be removed. The technology requires the drilling of injection and extraction wells on site and reduces the need for excavation, handling, or transportation of hazardous substances. Contaminants considered for treatment by in situ soil flushing include heavy metals (such as lead, copper, and zinc), aromatics, and PCBs. See also Aromatics, Heavy Metal, and Polychlorinated Biphenyl.

In Situ Vitrification In situ vitrification is a soil treatment technology that stabilizes metal and other inorganic contaminants in place at temperatures of approximately 3000• F. Soils and sludges are fused to form a stable glass and crystalline structure with very low leaching characteristics.

Institutional Controls An institutional control is a legal or institutional measure which subjects a property owner to limit activities at or access to a particular property. They are used to ensure protection of human health and the environment, and to expedite property reuse. Fences, posting or warning signs, and zoning and deed restrictions are examples of institutional controls.

Integrated Risk Information System (IRIS) IRIS is an electronic database that contains EPA's latest descriptive and quantitative regulatory information about chemical constituents. Files on chemicals maintained in IRIS contain information related to both non-carcinogenic and carcinogenic health effects.

Landfarming Landfarming is the spreading and incorporation of wastes into the soil to initiate biological treatment.

Landfill A sanitary landfill is a land disposal site for nonhazardous solid wastes at which the waste is spread in layers compacted to the smallest practical volume.

Laser-Induced Fluorescence/Cone Penetrometer Laser-induced fluorescence/cone penetrometer is a field screening method that couples a fiber optic-based chemical sensor system to a cone penetrometer mounted on a truck. The technology can be used for investigating and assessing soil and water contamination.

Lead Lead is a heavy metal that is hazardous to health if breathed or swallowed. Its use in gasoline, paints, and plumbing compounds has been sharply restricted or eliminated by Federal laws and regulations. See also Heavy Metal.

Leaking Underground Storage Tank (LUST) LUST is the acronym for "leaking underground storage tank." See also Underground Storage Tank.

Magnetrometry Magnetrometry is a geophysical technology used to detect disruptions that metal objects cause in the earth's localized magnetic field.

Mass Spectrometry Mass spectrometry is an analytical process by which molecules are broken into fragments to determine the concentrations and mass/charge ratio of the fragments. Innovative mass spectroscopy units, developed through modification of large laboratory instruments, are sometimes portable, weatherproof units with self-contained power supplies.

Medium A medium is a specific environment -- air, water, or soil -- which is the subject of regulatory concern and activities.

Mercury Mercury is a heavy metal that can accumulate in the environment and is highly toxic if breathed or swallowed. Mercury is found in thermometers, measuring devices, pharmaceutical and agricultural chemicals, chemical manufacturing, and electrical equipment. See also Heavy Metal.

Mercury Vapor Analyzer A mercury vapor analyzer is an instrument that provides real-time measurements of concentrations of mercury in the air.

Methane Methane is a colorless, nonpoisonous, flammable gas created by anaerobic decomposition of organic compounds.

Migration Pathway A migration pathway is a potential path or route of contaminants from the source of contamination to contact with human populations or the environment. Migration pathways include air, surface water, groundwater, and land surface. The existence and identification of all potential migration pathways must be considered during assessment and characterization of a waste site.

Mixed Waste Mixed waste is low-level radioactive waste contaminated with hazardous waste that is regulated under the Resource Conservation and Recovery Act (RCRA). Mixed waste can be disposed only in compliance with the requirements under RCRA that govern disposal of hazardous waste and with the RCRA land disposal restrictions, which require that waste be treated before it is disposed of in appropriate landfills.

Monitoring Well A monitoring well is a well drilled at a specific location on or off a hazardous waste site at which groundwater can be sampled at selected depths and studied to determine the direction of groundwater flow and the types and quantities of contaminants present in the groundwater.

National Pollutant Discharge Elimination System (NPDES) NPDES is the primary permitting program under the Clean Water Act, which regulates all discharges to surface water. It prohibits discharge of pollutants into waters of the United States unless EPA, a state, or a tribal government issues a special permit to do so.

National Priorities List (NPL) The NPL is EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term cleanup under Superfund. Inclusion of a site on the list is based primarily on the score the site receives under the Hazard Ranking System (HRS). Money from Superfund can be used for cleanup only at sites that are on the NPL. EPA is required to update the NPL at least once a year.

Natural Attenuation Natural attenuation is an approach to cleanup that uses natural processes to contain the spread of contamination from chemical spills and reduce the concentrations and amounts of pollutants in contaminated soil and groundwater. Natural subsurface processes, such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials, reduce concentrations of contaminants to acceptable levels. An in situ treatment method that leaves the contaminants in place while those processes occur, natural attenuation is being used to clean up petroleum contamination from leaking underground storage tanks (LUST) across the country.

Non-Point Source The term non-point source is used to identify sources of pollution that are diffuse and do not have a point of origin or that are not introduced into a receiving stream from a specific outlet. Common non-point sources are rain water, runoff from agricultural lands, industrial sites, parking lots, and timber operations, as well as escaping gases from pipes and fittings.

Operation and Maintenance (O&M) O&M refers to the activities conducted at a site, following remedial actions, to ensure that the cleanup methods are working properly. O&M activities are conducted to maintain the effectiveness of the cleanup and to ensure that no new threat to human health or the environment arises. O&M may include such activities as groundwater and air monitoring, inspection and maintenance of the treatment equipment remaining on site, and maintenance of any security measures or institutional controls.

Organic Chemical or Compound An organic chemical or compound is a substance produced by animals or plants that contains mainly carbon, hydrogen, and oxygen.

Permeability Permeability is a characteristic that represents a qualitative description of the relative ease with which rock, soil, or sediment will transmit a fluid (liquid or gas).

Pesticide A pesticide is a substance or mixture of substances intended to prevent or mitigate infestation by, or destroy or repel, any pest. Pesticides can accumulate in the food chain and/or contaminate the environment if misused.

Phenols A phenol is one of a group of organic compounds that are byproducts of petroleum refining, tanning, and textile, dye, and resin manufacturing. Low concentrations of phenols cause taste and odor problems in water; higher concentrations may be harmful to human health or the environment.

Photoionization Detector (PID) A PID is a nondestructive detector, often used in conjunction with gas chromatography, that measures the change of signal as analytes are ionized by an ultraviolet lamp. The PID is also used to detect VOCs and petroleum hydrocarbons.

Phytoremediation Phytoremediation is an innovative treatment technology that uses plants and trees to clean up contaminated soil and water. Plants can break down, or degrade, organic pollutants or stabilize metal contaminants by acting as filters or traps. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polyaromatic hydrocarbons, and landfill leachates. Its use generally is limited to sites at which concentrations of contaminants are relatively low and contamination is found in shallow soils, streams, and groundwater.

Plasma High-Temperature Metals Recovery Plasma high-temperature metals recovery is a thermal treatment process that purges contaminants from solids and soils such as metal fumes and organic vapors. The vapors can be burned as fuel, and the metal fumes can be recovered and recycled. This innovative treatment technology is used to treat contaminated soil and groundwater.

Plume A plume is a visible or measurable emission or discharge of a contaminant from a given point of origin into any medium. The term also is used to refer to measurable and potentially harmful radiation leaking from a damaged reactor.

Point Source A point source is a stationary location or fixed facility from which pollutants are discharged or emitted; or any single, identifiable discharge point of pollution, such as a pipe, ditch, or smokestack.

Polychlorinated Biphenyl (PCB) PCBs are a group of toxic, persistent chemicals, produced by chlorination of biphenyl, that once were used in high voltage electrical transformers because they conducted heat well while being fire resistant and good electrical insulators. These contaminants typically are generated from metal degreasing, printed circuit board cleaning, gasoline, and wood preserving processes. Further sale or use of PCBs was banned in 1979.

Polyaromatic Hydrocarbon (PAH) A PAH is a chemical compound that contains more than one fused benzene ring. They are commonly found in petroleum fuels, coal products, and tar.

Pump and Treat Pump and treat is a general term used to describe cleanup methods that involve the pumping of groundwater to the surface for treatment. It is one of the most common methods of treating polluted aquifers and groundwater.

Radioactive Waste Radioactive waste is any waste that emits energy as rays, waves, or streams of energetic particles. Sources of such wastes include nuclear reactors, research institutions, and hospitals.

Radionuclide A radionuclide is a radioactive element characterized according to its atomic mass and atomic number, which can be artificial or naturally occurring. Radionuclides have a long life as soil or water pollutants. Radionuclides cannot be destroyed or degraded; therefore, applicable technologies involve separation, concentration and volume reduction, immobilization, or vitrification. See also Solidification and Stabilization.

Radon Radon is a colorless, naturally occurring, radioactive, inert gaseous element formed by radioactive decay of radium atoms. See also Radioactive Waste and Radionuclide.

Release A release is any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, leaching, dumping, or disposing into the environment of a hazardous or toxic chemical or extremely hazardous substance, as defined under RCRA. See also Resource Conservation and Recovery Act.

Resource Conservation and Recovery Act (RCRA) RCRA is a Federal law enacted in 1976 that established a regulatory system to track hazardous substances from their generation to their disposal. The law requires the use of safe and secure procedures in treating, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent the creation of new, uncontrolled hazardous waste sites.

Risk Communication Risk communication, the exchange of information about health or environmental risks among risk assessors, risk managers, the local community, news media and interest groups, is the process of informing members of the local community about environmental risks associated with a site and the steps that are being taken to manage those risks.

Saturated Zone The saturated zone is the area beneath the surface of the land in which all openings are filled with water at greater than atmospheric pressure.

Seismic Reflection and Refraction Seismic reflection and refraction is a technology used to examine the geophysical features of soil and bedrock, such as debris, buried channels, and other features.

Semi-Volatile Organic Compound (SVOC) SVOCs, composed primarily of carbon and hydrogen atoms, have boiling points greater than 200• C. Common SVOCs include PCBs and phenol. See also Polychlorinated Biphenyl.

Site Assessment A site assessment is an initial environmental investigation that is limited to a historical records search to determine ownership of a site and to identify the kinds of chemical processes that were carried out at the site. A site assessment includes a site visit, but does not include any sampling. If such an assessment identifies no significant concerns, a site investigation is not necessary.

Site Investigation A site investigation is an investigation that includes tests performed at the site to confirm the location and identity environmental hazards. The assessment includes preparation of a report that includes recommendations for cleanup alternatives.

Sludge Sludge is a semisolid residue from air or water treatment processes. Residues from treatment of metal wastes and the mixture of waste and soil at the bottom of a waste lagoon are examples of sludge, which can be a hazardous waste.

Slurry-Phase Bioremediation Slurry-phase bio-remediation, a treatment technology that can be used alone or in conjunction with other biological, chemical, and physical treatments, is a process through which organic contaminants are converted to innocuous compounds. Slurry-phase bioremediation can be effective in treating various semi-volatile organic carbons (SVOCs) and nonvolatile organic compounds, as well as fuels, creosote, pentachlorophenols (PCP), and PCBs. See also Polychlorinated Biphenyl and Semi-Volatile Organic Carbon.

Soil Boring Soil boring is a process by which a soil sample is extracted from the ground for chemical, biological, and analytical testing to determine the level of contamination present.

Soil Gas Soil gas consists of gaseous elements and compounds that occur in the small spaces between particles of the earth and soil. Such gases can move through or leave the soil or rock, depending on changes in pressure.

Soil Washing Soil washing is an innovative treatment technology that uses liquids (usually water, sometimes combined with chemical additives) and a mechanical process to scrub soils, removes hazardous contaminants, and concentrates the contaminants into a smaller volume. The technology is used to treat a wide range of contaminants, such as metals, gasoline, fuel oils, and pesticides. Soil washing is a relatively low-cost alternative for separating waste and minimizing volume as necessary to facilitate subsequent treatment. It is often used in combination with other treatment technologies. The technology can be brought to the site, thereby eliminating the need to transport hazardous wastes.

Solidification and Stabilization Solidification and stabilization are the processes of removing wastewater from a waste or changing it chemically to make the waste less permeable and susceptible to transport by water. Solidification and stabilization technologies can immobilize many heavy metals, certain radionuclides, and selected organic compounds, while decreasing the surface area and permeability of many types of sludge, contaminated soils, and solid wastes.

Solvent A solvent is a substance, usually liquid, that is capable of dissolving or dispersing one or more other substances.

Solvent Extraction Solvent extraction is an innovative treatment technology that uses a solvent to separate or remove hazardous organic contaminants from oily-type wastes, soils, sludges, and sediments. The technology does not destroy contaminants, but concentrates them so they can be recycled or destroyed more easily by another technology. Solvent extraction has been shown to be effective in treating sediments, sludges, and soils that contain primarily organic contaminants, such as PCBs, VOCs, halogenated organic compounds, and petroleum wastes. Such contaminants typically are generated from metal degreasing, printed circuit board cleaning, gasoline, and wood preserving processes. Solvent extraction is a transportable technology that can be brought to the site. See also Polychlorinated

Biphenyl and Volatile Organic Compound.

Surfactant Flushing Surfactant flushing is an innovative treatment technology used to treat contaminated groundwater. Surfactant flushing of NAPLs increases the solubility and mobility of the contaminants in water so that the NAPLs can be biodegraded more easily in an aquifer or recovered for treatment aboveground.

Surface Water Surface water is all water naturally open to the atmosphere, such as rivers, lakes, reservoirs, streams, and seas.

Superfund Superfund is the trust fund that provides for the cleanup of significantly hazardous substances released into the environment, regardless of fault. The Superfund was established under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and subsequent amendments to CERCLA. The term Superfund is also used to refer to cleanup programs designed and conducted under CERCLA and its subsequent amendments.

Superfund Amendment and Reauthorization Act (SARA) SARA is the 1986 act amending Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) that increased the size of the Superfund trust fund and established a preference for the development and use of permanent remedies, and provided new enforcement and settlement tools.

Thermal Desorption Thermal desorption is an innovative treatment technology that heats soils contaminated with hazardous wastes to temperatures from 200• to 1,000• F so that contaminants that have low boiling points will vaporize and separate from the soil. The vaporized contaminants are then collected for further treatment or destruction, typically by an air emissions treatment system. The technology is most effective at treating VOCs, SVOCs and other organic contaminants, such as PCBs, polyaromatic hydrocarbons (PAHs), and pesticides. It is effective in separating organics from refining wastes, coal tar wastes, waste from wood treatment, and paint wastes. It also can separate solvents, pesticides, PCBs, dioxins, and fuel oils from contaminated soil. See also Polyaromatic Hydrocarbon, Polychlorinated Biphenyl, Semivolatile Organic Compound, and Volatile Organic Compound.

Total Petroleum Hydrocarbon (TPH) TPH refers to a measure of concentration or mass of petroleum hydrocarbon constituents present in a given amount of air, soil, or water.

Toxicity Toxicity is a quantification of the degree of danger posed by a substance to animal or plant life.

Toxicity Characteristic Leaching Procedure (TCLP) The TCLP is a testing procedure used to identify the toxicity of wastes and is the most commonly used test for determining the degree of mobilization offered by a solidification and stabilization process. Under this procedure, a waste is subjected to a process designed to model the leaching effects that would occur if the waste was disposed of in a RCRA Subtitle D municipal landfill. See also Solidification and Stabilization.

Toxic Substance A toxic substance is a chemical or mixture that may present an unreasonable risk of injury to health or the environment.

Treatment Wall (also Passive Treatment Wall) A treatment wall is a structure installed underground to treat contaminated groundwater found at hazardous waste sites. Treatment walls, also called passive treatment walls, are put in place by constructing a giant trench across the flow path of contaminated groundwater and filling the trench with one of a variety of materials carefully selected for the ability to clean up specific types of contaminants. As the contaminated groundwater passes through the treatment wall, the contaminants are trapped by the treatment wall or transformed into harmless substances that flow out of the wall. The major advantage of using treatment walls is that they are passive systems that treat the contaminants in place so the property can be put to productive use while it is being cleaned up. Treatment walls are useful at some sites contaminated with chlorinated solvents, metals, or radioactive contaminants.

Underground Storage Tank (UST) A UST is a tank located entirely or partially underground that is designed to hold gasoline or other petroleum products or chemical solutions.

Unsaturated Zone The unsaturated zone is the area between the land surface and the uppermost aquifer (or saturated zone). The soils in an unsaturated zone may contain air and water.

Vadose Zone The vadose zone is the area between the surface of the land and the aquifer water table in which the moisture content is less than the saturation point and the pressure is less than atmospheric. The openings (pore spaces) also typically contain air or other gases.

Vapor Vapor is the gaseous phase of any substance that is liquid or solid at atmospheric temperatures and pressures. Steam is an example of a vapor.

Volatile Organic Compound (VOC) A VOC is one of a group of carbon-containing compounds that evaporate readily at room temperature. Examples of volatile organic compounds include trichloroethane, trichloroethylene, benzene, toluene, ethylbenzene, and xylene (BTEX). These contaminants typically are generated from metal degreasing, printed circuit board cleaning, gasoline, and wood preserving processes.

Volatilization Volatilization is the process of transfer of a chemical from the aqueous or liquid phase to the gas phase. Solubility, molecular weight, and vapor pressure of the liquid and the nature of the gas- liquid affect the rate of volatilization.

Voluntary Cleanup Program (VCP) A VCP is a formal means established by many states to facilitate assessment, cleanup, and redevelopment of brownfields sites. VCPs typically address the identification and cleanup of potentially contaminated sites that are not on the National Priorities List (NPL). Under VCPs, owners or developers of a site are encouraged to approach the state voluntarily to work out a process by which the site can be readied for development. Many state VCPs provide technical assistance, liability assurances, and funding support for such efforts.

Wastewater Wastewater is spent or used water from an individual home, a community, a farm, or an industry that contains dissolved or suspended matter.

Water Table A water table is the boundary between the saturated and unsaturated zones beneath the surface of the earth, the level of groundwater, and generally is the level to which water will rise in a well. See also Aquifer and Groundwater.

X-Ray Fluorescence Analyzer An x-ray fluorescence analyzer is a self-contained, field-portable instrument, consisting of an energy dispersive x-ray source, a detector, and a data processing system that detects and quantifies individual metals or groups of metals.

(This page is intentionally left blank.)

Appendix C
Testing Technologies

Table C-1. Non-Invasive Assessment Technologies

Applications	Strengths	Weaknesses	Typical Costs[1]
Infrared Thermography (IR/T)			
Locates buried USTs. • Locates buried leaks from USTs. • Locates buried sludge pits. • Locates buried nuclear and nonnuclear waste. • Locates buried oil, gas, chemical and sewer pipelines. • Locates buried oil, gas, chemical and sewer pipeline leaks. • Locates water pipelines. • Locates water pipeline leaks. • Locates seepage from waste dumps. • Locates subsurface smoldering fires in waste dumps. • Locates unexploded ordinance on hundreds or thousands of acres. • Locates buried landmines.	• Able to collect data on large areas very efficiently. (Hundreds of acres per flight) • Able to collect data on long cross country pipelines very efficiently (300-500 miles per day.) • Low cost for analyzed data per acre unit. • Able to prescreen and eliminate clean areas from further costly testing and unneeded rehabilitation. • Able to fuse data with other techniques for even greater accuracy in more situations. • Able to locate large and small leaks in pipelines and USTs. (Ultrasonic devices can only locate small, high pressure leaks containing ultrasonic noise.) • No direct contact with objects under test is required. (Ultrasonic devices must be in contact with buried pipelines or USTs.) • Has confirmed anomalies to depths greater than 38 feet with an accuracy of better than 80%. • Tests can be performed during both daytime and nighttime hours. • Normally no inconvenience to the public. •	• Cannot be used in rainy conditions. • Cannot be used to determine depth or thickness of anomalies. • Cannot determine what specific anomalies are detected. • Cannot be used to detect a specific fluid or contaminant, but all items not native to the area will be detected.	• Depends upon volume of data collected and type of targets looked for. • Small areas <1 acre: $1,000-$3,500. • Large areas>1,000 acres: $10 - $200 per acre.
Ground Penetrating Radar (GPR)			
• Locates buried USTs. • Locates buried leaks from USTs. • Locates buried sludge pits. • Locates buried nuclear and nonnuclear waste. • Locates buried oil, gas, chemical and sewer pipelines. • Locates buried oil and chemical pipeline leaks. • Locates water pipelines. • Locates water pipeline leaks. • Locates seepage from waste dumps. • Locates cracks in subsurface strata such as limestone.	• Can investigate depths from 1 centimeter to 100 meters+ depending upon soil or water conditions. • Can locate small voids capable of holding contamination wastes. • Can determine different types of materials such as steel, fiberglass or concrete. • Can be trailed behind a vehicle and travel at high speeds.	• Cannot be used in highly conductive environments such as salt water. • Cannot be used in heavy clay soils. • Data are difficult to interpret and require a lot of experience.	• Depends upon volume of datacollected and type of targets looked for. • Small areas <1 acre: $3,500 - $5,000 • Large areas > 10 acres: $2,500 - $3,500 per acre

Non-Invasive Assessment Technologies **Continued**

Electromagnetic Offset Logging (EOL)			
• Locates buried hydrocarbon pipelines • Locates buried hydrocarbon USTs. • Locates hydrocarbon tanks. • Locates hydrocarbon barrels. • Locates perched hydrocarbons. • Locates free floating hydrocarbons. • Locates dissolved hydrocarbons. • Locates sinker hydrocarbons. • Locates buried well casings.	• Produces 3D images of hydrocarbon plumes. • Data can be collected to depth of 100 meters. • Data can be collected from a single, unlined or nonmetal lined well hole. • Data can be collected within a 100 meter radius of a single well hole. • 3D images can be sliced in horizontal and vertical planes. • DNAPLs can be imaged.	• Small dead area around well hole of approximately 8 meters. • This can be eliminated by using 2 complementary well holes from which to collect data.	• Depends upon volume of data collected and type of targets looked for. • Small areas < 1 acre: $10,000 - $20,000 • Large areas > 10 acres: $5,000 - $10,000 per acre
Magnetometer (MG)			
• Locates buried ferrous materials such as barrels, pipelines, USTs, and buckets.	• Low cost instruments can be be used that produce results by audio signal strengths. • High cost instruments can be used that produce hard copy printed maps of targets. • Depths to 3 meters. 1 acre per day typical efficiency in data collection.	• Non-relevant artifacts can be confusing to data analyzers. • Depth limited to 3 meters.	• Depends upon volume of data collected and type of targets looked for. • Small areas < 1 acre: $2,500 - $5,000 • Large areas > 10 acres: $1,500 -$2,500 per acre

[1] Cost based on case study data in 1997 dollars.

Table C-2. Soil and Subsurface Sampling Tools

	Media			
Technique/Instrumentation	Soil	Ground Water	Relative Cost per Sample	Sample Quality
Drilling Methods				
Cable Tool	X	X	Mid-range expensive	Soil properties will probably be altered
Casing Advancement	X	X	Most expensive	Soil properties will likely be altered
Direct Air Rotary with Rotary Bit Downhole Hammer	X	X	Mid-range expensive	Soil properties will probably be altered
Direct Mud Rotary	X	X	Mid-range expensive	Soil properties may be altered
Directional Drilling	X	X	Most expensive	Soil properties may be altered
Hollow-Stem Auger	X	X	Mid-range expensive	Soil properties may be altered
Jetting Methods	X	X	Least expensive	Soil properties may be altered
Rotary Diamond Drilling	X	X	Most expensive	Soil properties may be altered
Rotating Core	X		Mid-range expensive	Soil properties may be altered
Solid Flight and Bucket Augers	X	X	Mid-range expensive	Soil properties will likely be altered
Sonic Drilling	X	X	Most expensive	Soil properties will probably be unaltered
Split and Solid Barrel	X		Least expensive	Soil properties may be altered
Thin-Wall Open Tube	X		Mid-range expensive	Soil properties will probably be unaltered
Thin-Wall Piston/l Specialized Thin Wall	X		Mid-range expensive	Soil properties will probably be unaltered
Direct Push Methods				
Cone Penetrometer	X	X	Mid-range expensive	Soil properties may be altered
Driven Wells		X	Mid-range expensive	Soil properties may be altered
Hand-Held Methods				
Augers	X	X	Least expensive	Soil properties may be altered
Rotating Core	X		Mid-range expensive	Soil properties may be altered
Scoop, Spoons, and Shovels	X		Least expensive	Soil properties may be altered
Split and Solid Barrel	X		Least expensive	Soil properties may be altered
Thin-Wall Open Tube	X		Mid-range expensive	Soil properties will probably be unaltered
Thin-Wall Piston Specialized Thin Wall	X		Mid-range expensive	Soil properties will probably be unaltered
Tubes	X		Least expensive	Soil properties will probably be unaltered

Table C-3. Groundwater Sampling Tools

Technique/Instrumentation	Contaminants[1]	Relative Cost per Sample	Sample Quality
Portable Groundwater Sampling Pumps			
Bladder Pump	SVOCs, PAHs, metals	Mid-range expensive	Liquid properties will probably be unaltered
Gas-Driven Piston Pump	SVOCs, PAHs, metals	Most Expensive	Liquid properties will probably be unaltered by sampling
Gas-Driven Displacement Pumps	SVOCs, PAHs, metals	Least expensive	Liquid properties will probably be unaltered by sampling
Gear Pump	SVOCs, PAHs, metals	Mid-range expensive	Liquid properties may be altered
Inertial-Lift Pumps	SVOCs, PAHs, metals	Least expensive	Liquid properties will probably be unaltered
Submersible Centrifugal Pumps	SVOCs, PAHs, metals	Most expensive	Liquid properties may be altered
Submersible Helical-Rotor Pump	SVOCs, PAHs, metals	Most expensive	Liquid properties may be altered
Suction-Lift Pumps (peristaltic)	SVOCs, PAHs, metals	Least expensive	Liquid properties may be altered
Portable Grab Samplers			
Bailers	VOCs, SVOCs, PAHs, metals	Least expensive	Liquid properties may be altered
Pneumatic Depth-Specific Samplers	VOCs, SVOCs, PAHs, metals	Mid-range expensive	Liquid properties will probably be unaltered
Portable In Situ Groundwater Samplers/Sensors			
Cone Penetrometer Samplers	VOCs, SVOCs, PAHs, metals	Least expensive	Liquid properties will probably be unaltered
Direct Drive Samplers	VOCs, SVOCs, PAHs, metals	Least expensive	Liquid properties will probably be unaltered
Hydropunch	VOCs, SVOCs, PAHs, metals	Mid-range expensive	Liquid properties will probably be unaltered
Fixed In Situ Samplers			
Multilevel Capsule Samplers	VOCs, SVOCs, PAHs, metals	Mid-range expensive	Liquid properties will probably be unaltered
Multiple-Port Casings	VOCs, SVOCs, PAHs, metals	Least expensive	Liquid properties will probably be unaltered
Passive Multilayer Samplers	VOCs	Least expensive	Liquid properties will probably be unaltered

Bold	Most commonly used field techniques
VOCs	Volatile Organic Carbons
SVOCs	Semivolatile Organic Carbons
PAHs	Polyaromatic Hydrocarbons

Table C-4. Sample Analysis Technologies

		Media						
Technique/ Instrumentation	**Analytes**	**Soil**	**Ground Water**	**Gas**	**Relative Detection**	**Relative Cost per Analysis**	**Application****	**Produces Quantitative Data**
Metals								
Laser-Induced Breakdown Spectrometry	Metals	X			ppb	Least expensive	Usually used in field	Additional effort required
Titrimetry Kits	Metals	X	X		ppm	Least expensive	Usually used in laboratory	Additional effort required
Particle-Induced X-ray Emissions	Metals	X	X		ppm	Mid-range expensive	Usually used in laboratory	Additional effort required
Atomic Adsorption Spectrometry	Metals	X*	X	X	ppb	Most expensive	Usually used in laboratory	Yes
Inductively Coupled Plasma--Atomic Emission Spectroscopy	Metals	X*	X	X	ppb	Most expensive	Usually used in laboratory	Yes
Field Bioassessment	Metals	X	X			Most expensive	Usually used in field	No
X-Ray Fluorescence	Metals	X	X	X	ppm	Least expensive	Laboratory and field	Yes (limited)
PAHs, VOCs, and SVOCs								
Laser-Induced Fluorescence (LIF)	PAHs	X	X		ppm	Least expensive	Usually used in field	Additional effort required
Solid/Porous Fiber Optic	VOCs	X*	X	X	ppm	Least expensive	Immediate, can be used in field	Additional effort required
Chemical Calorimetric Kits	VOCs, SVOCs, PAHs	X	X		ppm	Least expensive	Can be used in field, usually used in laboratory	Additional effort required
Flame Ionization Detector (hand-held)	VOCs	X*	X*	X	ppm	Least expensive	Immediate, can be used in field	No
Explosimeter	VOCs	X*	X*	X	ppm	Least expensive	Immediate, can be used in field	No
Photo Ionization Detector (hand-held)	VOCs, SVOCs	X*	X*	X	ppm	Least expensive	Immediate, can be used in field	No
Catalytic Surface Oxidation	VOCs	X*	X*	X	ppm	Least expensive	Usually used in laboratory	No
Near IR Reflectance/Trans Spectroscopy	VOCs	X			100-1,000 ppm	Mid-range expensive	Usually used in laboratory	Additional effort required
Ion Mobility Spectrometer	VOCs, SVOCs	X*	X*	X	100-1,000 ppb	Mid-range expensive	Usually used in laboratory	Yes

Sample Analysis Technologies (continued)

		Media						
Technique/ Instrumentation	**Analytes**	**Soil**	**Ground Water**	**Gas**	**Relative Detection**	**Relative Cost per Analysis**	**Application****	**Produces Quantitative Data**
Infrared Spectroscopy	VOCs, SVOCs	X	X	X	100-1,000 ppm	Mid-range expensive	Usually used in laboratory	Additional effort required
Scattering/Absorption Lidar	VOCs	X*	X*	X	100-1,000 ppm	Mid-range expensive	Usually used in laboratory	Additional effort required
FTIR Spectroscopy	VOCs	X*	X*	X	ppm	Mid-range expensive	Laboratory and field	Additional effort required
Synchronous Luminescence/ Fluorescence	VOCs, SVOCs	X*	X		ppb	Mid-range expensive	Usually used in laboratory, can be used in field	Additional effort required
Gas Chromatography (GC) (can be used with numerous detectors)	VOCs, SVOCs	X*	X	X	ppb	Mid-range expensive	Usually used in laboratory, can be used in field	Yes
UV-Visible Spectrophotometry	VOCs	X*	X	X	ppb	Mid-range expensive	Usually used in laboratory	Additional effort required
UV Fluorescence	VOCs	X	X	X	ppb	Mid-range expensive	Usually used in laboratory	Additional effort required
Ion Trap	VOCs, SVOCs	X*	X*	X	ppb	Most expensive	Laboratory and field	Yes
Other								
Chemical Reaction- Based Test Papers	VOCs, SVOCs, Metals	X	X		ppm	Least expensive	Usually used in field	Yes
Immunoassay and Calorimetric Kits	VOCs, SVOCs, Metals	X	X		ppm	Least expensive	Usually used in laboratory, can be used in field	Additional effort required

VOCs	Volatile Organic Compounds
SVOCs	Semivolatile Organic Compounds (may be present in oil and grease)
PAHs	Polyaromatic Hydrocarbons
X*	Indicates there must be extraction of the sample to gas or liquid phase
**	Samples sent to laboratory require shipping time and usually 14 to 35 days turnaround time for analysis. Rush orders cost an additional amount per sample.

Appendix D
Cleanup Technologies

Exhibit D-1 Table of Cleanup Technologies

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Containment Technologies				
Capping	• Used to cover buried waste materials to prevent migration.Consist of a relatively impermeable material that will minimize rainfall infiltration.Waste materials can be left in place.Requires periodic inspections and routine monitoring.Contaminant migration must be monitored periodically.	• MetalsCyanide	• Costs associated with routine sampling and analysis may be high.Long-term maintenance may be required to ensure impermeability.May have to be replaced after 20 to 30 years of operation.May not be effective if groundwater table is high.	• $11 to $40 per square foot.[1]
Sheet Piling	• Steel or iron sheets are driven into the ground to form a subsurface barrier.Low-cost containment method.Used primarily for shallow aquifers.	• Not contaminant-specific	• Not effective in the absence of a continuous aquitard.Can leak at the intersection of the sheets and the aquitard or through pile wall joints.	• $8 to $17 per square foot.[2]
Grout Curtain	• Grout curtains are injected into subsurface soils and bedrock.Forms an impermeable barrier in the subsurface.	• Not contaminant-specific	• Difficult to ensure a complete curtain without gaps through which the plume can escape; however new techniques have improved continuity of curtain.	• $6 to $14 per square foot.[2]

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	**Technology Description**	**Contaminants Treated by this Technology**	**Limi**	**Cost**
Slurry Walls	• Used to contain contaminated ground water, landfill leachate, divert contaminated groundwater from drinking water intake, divert uncontaminated groundwater flow, or provide a barrier for the groundwater treatment system.Consist of a vertically excavated slurry-filled trench.The slurry hydraulically shores the trench to prevent collapse and forms a filtercake to reduce groundwater flow.Often used where the waste mass is too large for treatment and where soluble and mobile constituents pose an imminent threat to a source of drinking threat to a source of drinking water.Often constructed of a soil, bentonite, and water mixture.	• Not contaminant-specific	• Contains contaminants only within a specified area.Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals.Potential for the slurry walls to degrade or deteriorate over time.	• Design and installation costs of $5 to $7 per square foot (1991 dollars) for a standard soil-bentonite wall in soft to medium soil.[3]Above costs do not include variable costs required for chemical analyses, feasibility, or compatibility testing.
Ex Situ Technologies				
Excavation/Offsite Disposal	• Removes contaminated material to an EPA approved landfill.	• Not contaminant-specific	• Generation of fugitive emissions may be a problem during operations.The distance from the contaminated site to the nearest disposal facility will affect cost.Depth and composition of the media requiring excavation must be considered.Transportation of the soil through populated areas may affect community acceptability.Disposal options for certain waste (e.g., mixed waste or transuranic waste) may be limted. There is currently only one licensed disposal facility for radioactive and mixed waste in the United States.	• $270 to $460 per ton.[2]

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Composting	• Controlled microbiological process by which biodegradable hazardous materials in soils are converted to innocuous, stabilized byproducts.Typically occurs at temperatures ranging from 50° to 55°C (120° to 130°F).May be applied to soils and lagoon sediments.Maximum degradation efficiency is achieved by maintaining moisture content, pH, oxygenation, temperature, and the carbon-nitrogen ratio.	• SVOCs.	• Substantial space is required. Excavation of contaminated soils is required and may cause the uncontrolled release of VOCs.Composting results in a volumetric increase in material and space required for treatment.Metals are not treated by this method and can be toxic to the microorganisms.The distance from the contaminated site to the nearest disposal facility will affect cost.	• $190 or greater per cubic yard for soil volumes of approximately 20,000 cubic yards.[3]Costs will vary with the amount of soil to be treated, the soil fraction of the com post, availability of amendments, the type of contaminant and the type of process design employed.
Chemical Oxidation/ Reduction	• Reduction/oxidation (Redox) reactions chemically convert hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, or inert.Redox reactions involve the transfer of electrons from one compound to another.The oxidizing agents commonly used are ozone, hydrogen peroxide, hypochlorite, chlorine, and chlorine dioxide.	• MetalsCyanide	• Not cost-effective for high contaminant concentrations because of the large amounts of oxidizing agent required.Oil and grease in the media should be minimized to optimize process efficiency.	• $190 to $660 per cubic meter of soil.[3]
Soil Washing	• A water-based process for scrubbing excavated soils ex situ to remove contaminants.Removes contaminants by dissolving or suspending them in the wash solution, or by concentrating them into a smaller volume of soil through particle size separation, gravity separation, and attrition scrubbing.Systems incorporating most of the removal techniques offer the greatest promise for application to soils contaminated with a wide variety of metals and organic contaminants.	• SVOCsMetals	• Fine soil particles may require the addition of a polymer to remove them from the washing fluid.Complex waste mixtures make formulating washing fluid difficult.High humic content in soil may require pretreatment.The washing fluid produces an aqueous stream that requires treatment.	• $120 to $200 per ton of soil.[3]Cost is dependent upon the target waste quantity and concentration.

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Thermal Desorption	• Low temperatures (200°F to 900°F) are used to remove organic contaminants from soils and sludges.Off-gases are collected and treated. Requires treatment system after heating chamber.Can be performed on site or off site.	• VOCsPCBsPAHs	• Cannot be used to treat heavy metals, with exception of mercury.Contaminants of concern must have a low boiling point.Transportation costs to off-site facilities can be expensive.	• $50 to $300 per ton of soil.[3]Transportation charges are additional.
Incineration	• High temperatures 870° to 1,200° C (1400°F to 2,200°F) are used to volatilize and combust hazardous wastes.The destruction and removal efficiency for properly operated incinerators exceeds the 99.99% requirement for hazardous waste and can be operated to meet the 99.9999% requirement for PCBs and dioxins.Commercial incinerator designs are rotary kilns, equipped with an afterburner, a quench, and an air pollution control system.	• VOCsPCBsdioxins	• Only one off-site incinerator is permitted to burn PCBs and dioxins. Specific feed size and materials handling requirements that can affect applicability or cost at specific sites.Metals can produce a bottom ash that requires stabilization prior to disposal.Volatile metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal.Metals can react with other elements in the feed stream, such as chlorine or sulfur, forming more volatile and toxic compounds than the original species.	• $200 to $1,000 per ton of soil at off-site incinerators.$1,500 to $6,000 per ton of soil for soils contaminated with PCBs or dioxins.[3]Mobile units that can operate onsite reduce soil transportation costs.
UV Oxidation	• Destruction process that oxidizes constituents in wastewater by the addition of strong oxidizers and irradiation with UV light.Practically any organic contaminant that is reactive with the hydroxyl radical can potentially be treated. The oxidation reactions are achieved through the synergistic action of UV light in combination with ozone or hydrogen peroxide.Can be configured in batch or continuous flow models, depending on the throughput rate under consideration.	• VOCs	• The aqueous stream being treated must provide for good transmission of UV light (high turbidity causes interference).Metal ions in the wastewater may limit effectiveness.VOCs may volatilize before oxidation can occur. Off-gas may require treatment.Costs may be higher than competing technologies because of energy requirements.Handling and storage of oxidizers require special safety precautions.Off-gas may require treatment.	• $0.10 to $10 per 1,000 gallons are treated.[3]

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Pyrolysis	• A thermal treatment technology that uses chemical decomposition induced in organic materials by heat in the absence of oxygen. Pyrolysis transforms hazardous organic materials into gaseous components, small amounts of liquid, and a solid residue (coke) containing fixed carbon and ash.	• MetalsCyanide. PAHs	• Specific feed size and materials handling requirements affect applicability or cost at specific sites.Requires drying of the soil to achieve a low soil moisture content (<1%).Highly abrasive feed can potentially damage the processor unit.High moisture content increases treatment costs.Treated media containing heavy metals may require stabilization.May produce combustible gases, including carbon monoxide, hydrogen and methane, and other hydrocarbons.If the off-gases are cooled, liquids condense, producing an oil/tar residue and contaminated water.	• Capital and operating costs are expected to be approximately $330 per metric ton ($300 per ton).[3]
Precipitation	• Involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate.Precipitate can be physical methods such as clarification or filtration.Often used as a pretreatment for other treatment technologies where the presence of metals would interfere with the treatment processes.Primary method for treating metal-laden industrial wastewater.	• Metals.	• Contamination source is not removed.The presence of multiple metal species may lead to removal difficulties.Discharge standard may necessitate further treatment of effluent.Metal hydroxide sludges must pass TCLP criteria prior to land disposal.Treated water will often require pH adjustment.	• Capital costs are $85,000 to $115,000 for 20 to 65 gpm precipitation systems.Primary capital cost factor is design flow rate.Operating costs are $0.30 to $0.70 per 1,000.[3] Sludge disposal may be estimated to increase operating costs by $0.50 per 1,000 gallons treated.[3]

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	**Technology Description**	**Contaminants Treated by this Technology**	**Limi**	**Cost**
Liquid Phase Carbon Adsorption	• Groundwater is pumped through a series of vessels containing activated carbon, to which dissolved contaminants adsorb.Effective for polishing water discharges from other remedial technologies to attain regulatory compliance.Can be quickly installed.High contaminant-removal efficiencies.	• Low levels of metals.VOCs.SVOCs.	• The presence of multiple contaminants can affect process performance.Metals can foul the system.Costs are high if used as the primary treatment on waste streams with high contaminant concentration levels.Type and pore size of the carbon and operating temperature will impact process performance.Transport and disposal of spent carbon can be expensive.Water soluble compounds and small molecules are not adsorbed well.	• $1.20 to $6.30 per 1,000 gallons treated at flow rates of 0.1 mgd.Costs decrease with increasing low rates and concentrations.[3]Costs are dependent on waste stream flow rates, type of contaminant, concentration, and timing requirements.[3]
Air Stripping **In Situ Technologies**	• Contaminants are partitioned from groundwater by greatly increasing the surface area of the contaminated water exposed to air.Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.Can be operated continuously or in a batch mode, where the air stripper is intermittently fed from a collection tank.The batch mode ensures consistent air stripper performance and greater efficiency than continuously operated units because mixing in the storage tank eliminates any inconsistencies in feed water composition.	• VOCs.	• Potential for inorganic (iron greater than 5 ppm, hardness greater than 800 ppm) or biological fouling of the equipment, requiring pretreatment of groundwater or periodic column cleaning.Consideration should be given to the Henry's law constant of the VOCs in the water stream and the type and amount of packing used in the tower.Compounds with low volatility at ambient temperature may require preheating of the groundwater.Off-gases may require treatment based on mass emission rate and state and federal air pollution laws.	• $0.04 to $0.20 per 1,000 gallons.[3]A major operating cost of air strippers is the electricity required for the groundwater pump, the sump discharge pump, and the air blower.

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Natural Attenuation	• Natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface media can reduce contaminant concentrations to acceptable levels.Consideration of this option requires modeling and evaluation of contaminant degradation rates and pathways.Sampling and analyses must be conducted throughout the process to confirm that degradation is proceeding at sufficient rates to meet cleanup objectives.Nonhalogenated volatile and semivolatile organic compounds.	• VOCs	• Intermediate degradation products may be more mobile and more toxic than original contaminants.Contaminants may migrate before they degrade.The site may have to be fenced and may not be available for reuse until hazard levels are reduced.Source areas may require removal for natural attenuation to be effective.Modeling contaminant degradation rates, and sampling and analysis to confirm modeled predictions extremely expensive.	• Not available
Soil Vapor Extraction	• A vacuum is applied to the soil to induce controlled air flow and remove contaminants from the unsaturated (vadose) zone of the soil.The gas leaving the soil may be treated to recover or destroy the contaminants.The continuous air flow promotes in situ biodegradation of low-volatility organic compounds that may be present.	• VOCs	• Tight or very moist content (>50%) has a reduced permeability to air, requiring higher vacuums.Large screened intervals are required in extraction wells for soil with highly variable permeabilities.Air emissions may require treatment to eliminate possible harm to the public or environment.Off-gas treatment residual liquids and spent activated carbon may require treatment or disposal.Not effective in the saturated zone.	• $10 to $50 per cubic meter of soil.[3]Cost is site specific depending on the size of the site, the nature and amount of contamination, and the hydro-geological setting, which affect the number of wells, the blower capacity and vacuum level required, and length of time required to remediate the site.Off-gas treatment significantly adds to the cost.

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Soil Flushing	• Extraction of contaminants from the soil with water or other aqueous solutions.Accomplished by passing the extraction fluid through in-place soils using injection or infiltration processes.Extraction fluids must be recovered with extraction wells from the underlying aquifer and recycled when possible.	• Metals	• Low-permeability soils are difficult to treat.Surfactants can adhere to soil and reduce effective soil porosity.Reactions of flushing fluids with soil can reduce contaminant mobility.Potential of washing the contaminant beyond the capture zone and the introduction of surfactants to the subsurface.	• The major factor affecting cost is the separation of surfactants from recovered flushing fluid.[3]
Solidification/ Stabilization	• Reduces the mobility of hazardous substances and contaminants through chemical and physical means.Seeks to trap or immobilize contaminants within their "host" medium, instead of removing them through chemical or physical treatment.Can be used alone or combined with other treatment and disposal methods.	• MetalsLimited effectiveness for VOCs and SVOCs.	• Depth of contaminants may limit effectiveness.Future use of site may affect containment materials, which could alter the ability to maintain immobilization of contaminants.Some processes result in a significant increase in volume.Effective mixing is more difficult than for ex situ applications.Confirmatory sampling can be difficult.	• $50 to $80 per cubic meter for shallow applications.$190 to $330 per cubic meter for deeper applications.[3]Costs for cement-based stabilization techniques vary according to materials or reagents used, their availability, project size, and the chemical nature of the contaminant.

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Air Sparging	• In situ technology in which air is injected under pressure below the water table to increase groundwater oxygen concentrations and enhance the rate of biological degradation of contaminants by naturally occurring microbes.Increases the mixing in the saturated zone, which increases the contact between groundwater and soil. Air bubbles traverse horizontally and vertically through the soil column, creating an underground stripper that removes contaminants by volatilization.Air bubbles travel to a soil vapor extraction system.Air sparging is effective for facilitating extraction of deep contamination, contamination in low-permeability soils, and contamination in the saturated zone.	• VOCs	• Depth of contaminants and specific site geology must be considered.Air flow through the saturated zone may not be uniform.A permeability differential such as a clay layer above the air injection zone can reduce the effectiveness.Vapors may rise through the vadose zone and be released into the atmosphere.Increased pressure in the vadose zone can build up vapors in basements, which are generally low-pressure areas.	• $50 to $100 per 1,000 gallons of groundwater treated.[3]
Passive Treatment Walls	• A permeable reaction wall is installed inground, across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall.Allows the passage of water while prohibiting the movement of contaminants by employing such agents as iron, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and others.Contaminants are typically completely degraded by the treatment wall.	• MetalsVOCs	• The system requires control of pH levels. When pH levels within the passive treatment wall rise, it reduces the reaction rate and can inhibit the effectiveness of the wall.Depth and width of the plume. For large-scale plumes, installation cost may be high.Cost of treatment medium (iron).Biological activity may reduce the permeability of the wall.Walls may lose their reactive capacity, requiring replacement of the reactive medium.	• Capital costs for these projects range from $250,000 to $1,000,000.[3]Operations and maintenance costs approximately 5 to 10 times less than capital costs.
Chemical Oxidation	• Destruction process that oxidizes constituents in groundwater by the addition of strong oxidizers.Practically any organic contaminant that is reactive with the hydroxyl radical can potentially be treated.	• VOCs	• The addition of oxidizing compounds must be hydraulically controlled and closely monitored.Metal additives will precipitate out of solution and remain in the aquifer.Handling and storage of oxidizers require special safety precautions.	• Depends on mass present and hydrogeologic conditions.[3]

Exhibit D-1 Table of Cleanup Technologies (continued)

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Bioventing	• Stimulates the natural in-situ biodegradation of volatile organics in soil by providing oxygen to existing soil microorganisms.Oxygen commonly supplied through direct air injection.Uses low air flow rates to provide only enough oxygen to sustain microbial activity.Volatile compounds are biodegraded as vapors and move slowly through the biologically active soil.	• VOCs.	• Low soil-gas permeability.High water table or saturated soil layers.Vapors can build up in basements within the radius of influence of air injection wells.Low soil moisture content may limit biodegradation by drying out the soils.Low temperatures slow remediation.Chlorinated solvents may not degrade fully under certain subsurface conditions.Vapors may need treatment, depending on emission level and state regulations.	• $10 to $70 per cubic meter of soil.[3]Cost affected by contaminant type and concentration, soil permeability, well spacing and number, pumping rate, and off-gas treatment.
Biodegradation	• Indigenous or introduced microorganisms degrade organic contaminants found in soil and groundwater.Used successfully to remediate soils, sludges, and groundwater.Especially effective for remediating low-level residual contamination in conjunction with source removal.	• VOCs.	• Cleanup goals may not be attained if the soil matrix prevents sufficient mixing.Circulation of water-based solutions through the soil may increase contaminant mobility and necessitate treatment of underlying groundwater. • Injection wells may clog and prevent adequate flow rates.Preferential flow paths may result in nonuniform distribution of injected fluids.Should not be used for clay, highly layered, or heterogeneous subsurface environments.High concentrations of heavy metals, highly chlorinated organics, long chain hydrocarbons, or inorganic salts are likely to be toxic to microorganisms.Low temperatures slow bioremediation.Chlorinated solvents may not degrade fully under certain subsurface conditions.	• $30 to $100 per cubic meter of soil.[3]Cost affected by the nature and depth of the contaminants, use of bioaugmentation or hydrogen peroxide addition, and groundwater pumping rates.

Applicable Technology	Technology Description	Contaminants Treated by this Technology	Limi	Cost
Oxygen Releasing Compounds	- Based on Fenton's Reagent Chemistry.Stimulates the natural in situ biodegradation of petroleum hydrocarbons in soil and groundwater by providing oxygen to existing microorganisms.Oxygen supplied through the controlled dispersion and diffusion of active reagents, such as hydrogen peroxide.Active reagents are injected into the affected area using semi-permanent injection wells.	- TPHsVOCs	- Low soil permeability limits dispersion.Low soil moisture limits reaction time.Low temperatures slow reaction.Not cost-effective in the presence of unusually thick layers of free product.	- Relatively low cost in applications on small areas of contamination. Cost depends on size of treatment area and amount of contaminant present as free product.

1. Interagency Cost Workgroup, 1994.
2. Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites, U.S. EPA, 1986.
3. Federal Remediation Technology Roundtable. Http://www.frtr.gov/matrix/top_page.html

UST = underground storage tank
SVOCs = semi-volatile organic compounds
VOCs = volatile organic compounds
PAHs = polyaromatic hydrocarbons
PCBs = polychlorinated biphenyls
TPH = total petroleum hydrocarbons

Appendix E
Works Cited

A "PB" publication number in parentheses indicates that the document is available from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, VA 22161, (703-487-4650).

Landfill and Illegal Dump Sources

Center for Public Environmental Oversight. 1998. Landfill Caps and Enhancements. http://www.cpeo.org/techtree/ttdescript/lancap.htm

Energy Efficiency and Renewable Energy Network. 2000. How Landfill Gas to Electricity Works. http://www.eren.doe.gov/citie_counties/landfil1.html

Ewall, Mike. 1999. Primer on Landfill Gas as "Green" Energy. Pennsylvania Environmental Network. http://www.penweb.org/issues/energy/green4.html

Federal Remediation Technologies Roundtable. 2000. Landfill Cap. http://www.frtr.gov/matrix2/section4/4_30.html

Site Assessment

ASTM. 1997. Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process. American Society for Testing Materials (ASTM E1527-97).

ASTM. 1996. Standard Practice for Environmental Site Assessments: Transaction Screen Process. American Society for Testing Materials (ASTM E1528-96).

ASTM. 1995. Guide for Developing Conceptual Site Models for Contaminated Sites. American Society for Testing and Materials (ASTM E1689-95).

ASTM. 1995. Provisional Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases. American Society for Testing and Materials (ASTM PS3-95).

Data Quality Objectives Process for Hazardous Waste Site Investigations (EPA 2000)

Go-Environmental Solutions. N.D. http://www.gesolutions.com/assess.htm.

Geoprobe Systems, Inc. 1998. Rental Rate Sheet. September 15.

Robbat, Albert, Jr. 1997. Dynamic Workplans and Field Analytics: The Keys to Cost Effective Site Characterization and Cleanup. Tufts University under Cooperative Agreement with the U.S. Environmental Protection Agency. October.

U.S. EPA. 2000. Assessing Contractor Capabilities for Streamlined Site Investigations (EPA/542-R-00-001)

U.S. EPA. 1999. Cost Estimating Tools and Resources for Addressing Sites Under the Brownfields Initiative (EPA/625/R-99-001)

U.S. EPA. 1997. Expedited Site Assessment Tools for Underground Storage Tank Sites: A Guide for Regulators and Consultants (EPA 510-B-97-001).

U.S. EPA. 1997. Field Analytical and Site Characterization Technologies, Summary of Applications (EPA-542-R-97-011).

U.S. EPA. 1997. Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup. OSWER. (PB97-144810).

U.S. EPA. 1997. The Tool Kit of Technology Information Resources for Brownfields Sites. OSWER. (PB97-144828).

U.S. EPA. 1996. Consortium for Site Characterization Technology: Fact Sheet (EPA 542-F-96-012).

U.S. EPA. 1996. Field Portable X-Ray Fluorescence (FPXRF), Technology Verification Program: Fact Sheet (EPA 542-F-96-009a).

U.S. EPA. 1996. Portable Gas Chromatograph/Mass Spectrometers (GC/MS), Technology Verification Program: Fact Sheet (EPA 542-F-96-009c).

U.S. EPA. 1996. Site Characterization Analysis Penetrometer System (SCAPS) LIF Sensor (EPA 540-MR-95-520, EPA 540 R-95-520).

U.S. EPA. 1996. Site Characterization and Monitoring: A Bibliography of EPA Information Resources (EPA 542-B-96-001).

U.S. EPA. 1996. Soil Screening Guidance (540/R-96/128).

U.S. EPA. 1995. Clor-N-Soil PCB Test Kit L2000 PCB/Chloride Analyzer (EPA 540-MR-95-518, EPA 540-R-95-518).

U.S. EPA. 1995. Contract Laboratory Program: Volatile Organics Analysis of Ambient Air in Canisters Revision VCAA01.0 (PB95-963524).

U.S. EPA. 1995. Contract Lab Program: Draft Statement of Work for Quick Turnaround Analysis (PB95-963523).

U.S. EPA. 1995. EnviroGard PCB Test Kit (EPA 540-MR-95-517, EPA 540-R-95-517).

U.S. EPA. 1995. Field Analytical Screening Program: PCB Method (EPA 540-MR-95-521, EPA 540-R-95-521).

U.S. EPA. 1995. PCB Method, Field Analytical Screening Program (Innovative Technology Evaluation Report) (EPA 540-R-95-521, PB96-130026); Demonstration Bulletin (EPA 540-MR-95-521).

U.S. EPA. 1995. Profile of the Iron and Steel Industry (EPA 310-R-95-005).

U.S. EPA. 1995. Rapid Optical Screen Tool (ROST$^{\text{TM}}$) (EPA 540-MR-95-519, EPA 540-R-95-519).

U.S. EPA. 1995. Risk Assessment Guidance for Superfund.

http://www.epa.gov/ncepihom/Catalog/EPA540R95132.html.

U.S. EPA. 1994. Assessment and Remediation of Contaminated Sediments (ARCS) Program (EPA 905-R-94-003).

U.S. EPA. 1994. Characterization of Chromium-Contaminated Soils Using Field-Portable X-ray Fluorescence (PB94-210457).

U.S. EPA. 1994. Development of a Battery-Operated Portable Synchronous Luminescence Spectrofluorometer (PB94-170032).

U.S. EPA. 1994. Engineering Forum Issue: Considerations in Deciding to Treat Contaminated Unsaturated Soils In Situ (EPA 540-S-94-500, PB94-177771).

U.S. EPA. 1994. SITE Program: An Engineering Analysis of the Demonstration Program (EPA 540-R-94-530).

U.S. EPA. 1993. Data Quality Objectives Process for Superfund (EPA 540-R-93-071).

U.S. EPA. 1993. Conference on the Risk Assessment Paradigm After 10 Years: Policy and Practice, Then, Now, and in the Future. http://www.epa.gov/ncepihom/Catalog/EPA600R93039.html.

U.S. EPA. 1993. Guidance for Evaluating the Technical Impracticability of Ground Water Restoration. OSWER directive (9234.2-25).

U.S. EPA. 1993. Guide for Conducting Treatability Studies Under CERCLA: Biodegradation Remedy Selection (EPA 540-R-93-519a, PB94-117470).

U.S. EPA. 1993. Subsurface Characterization and Monitoring Techniques (EPA 625-R-93-003a&b).

U.S. EPA. 1992. Characterizing Heterogeneous Wastes: Methods and Recommendations (March 26-28,1991) (PB92-216894).

U.S. EPA. 1992. Conducting Treatability Studies Under RCRA (OSWER Directive 9380.3-09FS, PB92-963501)

U.S. EPA. 1992. Guidance for Data Useability in Risk Assessment (Part A) (9285.7-09A).

U.S. EPA. 1992. Guide for Conducting Treatability Studies Under CERCLA: Final (EPA 540-R-92-071A, PB93-126787).

U.S. EPA. 1992. Guide for Conducting Treatability Studies Under CERCLA: Soil Vapor Extraction (EPA 540-2-91-019a&b, PB92-227271 & PB92-224401).

U.S. EPA. 1992. Guide for Conducting Treatability Studies Under CERCLA: Soil Washing (EPA 540-2-91-020a&b, PB92-170570 & PB92-170588).

U.S. EPA. 1992. Guide for Conducting Treatability Studies Under CERCLA: Solvent Extraction (EPA 540-R-92-016a, PB92-239581).

U.S. EPA. 1992. Guide to Site and Soil Description for Hazardous Waste Site Characterization, Volume 1: Metals (PB92-146158).

U.S. EPA. 1992. International Symposium on Field Screening Methods for Hazardous Wastes and Toxic Chemicals (2nd), Proceedings. Held in Las Vegas, Nevada on February 12-14, 1991 (PB92-125764).

U.S. EPA. 1992. Sampling of Contaminated Sites (PB92-110436).

U.S. EPA. 1991. Ground Water Issue: Characterizing Soils for Hazardous Waste Site Assessment (PB-91-921294).

U.S. EPA. 1991. Guide for Conducting Treatability Studies Under CERCLA: Aerobic Biodegradation Remedy Screening (EPA 540-2-91-013a&b, PB92-109065 & PB92-109073).

U.S. EPA. 1991. Interim Guidance for Dermal Exposure Assessment (EPA 600-8-91-011A).

U.S. EPA. 1990. A New Approach and Methodologies for Characterizing the Hydrogeologic Properties of Aquifers (EPA 600-2-90-002).

U.S. EPA. 1986. Superfund Public Health Evaluation Manual (EPA 540-1-86-060).

U.S. EPA. N.D. Status Report on Field Analytical Technologies Utilization: Fact Sheet (no publication number available).

U.S.G.S. http://www.mapping.usgs.gov/esic/to_order.hmtl.

Vendor Field Analytical and Characterization Technologies System (Vendor FACTS), Version 1.0 (Vendor FACTS can be downloaded from the Internet at www.prcemi.com/visitt or from the CLU-IN Web site at http://clu-in.com).

The Whitman Companies. Last modified October 4, 1996. Environmental Due Diligence. http://www.whitmanco.com/dilgnce1.html.

Site Cleanup

ASTM. N.D. New Standard Guide for Remediation by Natural Attenuation at Petroleum Release Sites (ASTM E50.01).

Brownfields Redevelopment: A Guidebook for Local Governments & Communities, International City/County Management Association, 1997

Federal Register. September 9, 1997. www.access.gpo.gov/su_docs/aces/aces140.html, vol.62, no.174, p. 47495-47506.

Federal Remediation Technology Roundtable. http://www.frtr.gov/matrix/top_page.html.

Interagency Cost Workgroup. 1994. Historical Cost Analysis System. Version 2.0.

Los Alamos National Laboratory. 1996. A Compendium of Cost Data for Environmental Remediation Technologies (LA-UR-96-2205).

Oak Ridge National Laboratory. N.D. Treatability of Hazardous Chemicals in Soils: Volatile and Semi-Volatile Organics (ORNL-6451).

Robbat, Albert, Jr. 1997. Dynamic Workplans and Field Analytics: The Keys to Cost Effective Site Characterization and Cleanup. Tufts University under Cooperative Agreement with the U.S. Environmental Protection Agency. October.

U.S. EPA. 1999. Technical Approaches to Characterizing and Cleaning Up Metal Finishing Sites under the Brownfields Initiative. (EPA/625/R-98/006)

U.S. EPA. 1997. Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup. OSWER. PB97-144810).

U.S. EPA. 1997. The Tool Kit of Technology Information Resources for Brownfields Sites. OSWER. (PB97-144828).

U.S. EPA. 1996. Bioremediation Field Evaluation: Champion International Superfund Site, Libby, Montana (EPA 540-R-96-500).

U.S. EPA. 1996. Bibliography for Innovative Site Clean-Up Technologies (EPA 542-B-96-003).

U.S. EPA. 1996. Bioremediation of Hazardous Wastes: Research, Development, and Field Evaluations (EPA 540-R-95-532, PB96-130729).

U.S. EPA. 1996. Citizen's Guides to Understanding Innovative Treatment Technologies (EPA 542-F-96-013):

Bioremediation (EPA 542-F-96-007, EPA 542-F-96-023) In addition to screening levels, EPA regional offices and some states have developed cleanup levels, known as corrective action levels; if contaminant concentrations are above corrective action levels, cleanup must be pursued. The section on "Performing a Phase II Site Assessment" in this document provides more information on screening levels, and the section on "Site Cleanup" provides more information on corrective action levels.

Chemical Dehalogenation (EPA 542-F-96-004, EPA 542-F-96-020)

In Situ Soil Flushing (EPA 542-F-96-006, EPA 542-F-96-022)

Innovative Treatment Technologies for Contaminated Soils, Sludges, Sediments, and Debris (EPA 542-F-96-001, EPA 542-F-96-017)

Phytoremediation (EPA 542-F-96-014, EPA 542-F-96-025)

Soil Vapor Extraction and Air Sparging (EPA 542-F-96-008, EPA 542-F-96-024)

Soil Washing (EPA 542-F-96-002, EPA 542-F-96-018)

Solvent Extraction (EPA 542-F-96-003, EPA 542-F-96-019)

Thermal Desorption (EPA 542-F-96-005, EPA 542-F-96-021)

Treatment Walls (EPA 542-F-96-016, EPA 542-F-96-027)

U.S. EPA. 1996. Cleaning Up the Nation's Waste Sites: Markets and Technology Trends (1996 Edition) (EPA 542-R-96-005, PB96-178041).

U.S. EPA. 1996. Completed North American Innovative Technology Demonstration Projects (EPA 542-B-96-002, PB96-153127).

U.S. EPA. 1996. Cone Penetrometer/Laser Induced Fluorescence (LIF) Technology Verification Program: Fact Sheet (EPA 542-F-96-009b).

U.S. EPA. 1996. EPA Directive: Initiatives to Promote Innovative Technologies in Waste Management Programs (EPA 540-F-96-012).

U.S. EPA. 1996. Errata to Guide to EPA materials on Underground Storage Tanks (EPA 510-F-96-002).

U.S. EPA. 1996. How to Effectively Recover Free Product at Leaking Underground Storage Tank Sites: A Guide for State Regulators (EPA 510-F-96-001; Fact Sheet: EPA 510-F-96-005).

U.S. EPA. 1996. Innovative Treatment Technologies: Annual Status Report Database (ITT Database).

U.S. EPA. 1996. Introducing TANK Racer (EPA 510-F96-001).

U.S. EPA. 1996. Market Opportunities for Innovative Site Cleanup Technologies: Southeastern States (EPA 542-R-96-007, PB96-199518).

U.S. EPA. 1996. Recent Developments for In situ Treatment of Metal-Contaminated Soils (EPA 542-R-96-008, PB96-153135).

U.S. EPA. 1996. Review of Intrinsic Bioremediation of TCE in Groundwater at Picatinny Arsenal, New Jersey and St. Joseph, Michigan (EPA 600-A-95-096, PB95-252995).

U.S. EPA. 1996. State Policies Concerning the Use of Injectants for In Situ Groundwater Remediation (EPA 542-R-96-001, PB96-164538).

U.S. EPA. 1995. Abstracts of Remediation Case Studies (EPA 542-R-95-001, PB95-201711).

U.S. EPA. 1995. Accessing Federal Data Bases for Contaminated Site Clean-Up Technologies, Fourth Edition (EPA 542-B-95-005, PB96-141601).

U.S. EPA. 1995. Bioremediation Field Evaluation: Eielson Air Force Base, Alaska (EPA 540-R-95-533).

U.S. EPA. 1995. Bioremediation Field Initiative Site Profiles:

Champion Site, Libby, MT (EPA 540-F-95-506a)

Eielson Air Force Base, AK (EPA 540-F-95-506b)

Hill Air Force Base Superfund Site, UT (EPA 540-F-95-506c)

Public Service Company of Colorado (EPA 540-F-95-506d)

Escambia Wood Preserving Site, FL (EPA 540-F-95-506g)

Reilly Tar and Chemical Corporation , MN (EPA 540-F-95-506h)

U.S. EPA. 1995. Bioremediation Final Performance Evaluation of the Prepared Bed Land Treatment System, Champion International Superfund Site, Libby, Montana: Volume I, Text (EPA 600-R-95-156a); Volume II, Figures and Tables (EPA 600-R-95-156b).

U.S. EPA. 1995. Bioremediation of Petroleum Hydrocarbons: A Flexible, Variable Speed Technology (EPA 600-A-95-140, PB96-139035).

U.S. EPA. 1995. Combined Chemical and Biological Oxidation of Slurry Phase Polycyclic Aromatic Hydrocarbons (EPA 600-A-95-065, PB95-217642).

U.S. EPA. 1995. Contaminants and Remedial Options at Selected Metal Contaminated Sites (EPA 540-R-95-512, PB95-271961).

U.S. EPA. 1995. Development of a Photothermal Detoxification Unit: Emerging Technology Summary (EPA 540-SR-95-526); Emerging Technology Bulletin (EPA 540-F-95-505).

U.S. EPA. 1995. Electrokinetic Soil Processing: Emerging Technology Bulletin (EPA 540-F-95-504); ET Project Summary (EPA 540-SR-93-515).

U.S. EPA. 1995. Emerging Abiotic In Situ Remediation Technologies for Groundwater and Soil: Summary Report (EPA 542-S-95-001, PB95-239299).

U.S. EPA. 1995. Emerging Technology Program (EPA 540-F-95-502).

U.S. EPA. 1995. ETI: Environmental Technology Initiative (document order form) (EPA 542-F-95-007).

U.S. EPA. 1995. Federal Publications on Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation, Fifth Edition (EPA 542-B-95-004, PB96-145099).

U.S. EPA. 1995. Federal Remediation Technologies Roundtable: 5 Years of Cooperation (EPA 542-F-95-007).

U.S. EPA. 1995. Guide to Documenting Cost and Performance for Remediation Projects (EPA 542-B-95-002, PB95-182960).

U.S. EPA. 1995. In Situ Metal-Enhanced Abiotic Degradation Process Technology, Environmental Technologies, Inc.: Demonstration Bulletin (EPA 540-MR-95-510).

U.S. EPA. 1995. In Situ Vitrification Treatment: Engineering Bulletin (EPA 540-S-94-504, PB95-125499).

U.S. EPA. 1995. Intrinsic Bioattenuation for Subsurface Restoration (book chapter) (EPA 600-A-95-112, PB95-274213).

U.S. EPA. 1995. J.R. Simplot Ex-Situ Bioremediation Technology for Treatment of TNT-Contaminated Soils: Innovative Technology Evaluation Report (EPA 540-R-95-529); Site Technology Capsule (EPA 540-R-95-529a).

U.S. EPA. 1995. Lessons Learned About In Situ Air Sparging at the Denison Avenue Site, Cleveland, Ohio (Project Report), Assessing UST Corrective Action Technologies (EPA 600-R-95-040, PB95-188082).

U.S. EPA. 1995. Microbial Activity in Subsurface Samples Before and During Nitrate-Enhanced Bioremediation (EPA 600-A-95-109, PB95-274239).

U.S. EPA. 1995. Musts for USTS: A Summary of the Regulations for Underground Tank Systems (EPA 510-K-95-002).

U.S. EPA. 1995. Natural Attenuation of Trichloroethene at the St. Joseph, Michigan, Superfund Site (EPA 600-SV-95-001).

U.S. EPA. 1995. New York State Multi-Vendor Bioremediation: Ex-Situ Biovault, ENSR Consulting and Engineering/Larson Engineers: Demonstration Bulletin (EPA 540-MR-95-525).

U.S. EPA. 1995. Process for the Treatment of Volatile Organic Carbon and Heavy-Metal-Contaminated Soil, International Technology Corp.: Emerging Technology Bulletin (EPA 540-F-95-509).

U.S. EPA. 1995. Progress in Reducing Impediments to the Use of Innovative Remediation Technology (EPA 542-F-95-008, PB95-262556).

U.S. EPA. 1995. Remedial Design/Remedial Action Handbook (PB95-963307-ND2).

U.S. EPA. 1995. Remedial Design/Remedial Action Handbook Fact Sheet (PB95-963312-NDZ).

U.S. EPA. 1995. Remediation Case Studies: Bioremediation (EPA 542-R-95-002, PB95-182911).

U.S. EPA. 1995. Remediation Case Studies: Fact Sheet and Order Form (EPA 542-F-95-003); Four Document Set (PB95-182903).

U.S. EPA. 1995. Remediation Case Studies: Groundwater Treatment (EPA 542-R-95-003, PB95-182929).

U.S. EPA. 1995. Remediation Case Studies: Soil Vapor Extraction (EPA 542-R-95-004, PB95-182937).

U.S. EPA. 1995. Remediation Case Studies: Thermal Desorption, Soil Washing, and In Situ Vitrification (EPA 542-R-95-005, PB95-182945).

U.S. EPA. 1995. Remediation Technologies Screening Matrix and Reference Guide, Second Edition (PB95-104782; Fact Sheet: EPA 542-F-95-002). Federal Remediation Technology Roundtable. Also see Internet: http://www.frtr.gov/matrix/top-page.html.

U.S. EPA. 1995. Removal of PCBs from Contaminated Soil Using the Cf Systems (trade name) Solvent Extraction Process: A Treatability Study (EPA 540-R-95-505, PB95-199030); Project Summary (EPA 540-SR-95-505).

U.S. EPA. 1995. Review of Mathematical Modeling for Evaluating Soil Vapor Extraction Systems (EPA 540-R-95-513, PB95-243051).

U.S. EPA. 1995. Selected Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation: A Bibliography of EPA Information Resources (EPA 542-B-95-001).

U.S. EPA. 1995. SITE Emerging Technology Program (EPA 540-F-95-502).

U.S. EPA. 1995. Soil Vapor Extraction (SVE) Enhancement Technology Resource Guide Air Sparging, Bioventing, Fracturing, Thermal Enhancements (EPA 542-B-95-003).

U.S. EPA. 1995. Soil Vapor Extraction Implementation Experiences (OSWER Publication 9200.5-223FS, EPA 540-F-95-030, PB95-963315).

U.S. EPA. 1995. Surfactant Injection for Ground Water Remediation: State Regulators' Perspectives and Experiences (EPA 542-R-95-011, PB96-164546).

U.S. EPA. 1995. Symposium on Bioremediation of Hazardous Wastes: Research, Development, and Field Evaluations, Abstracts: Rye Town Hilton, Rye Brook, New York, August 8-10, 1995 (EPA 600-R-95-078).

U.S. EPA. 1993-1995. Technology Resource Guides:.

Bioremediation Resource Guide (EPA 542-B-93-004)

Groundwater Treatment Technology Resource Guide (EPA 542-B-94-009, PB95-138657)

Physical/Chemical Treatment Technology Resource Guide (EPA 542-B-94-008, PB95-138665)

Soil Vapor Extraction (SVE) Enhancement Technology Resource Guide: Air Sparging, Bioventing, Fracturing, and Thermal Enhancements (EPA 542-B-95-003)

Soil Vapor Extraction (SVE) Treatment Technology Resource Guide (EPA 542-B-94-007)

U.S. EPA. 1995. Waste Vitrification Through Electric Melting, Ferro Corporation: Emerging Technology Bulletin (EPA 540-F-95-503).

U.S. EPA. 1994. Accessing EPA's Environmental Technology Programs (EPA 542-F-94-005).

U.S. EPA. 1994. Bioremediation: A Video Primer (video) (EPA 510-V-94-001).

U.S. EPA. 1994. Bioremediation in the Field Search System (EPA 540-F-95-507; Fact Sheet: EPA 540-F-94-506).

U.S. EPA. 1994. Contaminants and Remedial Options at Solvent-Contaminated Sites (EPA 600-R-94-203, PB95-177200).

U.S. EPA. 1990-1994. EPA Engineering Bulletins:.

Chemical Dehalogenation Treatment: APEG Treatment (EPA 540-2-90-015, PB91-228031)

Chemical Oxidation Treatment (EPA 540-2-91-025)

In Situ Biodegradation Treatment (EPA 540-S-94-502, PB94-190469)

In Situ Soil Flushing (EPA 540-2-91-021)

In Situ Soil Vapor Extraction Treatment (EPA 540-2-91-006, PB91-228072)

In Situ Steam Extraction Treatment (EPA 540-2-91-005, PB91-228064)

In Situ Vitrification Treatment (EPA 540-S-94-504, PB95-125499)

Mobile/Transportable Incineration Treatment (EPA 540-2-90-014)

Pyrolysis Treatment (EPA 540-S-92-010)

Rotating Biological Contactors (EPA 540-S-92-007)

Slurry Biodegradation (EPA 540-2-90-016, PB91-228049)

Soil Washing Treatment (EPA 540-2-90-017, PB91-228056)

Solidification/Stabilization of Organics and Inorganics (EPA 540-S-92-015)

Solvent Extraction Treatment (EPA 540-S-94-503, PB94-190477)

Supercritical Water Oxidation (EPA 540-S-92-006)

Technology Preselection Data Requirements (EPA 540-S-92-009)

Thermal Desorption Treatment (EPA 540-S-94-501, PB94-160603)

U.S. EPA. 1994. Field Investigation of Effectiveness of Soil Vapor Extraction Technology (Final Project Report) (EPA 600-R-94-142, PB94-205531).

U.S. EPA. 1994. Ground Water Treatment Technologies Resource Guide (EPA 542-B-94-009, PB95-138657).

U.S. EPA. 1994. How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers (EPA 510-B-94-003, S/N 055-000-00499-4); Pamphlet (EPA 510-F-95-003).

U.S. EPA. 1994. In Situ Steam Enhanced Recovery Process, Hughes Environmental Systems, Inc.: Innovative Technology Evaluation Report (EPA 540-R-94-510, PB95-271854); Site Technology Capsule (EPA 540-R-94-510a, PB95-270476).

U.S. EPA. 1994. In Situ Vitrification, Geosafe Corporation: Innovative Technology Evaluation Report (EPA 540-R-94-520, PB95-213245); Demonstration Bulletin (EPA 540-MR-94-520).

U.S. EPA. 1994. J.R. Simplot Ex-Situ Bioremediation Technology for Treatment of Dinoseb-Contaminated Soils: Innovative Technology Evaluation Report (EPA 540-R-94-508); Demonstration Bulletin (EPA 540-MR-94-508).

U.S. EPA. 1994. Literature Review Summary of Metals Extraction Processes Used to Remove Lead From Soils, Project Summary (EPA 600-SR-94-006).

U.S. EPA. 1994. Northeast Remediation Marketplace: Business Opportunities for Innovative Technologies (Summary Proceedings) (EPA 542-R-94-001, PB94-154770).

U.S. EPA. 1994. Physical/Chemical Treatment Technology Resource Guide (EPA 542-B-94-008, PB95-138665).

U.S. EPA. 1994. Profile of Innovative Technologies and Vendors for Waste Site Remediation (EPA 542-R-94-002, PB95-138418).

U.S. EPA. 1994. Radio Frequency Heating, KAI Technologies, Inc.: Innovative Technology Evaluation Report (EPA 540-R-94-528); Site Technology Capsule (EPA 540-R-94-528a, PB95-249454).

U.S. EPA. 1994. Regional Market Opportunities for Innovative Site Clean-up Technologies: Middle Atlantic States (EPA 542-R-95-010, PB96-121637).

U.S. EPA. 1994. Rocky Mountain Remediation Marketplace: Business Opportunities for Innovative Technologies (Summary Proceedings) (EPA 542-R-94-006, PB95-173738).

U.S. EPA. 1994. Selected EPA Products and Assistance On Alternative Cleanup Technologies (Includes Remediation

Guidance Documents Produced By The Wisconsin Department of Natural Resources) (EPA 510-E-94-001).

U.S. EPA. 1994. Soil Vapor Extraction Treatment Technology Resource Guide (EPA 542-B-94-007).

U.S. EPA. 1994. Solid Oxygen Source for Bioremediation Subsurface Soils (revised) (EPA 600-J-94-495, PB95-155149).

U.S. EPA. 1994. Solvent Extraction: Engineering Bulletin (EPA 540-S-94-503, PB94-190477).

U.S. EPA. 1994. Solvent Extraction Treatment System, Terra-Kleen Response Group, Inc. (EPA 540-MR-94-521).

U.S. EPA. 1994. Status Reports on In Situ Treatment Technology Demonstration and Applications:.

Altering Chemical Conditions (EPA 542-K-94-008)

Cosolvents (EPA 542-K-94-006)

Electrokinetics (EPA 542-K-94-007)

Hydraulic and Pneumatic Fracturing (EPA 542-K-94-005)

Surfactant Enhancements (EPA 542-K-94-003)

Thermal Enhancements (EPA 542-K-94-009)

Treatment Walls (EPA 542-K-94-004)

U.S. EPA. 1994. Subsurface Volatization and Ventilation System (SVVS): Innovative Technology Report (EPA 540-R-94-529, PB96-116488); Site Technology Capsule (EPA 540-R-94-529a, PB95-256111).

U.S. EPA. 1994. Superfund Innovative Technology Evaluation (SITE) Program: Technology Profiles, Seventh Edition (EPA 540-R-94-526, PB95-183919).

U.S. EPA. 1994. Thermal Desorption System, Maxymillian Technologies, Inc.: Site Technology Capsule (EPA 540-R94-507a, PB95-122800).

U.S. EPA. 1994. Thermal Desorption Treatment: Engineering Bulletin (EPA 540-S-94-501, PB94-160603).

U.S. EPA. 1994. Thermal Desorption Unit, Eco Logic International, Inc.: Application Analysis Report (EPA 540-AR-94-504).

U.S. EPA. 1994. Thermal Enhancements: Innovative Technology Evaluation Report (EPA 542-K-94-009).

U.S. EPA. 1994. The Use of Cationic Surfactants to Modify Aquifer Materials to Reduce the Mobility of Hydrophobic Organic Compounds (EPA 600-S-94-002, PB95-111951).

U.S. EPA. 1994. West Coast Remediation Marketplace: Business Opportunities for Innovative Technologies (Summary Proceedings) (EPA 542-R-94-008, PB95-143319).

U.S. EPA. 1993. Accutech Pneumatic Fracturing Extraction and Hot Gas Injection, Phase I: Technology Evaluation Report (EPA 540-R-93-509, PB93-216596).

U.S. EPA. 1993. Augmented In Situ Subsurface Bioremediation Process, Bio-Rem, Inc.: Demonstration Bulletin (EPA 540-MR-93-527).

U.S. EPA. 1993. Biogenesis Soil Washing Technology: Demonstration Bulletin (EPA 540-MR-93-510).

U.S. EPA. 1993. Bioremediation Resource Guide and Matrix (EPA 542-B-93-004, PB94-112307).

U.S. EPA. 1993. Bioremediation: Using the Land Treatment Concept (EPA 600-R-93-164, PB94-107927).

U.S. EPA. 1993. Fungal Treatment Technology: Demonstration Bulletin (EPA 540-MR-93-514).

U.S. EPA. 1993. Gas-Phase Chemical Reduction Process, Eco Logic International Inc. (EPA 540-R-93-522, PB95-100251, EPA 540-MR-93-522).

U.S. EPA. 1993. HRUBOUT, Hrubetz Environmental Services: Demonstration Bulletin (EPA 540-MR-93-524).

U.S. EPA. 1993. Hydraulic Fracturing of Contaminated Soil, U.S. EPA: Innovative Technology Evaluation Report (EPA 540-R-93-505, PB94-100161); Demonstration Bulletin (EPA 540-MR-93-505).

U.S. EPA. 1993. HYPERVENTILATE: A software Guidance System Created for Vapor Extraction Systems for Apple Macintosh and IBM PC-Compatible Computers (UST #107) (EPA 510-F-93-001); User's Manual (Macintosh disk included) (UST #102) (EPA 500-CB-92-001).

U.S. EPA. 1993. In Situ Bioremediation of Contaminated Ground Water (EPA 540-S-92-003, PB92-224336).

U.S. EPA. 1993. In Situ Bioremediation of Contaminated Unsaturated Subsurface Soils (EPA-S-93-501, PB93-234565).

U.S. EPA. 1993. In Situ Bioremediation of Ground Water and Geological Material: A Review of Technologies (EPA 600-SR-93-124, PB93-215564).

U.S. EPA. 1993. In Situ Treatments of Contaminated Groundwater: An Inventory of Research and Field Demonstrations and Strategies for Improving Groundwater Remediation Technologies (EPA 500-K-93-001, PB93-193720).

U.S. EPA. 1993. Laboratory Story on the Use of Hot Water to Recover Light Oily Wastes from Sands (EPA 600-R-93-021, PB93-167906).

U.S. EPA. 1993. Low Temperature Thermal Aeration (LTTA) System, Smith Environmental Technologies Corp.: Applications Analysis Report (EPA 540-AR-93-504); Site Demonstration Bulletin (EPA 540-MR-93-504).

U.S. EPA. 1993. Mission Statement: Federal Remediation Technologies Roundtable (EPA 542-F-93-006).

U.S. EPA. 1993. Mobile Volume Reduction Unit, U.S. EPA: Applications Analysis Report (EPA 540-AR-93-508, PB94-130275).

U.S. EPA. 1993. Overview of UST Remediation Options (EPA 510-F-93-029).

U.S. EPA. 1993. Soil Recycling Treatment, Toronto Harbour Commissioners (EPA 540-AR-93-517, PB94-124674).

U.S. EPA. 1993. Synopses of Federal Demonstrations of Innovative Site Remediation Technologies, Third Edition (EPA

542-B-93-009, PB94-144565).

U.S. EPA. 1993. XTRAX Model 200 Thermal Desorption System, OHM Remediation Services Corp.: Site Demonstration Bulletin (EPA 540-MR-93-502).

U.S. EPA. 1992. Aostra Soil-tech Anaerobic Thermal Process, Soiltech ATP Systems: Demonstration Bulletin (EPA 540-MR-92-008).

U.S. EPA. 1992. Basic Extractive Sludge Treatment (B.E.S.T.) Solvent Extraction System, Ionics/Resources Conservation Co.: Applications Analysis Report (EPA 540-AR-92-079, PB94-105434); Demonstration Summary (EPA 540-SR-92-079).

U.S. EPA. 1992. Bioremediation Case Studies: An Analysis of Vendor Supplied Data (EPA 600-R-92-043, PB92-232339).

U.S. EPA. 1992. Bioremediation Field Initiative (EPA 540-F-92-012).

U.S. EPA. 1992. Carver Greenfield Process, Dehydrotech Corporation: Applications Analysis Report (EPA 540-AR-92-002, PB93-101152); Demonstration Summary (EPA 540-SR-92-002).

U.S. EPA. 1992. Chemical Enhancements to Pump-and-Treat Remediation (EPA 540-S-92-001, PB92-180074).

U.S. EPA. 1992. Cyclone Furnace Vitrification Technology, Babcock and Wilcox: Applications Analysis Report (EPA 540-AR-92-017, PB93-122315).

U.S. EPA. 1992. Evaluation of Soil Venting Application (EPA 540-S-92-004, PB92-235605).

U.S. EPA. 1992. Excavation Techniques and Foam Suppression Methods, McColl Superfund Site, U.S. EPA: Applications Analysis Report (EPA 540-AR-92-015, PB93-100121).

U.S. EPA. 1992. In Situ Biodegradation Treatment: Engineering Bulletin (EPA 540-S-94-502, PB94-190469).

U.S. EPA. 1992. Low Temperature Thermal Treatment System, Roy F. Weston, Inc.: Applications Analysis Report (EPA 540-AR-92-019, PB94-124047).

U.S. EPA. 1992. Proceedings of the Symposium on Soil Venting (EPA 600-R-92-174, PB93-122323).

U.S. EPA. 1992. Soil/Sediment Washing System, Bergman USA: Demonstration Bulletin (EPA 540-MR-92-075).

U.S. EPA. 1992. TCE Removal From Contaminated Soil and Groundwater (EPA 540-S-92-002, PB92-224104).

U.S. EPA. 1992. Technology Alternatives for the Remediation of PCB-Contaminated Soil and Sediment (EPA 540-S-93-506).

U.S. EPA. 1992. Workshop on Removal, Recovery, Treatment, and Disposal of Arsenic and Mercury (EPA 600-R-92-105, PB92-216944).

U.S. EPA. 1991. Biological Remediation of Contaminated Sediments, With Special Emphasis on the Great Lakes: Report of a Workshop (EPA 600-9-91-001).

U.S. EPA. 1991. Debris Washing System, RREL. Technology Evaluation Report (EPA 540-5-91-006, PB91-231456).

U.S. EPA. 1991. Guide to Discharging CERCLA Aqueous Wastes to Publicly Owned Treatment Works (9330.2-13FS).

U.S. EPA. 1991. In Situ Soil Vapor Extraction: Engineering Bulletin (EPA 540-2-91-006, PB91-228072).

U.S. EPA. 1991. In Situ Steam Extraction: Engineering Bulletin (EPA 540-2-91-005, PB91-228064).

U.S. EPA. 1991. In Situ Vapor Extraction and Steam Vacuum Stripping, AWD Technologies (EPA 540-A5-91-002, PB92-218379).

U.S. EPA. 1991. Pilot-Scale Demonstration of Slurry-Phase Biological Reactor for Creosote-Contaminated Soil (EPA 540-A5-91-009, PB94-124039).

U.S. EPA. 1991. Slurry Biodegradation, International Technology Corporation (EPA 540-MR-91-009).

U.S. EPA. 1991. Understanding Bioremediation: A Guidebook for Citizens (EPA 540-2-91-002, PB93-205870).

U.S. EPA. 1990. Anaerobic Biotransformation of Contaminants in the Subsurface (EPA 600-M-90-024, PB91-240549).

U.S. EPA. 1990. Chemical Dehalogenation Treatment, APEG Treatment: Engineering Bulletin (EPA 540-2-90-015, PB91-228031).

U.S. EPA. 1990. Enhanced Bioremediation Utilizing Hydrogen Peroxide as a Supplemental Source of Oxygen: A Laboratory and Field Study (EPA 600-2-90-006, PB90-183435).

U.S. EPA. 1990. Guide to Selecting Superfund Remedial Actions (9355.0-27FS).

U.S. EPA. 1990. Slurry Biodegradation: Engineering Bulletin (EPA 540-2-90-016, PB91-228049).

U.S. EPA. 1990. Soil Washing Treatment: Engineering Bulletin (EPA 540-2-90-017, PB91-228056).

U.S. EPA. 1989. Facilitated Transport (EPA 540-4-89-003, PB91-133256).

U.S. EPA. 1989. Guide on Remedial Actions for Contaminated Ground Water (9283.1-02FS).

U.S. EPA. 1987. Compendium of Costs of Remedial Technologies at Hazardous Waste Sites (EPA 600-2-87-087).

U.S. EPA. 1987. Data Quality Objectives for Remedial Response Activities: Development Process (9355.0-07B).

U.S. EPA. 1986. Costs of Remedial Actions at Uncontrolled Hazardous Waste Sites (EPA/640/2-86/037).

U.S. EPA. N.D. Alternative Treatment Technology Information Center (ATTIC) (The ATTIC data base can be accessed by modem at (703) 908-2138).

U.S. EPA. N.D. Clean Up Information (CLU-IN) Bulletin Board System. (CLU-IN can be accessed by modem at (301) 589-8366 or by the Internet at http://clu-in.com).

U.S. EPA. N.D. Initiatives to Promote Innovative Technology in Waste Management Programs (OSWER Directive 9308.0-25).

U.S. EPA and University of Pittsburgh. N.D. Ground Water

Remediation Technologies Analysis Center. Internet address: http://www.gwrtac.org

Vendor Information System for Innovative Treatment Technologies (VISITT), Version 4.0 (VISITT can be downloaded from the Internet at http://www.prcemi.com/visitt or from the CLU-IN Web site at http://clu-in.com).

1. Interagency Cost Workgroup, 1994.
2. Costs of Remedial Actions at Uncontrolled Hazardous Wastes Sites, U.S. EPA, 1986.
3. Federal Remediation Technology Roundtable. http://www.frtr.gov/matrix/top_page.html

UST = underground storage tank
SVOCs = semi-volatile organic compounds
VOCs = volatile organic compounds
PAHs = polyaromatic hydrocarbons
PCBs = polychlorinated biphenyls
TPH = total petroleum hydrocarbons