

CHAPTER 8

Assessment and Cleanup



This chapter outlines contamination cleanup procedures, including:

- Site investigations to determine the extent of contamination after an oil spill or release
- Risk assessments to determine possible risks, including exposure and toxicity
- Conceptual site models (CSMs) and remediation strategies to efficiently address cleanup
- Different treatment technologies for cleaning contaminated soil, groundwater, and remediation system off-gas

8.1 Regulatory Background

The U.S. Environmental Protection Agency (EPA) has several programs to address the cleanup of environmental contamination. The goal of each program is to protect human health and the environment. If a spill has occurred, the environmental cleanup process begins as soon as emergency situations (such as fire, explosion, or vapor hazards) have been addressed and the proper agencies have been notified. See [Chapter 2, Incident and Spill Reporting](#) for a summary of these initial actions.

The environmental cleanup process or corrective action process consists of:

- Developing a CSM
- Conducting a **site assessment** or field investigation
- Updating the CSM
- Preparing a **risk assessment** and/or comparing investigation results to cleanup or action levels
- Developing a remediation strategy and endpoints
- Evaluating feasible treatment technologies or remedial options
- Implementing the remedy or corrective action

This is the general approach to corrective action for all types of cleanup sites.

For some releases into the environment, site assessments and cleanups may be relatively simple. It may be suitable to visually inspect a contaminated area and excavate the soil, followed by sampling to confirm the site is clean. However, a large release or one that originates underground (for example, leaking buried pipeline or tank bottom) may require a long and costly multiphased investigation to determine the type and extent of damage. It also may require assessing and addressing potential impacts to human health and the environment. This investigation may be followed by a long-term cleanup operation.

Because this guidance document is for DLA Energy, most of expected site cleanups will be associated with petroleum products. Therefore, although this



The Law Says

- Petroleum-contaminated soil cleaned up under an underground storage tank (UST) program is exempted as RCRA hazardous waste (40 CFR 261.4(b)(10)).
- EPA does not set cleanup levels for soils and groundwater contaminated by petroleum products from leaking USTs (40 CFR 280.66). Each individual state sets its own cleanup levels.
- EPA strongly encourages states to use risk-based decision-making to set the cleanup levels for any leaking UST site (Office of Solid Waste and Emergency Response Directive 9610.17 March 1, 1995).
- Remediation waste consists of all solid and hazardous waste, and all media (groundwater, surface water, soil, and sediment), and debris that are managed for implementing cleanup (40 CFR 260.10).



chapter touches on all aspects of remediation, the focus is on remediation of petroleum-contaminated sites.

8.1.1 Cleanup Programs

The main regulatory programs that address site cleanup include:

- Leaking underground storage tank (LUST) remediation programs
- Hazardous waste site remediation for facilities permitted or formerly permitted under the Resource Conservation and Recovery Act (called RCRA Corrective Action)
- Superfund and state Superfund-type programs
- Brownfield programs
- Voluntary cleanup programs

Federal regulations for LUST site assessments and corrective actions are covered in 40 CFR 280 and are summarized in the flow chart in [Appendix 8-1](#). Most states, territories, and many tribes and some local agencies have adopted their own UST regulations or are authorized to implement this program for EPA. These other UST requirements are similar to those summarized in [Appendix 8-1](#); however, notification time frames and submittals may be different. Check with your state and local agencies. [Appendix E](#) provides state agency contact information.

The RCRA Corrective Action program is discussed in 40 CFR 264, which lists the requirements for site monitoring, investigation, and remediation. Sites being addressed in the RCRA Corrective Action program will generally be issued a Consent Order from EPA or the authorized state agency under the authority in RCRA Section 3008(a) or 3004(u). In many cases, states have adopted their state Superfund regulations to implement remediation at RCRA Corrective Action sites. EPA and the states have issued guidance documents that provide additional direction.

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), also known as **Superfund**, addresses remediation of the most highly contaminated sites in the U.S.; the federal regulations are found in 40 CFR 300. Because the federal Superfund program addresses the worst sites, many sites aren't contaminated to high enough levels to be on the Superfund list but still need to be addressed. As a result, most states have state Superfund-type regulations that address these other sites. EPA and/or the state negotiate cleanup agreements with potentially responsible parties. These agreements are in the form of administrative orders on consent, administrative agreements, or judicial consent decrees. In the case of military installations, there is usually a Federal Facilities Agreement (FFA) that addresses Superfund requirements.

CERCLA specifically excludes petroleum from its definition of a hazardous substance (see [Chapter 2, Incident and Spill Reporting](#)). Therefore, if petroleum is released to soil, CERCLA cannot be used as the regulatory basis for remedial action. However, petroleum-contaminated media may be subject to corrective actions under other regulations, such as UST and state-specific aboveground storage tank (AST) remediation regulations, a RCRA Corrective Action program if contaminated soil is located at a permitted RCRA facility, state Superfund-type



programs, or the Clean Water Act if the petroleum was spilled into a water body or wetland.

Brownfield is a term applied to a property where its reuse and redevelopment is hampered by contamination. Many state, county, and city governments offer economic incentives (grants, liability protection, tax benefits) for cleanup, redevelopment, and revitalization of contaminated property and sometimes for abandoned, industrial, commercial, and military property. Some states combine their Brownfield and voluntary cleanup programs. Voluntary cleanup or voluntary remediation of non-priority contaminated sites is conducted on a site-by-site, state-by-state basis, and cleanup and remedial actions are generally negotiated in memoranda of agreements between state regulators and responsible parties.

Remedial processes are similar for all site remediation programs in terms of the end goals: to protect human health and the environment, to include the public in the remedial action decision-making process, and to clean up sites to regulated standards. [Appendix 8-2](#) contains a comparison of the RCRA, CERCLA, and Brownfield environmental cleanup and remedial processes.

8.1.2 Permitting Requirements

Many remediation technologies involve activities that are regulated and may require notification and/or permitting with a variety of agencies. For example, the soil vapor extraction technology described later in this chapter may require an air permit. It is important to investigate the federal and state regulations and permitting requirements regarding remediation technologies, including air emissions, water discharges, groundwater injection restrictions, air injection restrictions, land disposal requirements, and land application restrictions.

You may have heard of a Superfund exemption from permitting for some site remediation activities where you instead comply with applicable or relevant and appropriate requirements (ARARs) in the regulations. Specifically, actions at CERCLA sites must comply with substantive or technical aspects of ARARs but not the corresponding administrative requirements. That is, permit applications, reporting, recordkeeping, and other administrative procedures such as administrative reviews are not considered ARARs for actions conducted entirely on-site. However, don't count on always having the permit exemption at your Superfund site; some states impose exclusive (that is, no federal counterpart) or more stringent requirements than EPA. For instance, New Jersey and New York require the person conducting a remediation at a CERCLA site to submit most of the permit application information and will issue permit equivalents to address the remedial actions. It takes as much time to get a permit equivalent as to obtain an actual permit.

8.2 Conceptual Site Model

A **CSM** is an organized set of ideas and a written or graphical representation of site conditions. The development of a CSM is an integral part of site characterization efforts. A preliminary CSM should be compiled as soon as the release is discovered, using the information available at that time. As the work at the site proceeds, the CSM should be updated and reconsidered. A CSM serves as a

framework to understand how to plan and interpret underground investigations, as well as how to frame the value expected from additional investigations. The CSM generally consists of these six major elements:

- Source component (the type of product released, what it contains, its physical and chemical properties, the presence of light non-aqueous phase liquids [LNAPLs] or dense NAPLs [DNAPLs], where and how much was released)
- Spatial dimensions (depth and lateral extent of contaminants in the ground)
- Hydrogeological conditions (site geology, including types and depths of soil and rock, depth to **groundwater** and flow direction)
- Potential **receptors** and exposure pathways (and possible migration routes, such as utility corridors, surface water bodies, and basements)
- Mobility and stability of plume (whether **non-aqueous phase liquid**, groundwater, or soil vapor plumes are stable, diffusing, expanding, contracting, or migrating)
- Applicable regulatory standards (given the release, what end point can be identified to guide remediation planning?)

A CSM is sometimes represented as a two- or three-dimensional drawing. It is developed from available analytical data, historical records, aerial photographs, and the risk assessment. The model establishes a hypothesis about possible contaminant sources, transport, exposure pathways, and potential receptors. It can be used to present data supporting the implementation and monitoring of a selected remedy and for remedy evaluation and optimization.



Did You Know?

You can dial 8-1-1 to reach the national “Call Before You Dig” hotline to arrange for subsurface utilities to be marked before you begin excavation or drilling.

8.3 Site Investigation

After discovery of a problem, the next step is usually the site investigation, sometimes referred to as remedial investigation, field investigation, site evaluation, or hazard identification. Terms vary depending on what regulatory program you are under.

The purpose of a site investigation is to determine or confirm:

- Source of contamination
- Nature and extent of contamination (area, analytes present, concentrations, and variation with depth) in soil, groundwater, surface water, sediment, or soil vapor
- Presence of free-phase non-aqueous phase liquid
- Impact of contamination on soil, surface water, groundwater, or any structures

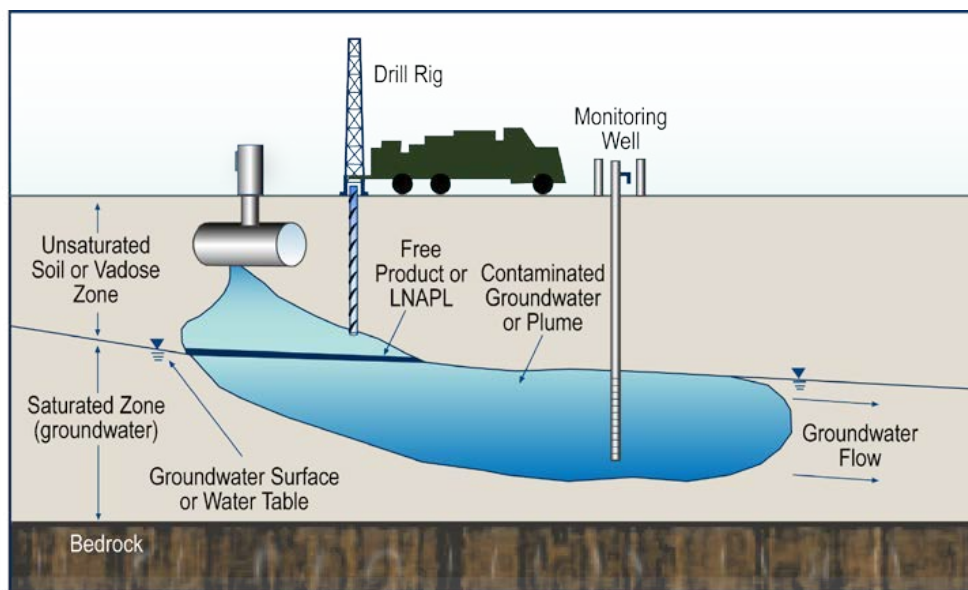
The site investigation often consists of collecting samples (soil, soil gas, groundwater, surface water, sediment, ambient or indoor air, and **biota**, as appropriate) for analysis either by field instruments or an off-site laboratory to determine the nature and extent of contamination. Collecting the samples sometimes requires the use of drill rigs with augers to collect split-spoon soil samples from soil borings. Drill rigs are also used to collect groundwater grab samples while drilling or to install **monitoring wells** to collect groundwater samples.

As an alternative, **direct push drill rigs** are used to quickly gather grab samples of soil vapor or groundwater, or to advance geophysical tools (such as **laser-induced fluorescence**). Direct push rigs have tools for probing and sampling that are pushed or driven into the ground (without rotation) and do not generate contaminated soil cuttings. The speed and depth of penetration largely depends on the soil type, the size of the sampler, and the weight and power of the rig. Direct push techniques are generally limited to shallow unconsolidated soil and are of limited use for deep site contamination.

Groundwater and soil vapor monitoring can help document the extent and stability of the **plume** (area of soil vapor and groundwater contamination). *Exhibit 8-1* illustrates common terms used in soil and groundwater investigations. Note also that vapors from the groundwater plume can travel upward through the soil and into buildings through cracks in the foundation or floor of basements.

Prior to starting any underground investigation, a utility clearance needs to be performed to identify the location of underground utilities. You can request utilities be marked in the investigation area prior to digging by calling 8-1-1, the national “call before you dig” hotline. It usually takes 2 to 3 days for the utilities to be marked, so plan accordingly. Note, however, that some one-call services do not provide identification of utilities that are on private property or federal facilities. The facility public works department (or equivalent) should also be contacted to identify site-specific utilities. It is not uncommon for a geophysical firm to be contracted to conduct non-invasive investigations using ground-penetrating radar, radio frequency utility-locating instruments, and electromagnetic metal detection methods to identify utilities and buried USTs in the proposed area of subsurface investigation. If there is remaining uncertainty, a drilling (or other contractor) can hand auger or air knife the first several feet in a borehole to identify buried utilities.

EXHIBIT 8-1 **Common Terms in Soil and Groundwater Investigations**



8.3.1 Oxygenates and Lead Scavengers

Because of the increasing prevalence of fuel **oxygenates**, states have begun to establish investigation requirements and cleanup levels for methyl tert-butyl ether (MTBE) and other related compounds called oxygenates. Oxygenates are oxygen-containing compounds that have been used for decades as gasoline additives to increase octane ratings and produce cleaner burning fuels. Tert-butyl alcohol (TBA) can be both a degradation product of MTBE and a fuel additive. Other oxygenates are tert-amyl methyl ether (TAME), diisopropyl ether (DIPE), ethyl-tert-butyl ether (ETBE), ethanol, and methanol. You may need to modify your investigation approach to look for oxygenates.

Oxygenates tend to migrate faster and farther in the groundwater. That is why at sites with notable groundwater flow, it is important to recognize whether oxygenates may be a concern so that investigation sampling further downgradient can be planned to identify the extent of the groundwater plume. In addition, MTBE has a tendency to move deeper into an aquifer, so searching at depth or vertically may be important, especially at the edge of the plume.

A recent transition has been made to replace a substantial portion of vehicle fuels with **biofuels**, such as ethanol. As a water-soluble constituent, ethanol migrates in the groundwater similarly to MTBE in that these constituents often migrate in advance of the other fuel constituents, such as benzene, toluene, ethylbenzene, and xylene (BTEX). In addition, if the groundwater is naturally aerobic (contains oxygen) and because of this fosters natural attenuation of the fuel constituents (see [Section 8.9.5](#)) ethanol can break down at the leading edge of the plume, using up oxygen that would have otherwise helped break down the fuel constituents (total petroleum hydrocarbons [TPH] or BTEX). This effect is called an oxygen shadow, and it can allow further migration of the TPH and BTEX plume than would have occurred had the fuel not contained ethanol. This affects investigation planning and may increase the cost of remediation.

Lead scavengers were another category of gasoline additive used through the end of the 1980s. Lead scavengers such as ethylene dibromide (EDB) and 1,2-dichloroethane (DCA) (also known as ethylene dichloride [EDC]) were used to prevent the buildup of lead deposits that can foul engines. EPA has found that these lead scavengers may persist in some groundwater environments. In addition, some aviation gasolines (AVGAS) continue to use leaded fuels. If the site history includes storage of gasoline prior to the late 1980s, or storage of AVGAS, the site environmental media should be analyzed for these potential contaminants.

8.3.2 Triad Approach

A comprehensive approach to the overall spill response and remedial action implementation promoted by EPA is the **Triad Approach**, which consists of the three elements: systematic planning, dynamic work strategies, and real-time measurement technologies. It is also known as **accelerated site characterization** and uses existing tools and methods in an integrated approach to improve speed, quality, and effectiveness.

The goal of this approach is to manage decision uncertainty. As mentioned, its principal elements are:

- *Systematic Planning* – Systematic planning usually includes identification of key decisions to be made (such as regulatory, scientific, toxicological, and engineering), the development of a CSM to support decision-making, and an evaluation of the uncertainties in the CSM.
- *Dynamic Work Strategies* – During contaminated site characterization, remediation, and monitoring, dynamic work strategies consist of being able to change or adapt based on information generated by real-time measurement technologies. Given the CSM, and the information about it as it is being gathered, this element enables decisions to be made about what additional activities would best resolve remaining uncertainties and/or best meet cleanup goals. For instance, some dynamic decisions could be triggered while the work crew is in the field and could lead to specific preapproved actions as new information becomes available.
- *Real-Time Measurement Technologies* – These technologies return results quickly enough to influence decisions about ongoing field efforts for data collection and site restoration. This could refer to rapid turnaround from a fixed laboratory (using either quantitative or screening analytical methods) or field-based measurement technologies, such as field screening analytical instruments, geophysics, cone penetrometer testing, and computer mapping.



The Triad Approach focuses on data collection methods that can increase spatial coverage (larger area) without sacrificing sample representativeness or increasing total sampling program costs. A weight of evidence approach to decision-making is used, where appropriate, based on collaborative data sets. Collaborative data sets can contain data from a number of sources, including quantitative and screening analytical methods.

In its essence, the Triad Approach is a planning approach that joins together the work being done in the field with the decisions that will be made to accomplish the cleanup. Because of this, the stakeholders are usually involved in deciding the rules for field decisions if the Triad Approach is used.

Whether a program fully adopts the elements of the Triad Approach or not, all programs benefit from understanding its principles and applying what can be incorporated. While simple site contamination may not benefit as much from this as larger, more complex sites do, it is good to be aware of the Triad Approach and its elements for increasing confidence and effectiveness during remedial design and implementation.

8.4 Risk-based Decision-making and Risk Assessments

EPA encourages the use of **risk-based decision-making** in the corrective action process. For large or complex spills and releases, complete removal of the contamination may be technically impossible, cost prohibitive, and not necessary from a health standpoint. Risk-based decision-making helps you develop necessary and appropriate actions that are based on the relative risks to human health and the environment.

The American Society for Testing and Materials (ASTM) developed a standard based on the risk-based decision-making process entitled *Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* [E-1739-95 (reapproved 2015)]. This process developed by ASTM is known as **risk-based corrective action (RBCA)**. The formal definition of RBCA is as follows:

A streamlined approach in which exposure and risk assessment practices are integrated with traditional components of the corrective action process to ensure that appropriate and cost-effective remedies are selected and that limited resources are properly allocated.

EPA has advised state agencies that the ASTM standard may be a good starting point for developing a risk-based process tailored to applicable state and local laws and regulatory practices. Most states have adopted some form of risk-based cleanup standards and many use the tiered approach outlined in the ASTM standard. Tier 1 uses a look-up table of screening level contaminant concentrations to determine if site conditions will allow a quick regulatory closeout or if a more detailed risk analysis needs to be completed. Some states have online tools that can assist in the determination of risk-based standards.

Because sites vary greatly in physical and chemical characteristics and the risks they pose, you may need to complete a **risk assessment** to make a site-specific, risk-based decision. A risk assessment usually consists of a **toxicity assessment**, **exposure assessment**, and **risk characterization**.

8.4.1 Toxicity Assessment

In a toxicity assessment, you (or your contracted environmental consultant) identify the contaminants of concern and the types of hazards or health effects associated with exposure to those chemicals. Both the National Institute for Occupational Safety and Health (NIOSH) and the Occupational Safety and Health Administration (OSHA) have published the physical, chemical, and toxicological properties of many chemicals (including chemicals found in fuels), which are available in several electronic databases. An example of a toxicological property is the estimated dose of a chemical that is considered “safe” or does not cause any ill effects. Chemicals can sometime cause **acute** (short-term) or **chronic** (long-term) toxicity or both.

8.4.2 Exposure Assessment

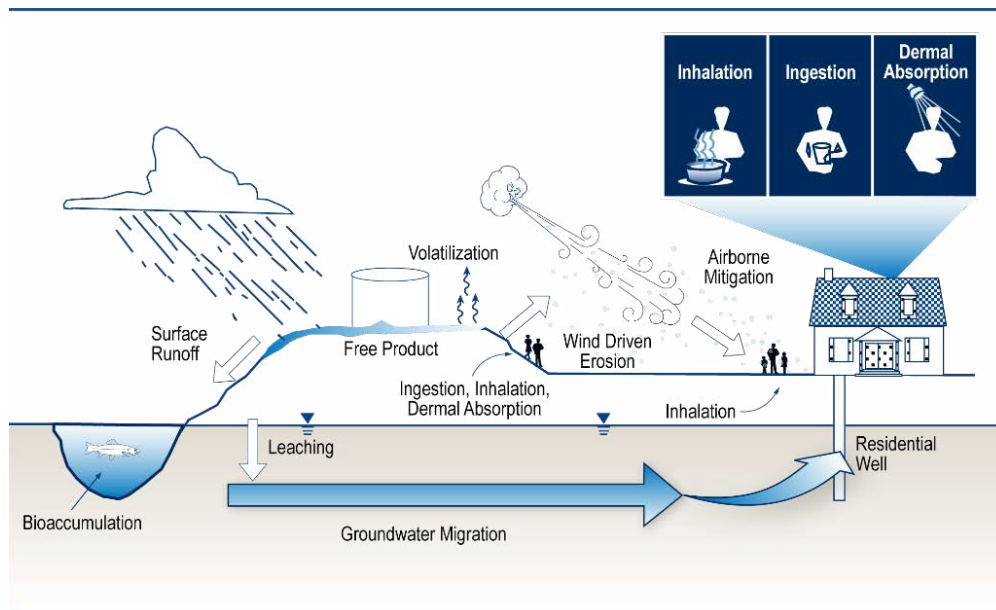
In an exposure assessment, you identify if an **exposure pathway** exists. An exposure pathway is a route that a chemical might travel from the contaminated area to people, animals, or aquatic life. An exposure pathway has four parts:

- Contaminant source (that is, area of contamination)
- Mechanism for contaminant release and transport (for example, dissolved, resuspension, volatilization, infiltration, percolation)
- Potential receptors (that is, people and environments)
- Feasible **exposure routes** (that is, inhalation, ingestion, and dermal absorption)



Exposure cannot occur unless each element of the pathway exists or is reasonably expected to exist. More specifically, an exposure pathway is complete if a chemical is released from a source area and is transported in an environmental media (such as by the wind, through groundwater, or via soil vapor intrusion) until there is a way for the receptor to take it in through ingestion, inhalation, or **dermal absorption** (skin contact). *Exhibit 8–2* illustrates potential exposure pathways.

EXHIBIT 8–2 Potential Exposure Pathways



8.4.3 Risk Characterization

In a risk characterization, you or an environmental consultant combine the results of the toxicity assessment and exposure assessment to estimate potential contaminant concentrations that receptors might be exposed to. If there's not enough site-specific data, you could estimate risk-based thresholds or levels that should be avoided to prevent adverse health effects. These target risk levels are sometimes used as cleanup levels or risk-based action levels. EPA has several guidance documents on the specific calculations and assumptions required in a risk characterization and can be found at their website.

With this information, you can propose cleanup levels to the state agencies or perhaps justify having a **no further action** or monitoring-only decision by the implementing regulatory agency. Based on your results, as well as other criteria, the state determines the cleanup level your site must achieve. You will then have to begin remediation to achieve this level, or be directed to simply monitor a site.

8.5 Cleanup Levels

Cleanup standards in soil, soil gas, and groundwater generally vary by state. Several associations and websites present state cleanup standards, including petroleum-hydrocarbon-contaminated soil and groundwater. Cleanup levels compiled by associations should be viewed with caution and confirmed with the appropriate state regulatory agency prior to use. Many states also provide

the option to develop site-specific risk-based cleanup levels as described in [Section 8.4](#).

EPA has established Regional Screening Levels (RSLs) to determine whether levels of contamination found at the site may warrant further investigation or site cleanup, or whether no further investigation or action may be required. RSLs are chemical-specific concentrations for individual contaminants in air, drinking water, and soil under a residential or industrial exposure scenario. [Section 8.12, For More Information](#) has a link to EPA's list of RSLs.

The RSLs contained in the EPA RSL table are generic; they are calculated without site-specific information. It should be emphasized that RSLs are not de facto cleanup standards. They may be used as initial cleanup goals, and exceeding an RSL may suggest that further evaluation of the potential risks by site contaminants is appropriate. RSLs can be incorporated into the CSM and help during the analysis of different remedial alternatives. However, the selection of final cleanup goals will need to take into consideration site-specific conditions, exposure routes, receptors, and exposure durations and accommodate relevant and appropriate regulations and land use. EPA provides an online RSL calculator format where default parameters can be changed to reflect site-specific risks (see [Section 8.12, For More Information](#)).

It should be noted that the EPA RSL tables are based on human health risk and do not address potential ecological risk. Some sites in sensitive ecological settings may need to be evaluated using an ecological risk assessment. Also, RSL tables, which are purely risk-based, may yield RSLs lower than naturally occurring background concentrations of some contaminants in some areas. Generally, EPA and state agencies do not require cleanup below natural background levels. Arsenic, aluminum, iron, and manganese are common elements in soils and have background levels that may exceed risk-based RSLs.

Other possible groundwater cleanup goals might include the maximum contaminant levels (MCLs) and secondary drinking water standards for over 90 contaminants in EPA's Safe Drinking Water Act regulations published in 40 CFR 141 and 143.

8.6 Remedial Strategies

Based on the CSM, the data collected during the site investigation and an assessment of risk and cleanup levels, the next step is to identify and implement the appropriate remedial strategy.

The remedial strategy consists of establishing specific, measurable, attainable, relevant, and time-bound (SMART) **remedial action objectives (RAOs)** and identifying remedial or treatment technologies to meet the objectives. It might include a rationale for coupling two or more treatment technologies, applied simultaneously or sequentially. The remedial strategy might include smaller pilot-scale tests to determine if technologies that appear to be likely candidates for treatment are effective at achieving the RAOs for the site. For groundwater remediation, the RAOs should clearly state if the objective is restoration of the groundwater, containment of the plume, or both.

The remedial strategy can involve passive or active measures, and may (or may not) achieve complete restoration (especially in cases of highly weathered, immobile, and inaccessible hydrocarbons). Between each remedial alternative there will be trade-offs of time, certainty, regulatory acceptance, cost, and effectiveness. In some cases, the future land use can influence the remedial strategy. For example, on a site that currently has an industrial use, with a long-term commitment to that use, the preferred remedial strategy might be an approach that focuses on containing the contamination at the property line, and imposing land use restrictions within it. Further, technologies that could be invasive or disruptive may not be compatible with the current land use.

Some other considerations for the overall remedial strategy for a site include:

- Removing **free product** from the groundwater.
- Understanding if the release contains oxygenate additives (if so, the potential exists that these compounds will migrate more quickly and further and may require differing methods for treatment).
- Reducing groundwater concentrations in the source (release) area through an active remedy. These concentrations will drive the total extent of the dissolved groundwater plume; reducing source area concentrations quickly will reduce the eventual impact of the groundwater plume.
- Understanding whether the site has the potential to naturally attenuate the contaminants (degrade or reduce concentrations), and if so, build the overall remedy around this natural attenuation capability.
- Employing an active plume management strategy if natural attenuation is not adequate.

Note that various site remediation programs may list specific criteria that need to be addressed in this evaluation of remedial alternatives. These criteria can include how established the technology of the proposed remedy is, time to complete cleanup, public acceptance, cost, and other regulatory-specific criteria. Check the regulations associated with your cleanup to determine what needs to be addressed.

8.6.1 Green and Sustainable Remediation

The Office of the Under Secretary of Defense released the first green and sustainable remediation memorandum in August 2009. The memorandum was later incorporated into a U.S. Department of Defense (DoD) Manual that states DoD is committed to conducting its environmental program in a sustainable manner and stresses the need to decrease the energy demand of existing and future remedial systems to minimize their environmental impact. DoD offers the following definition:

“Green and sustainable remediation expands upon the Department’s current environmental practices and employs strategies for environmental restoration that use natural resources and energy efficiently, reduce negative impacts on the environment, minimize or eliminate pollution at its source, and reduce waste to the greatest extent possible. Green and sustainable remediation uses strategies that consider all environmental effects of remedy implementation and operation



and incorporates options to maximize the overall environmental benefit of response actions.”

Fortunately, there are online tools that allow project team members to compare alternatives and their carbon equivalents of construction, operation, and vehicle use (see [Section 8.12, For More Information](#)).

8.6.2 Source and Barrier Treatment Strategies

Other strategic components to consider include the need to reduce elevated concentrations in a defined source area and the need to contain the contaminants.

In source area treatment, contaminants are addressed directly, at their location. At most spill locations, elevated concentrations at the source area will contribute over a long period of time to the downgradient groundwater plume, causing concentrations in the groundwater to increase and the overall groundwater plume to expand. In general, the larger extent of the groundwater plume, the more the future costs of remediation will increase. That is why treatment of elevated concentrations at the source, especially soon after the spill, is considered a cost-effective action.

Barrier treatment, in contrast to source area treatment, provides a form of containment-based treatment at the edge of the source area, or at the downgradient limit of elevated concentrations, or sometimes near a property line. With this approach, the groundwater is permitted to flow through the treatment zone, but the contaminants in the groundwater are treated and not allowed to flow past this zone. The flow-through treatment zone typically consists of a trench backfilled with permeable or reactive materials. In areas with coarse gravel or sandy soil, the most effective barrier may be a series of injection wells near one another. Because contaminants are treated as they migrate through this barrier, the effect on concentrations further downgradient is comparable to direct source treatment. Because a barrier or perimeter approach requires the source area contaminants to migrate to the treatment zone to be treated, this approach, if used alone, leaves the source area at higher concentrations for a longer time.

Most of the active treatment technologies described later in this chapter, except for excavation and the thermal methods, can be deployed in either source or barrier treatment. The design of a source area treatment tends to balance the treatment with the area, volume, and contamination load that is present. In the case of the barrier treatment, the design focuses on the area, volume, and contamination load that would *flow through* the treatment zone at any one time. For this reason, barrier systems tend to be more effective when installed early in the life of a plume, when most of the mass is still near the source area, and not already far downgradient.

One special barrier application is known as a **permeable reactive barrier**. When used for fuel spills, these take the form of a trench backfilled with pervious material (that is, gravel) and usually contain piping with screened sections to allow pumping in of treatment fluids or air (enabling oxidation or bioremediation).

Other types of barriers are passive (no active recharging or operation). One type that has been used for petroleum contamination consists of **oleophilic** clay, also known as organoclays, which attract petroleum oils but not water.

Source and barrier approaches can be used alone or in combination with each other. Barrier approaches, alone, can work well when the direction of groundwater flow is known with great certainty; when there is no overriding reason (for example, operational or regulatory) to accelerate the source area cleanup; and when time to closure is not important (barrier systems will need to continue to operate as long as there is contamination that could flow through them).

8.7 Free Product Management

In some remedial strategies, the most important aspect of releases to the subsurface is removal of the source area. This often addresses the presence of free-phase hydrocarbons in liquid form, usually called free product or NAPL. NAPL is often identified as one of two forms: LNAPL or DNAPL. Some examples of LNAPL include jet fuel (JP-4, JP-5, JP-8), kerosene, and gasoline. These are considered LNAPL because they are less dense than water and tend to stay above or float on top of the **water table**.

Other compounds, typically heavier oils, bunker fuel, or chlorinated solvents, can form DNAPL, which is usually found within and at the bottom of the groundwater-bearing zone. Each type of NAPL requires different remedial strategies. LNAPL strategies should consider:

- Free product may represent a source of explosive vapors in nearby vaults, sewers, or other spaces.
- Free product represents a large concentration of mass that will spread into the groundwater for years to come, if not recovered.
- Until free product is no longer present on or above the water table, nearby groundwater will not be likely to meet cleanup standards.

8.7.1 Near-term Product Recovery

Immediately after a release, the appropriate response is to contain the released material as much as possible. Refer to [Chapter 1, Environmental and Emergency Response Planning](#) for spill prevention and planning measures. If the spill infiltrates through soil and into the groundwater, the approach is to install collection sumps, trenches, or wells that gather the free product; pump the collected product to a safe, contained storage; and recycle or otherwise safely dispose of the recovered product. Temporary or short-term recovery programs typically use vacuum trucks (pumping both fuel and water) or skimmer pumps (pumping only fuel). Refer to [Chapter 2, Incident and Spill Reporting](#) for agency notification requirements when a spill occurs.

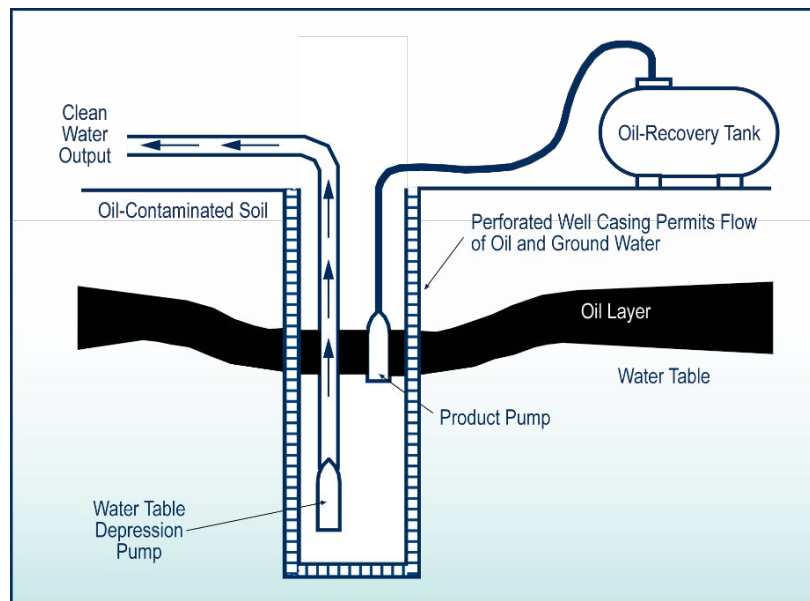
8.7.2 Long-term Product Recovery

For sites that are recovering fuel that has been in the ground a long time or that have soils that are silty or clayey in nature, free product recovery may need to continue for months or years. In these situations, it's usually best to automate the product recovery until most of the product has been removed and then follow

the final stages with periodic, manually operated recovery to extract the product and minimize the groundwater uptake and management as the free product or oil layer thins.

Many skimmer systems for recovering free product in the short term can be adapted for longer-term application. If more aggressive recovery is needed, a recovery system to be used at your facility can be designed on the basis of the hydrologic and geologic conditions of the site. **Dual-phase extraction** (also known as multiphase extraction, vacuum-enhanced extraction, or bioslurping) can be used successfully when the petroleum product floats on the water table (that is, LNAPL). In these systems, one pump draws down the water table and creates a **cone of depression** into which the free product floats. A skimmer pump transfers the free product to the surface for recovery (see *Exhibit 8–3*).

EXHIBIT 8–3
Free Product Recovery



The down-hole skimmer or product pump in this application only pumps fuel, with little or no groundwater. These types of pumps are becoming more widely used, as the removed fuel is typically pure enough to not require further treatment with an oil/ water separator, and it can usually be reused.

8.8 Soil Remediation Technologies

Numerous soil remediation technologies are available. Often a combination of soil remediation technologies (and groundwater treatment technologies discussed later) may be the most effective remedial strategy. Soil can be treated while still in the ground (**in situ**) or after excavation (**ex situ**). The volume of soil needing treatment, the location of contamination, and other site-specific conditions as described in the CSM will influence the choice of technologies. In addition, consideration of equipment and operation and maintenance (O&M) costs for some technologies may be justified only for large volumes of soil.



In situ treatment methods include soil vapor extraction, bioventing, and enhanced bioremediation.

If land and time are available, there may be several on-site ex situ treatment options:

- Biopiles or biomounding, in which the soil is treated in piles with nutrients and water
- Phytoremediation, in which the soil is spread, amended, and planted to be gradually treated by the roots of the grasses and plants
- Landfarming, in which the soil is spread, fertilized, irrigated, and heated by the sun to encourage biological treatment of the contaminants
- Portable low-temperature thermal units that can process limited quantities of soil, often more quickly and with more certainty
- Excavation and off-site disposal, generally for small volumes of contaminated soil.

The following sections discuss the above options; other treatment options may be available.

8.8.1 Soil Vapor Extraction

Soil vapor extraction (SVE) is an in situ treatment that physically separates contaminants from the soil. It uses wells screened above the water table (soil above the water table is called the **vadose zone**), with a vacuum applied by a blower system at the ground surface. The vacuum creates a flow of soil vapor to the well. The air drawn from the soil is made up by air that originally comes into the soil from the atmosphere, so this usually has two effects on the constituents in the vadose zone:

- The air flowing through the soil takes up vapors from the LNAPL as the LNAPL evaporates; these are carried to the well to be recovered
- The oxygen in the air adds to the dissolved oxygen in the soil moisture, which helps soil bacteria consume dissolved vapors

SVE systems are designed to remove contaminants that have a tendency to **volatilize** (evaporate easily). The extracted air, especially if it contains high concentrations of petroleum vapors, may initially be combustible or even explosive when it is brought to the surface to be treated. Care must be taken in handling these vapors, especially in the early stages of recovery; this typically involves the use of explosion-proof equipment and grounded, spark-arrested components. Often these systems must be permitted before operation, often with local fire departments, building departments, or state or local air quality agencies.

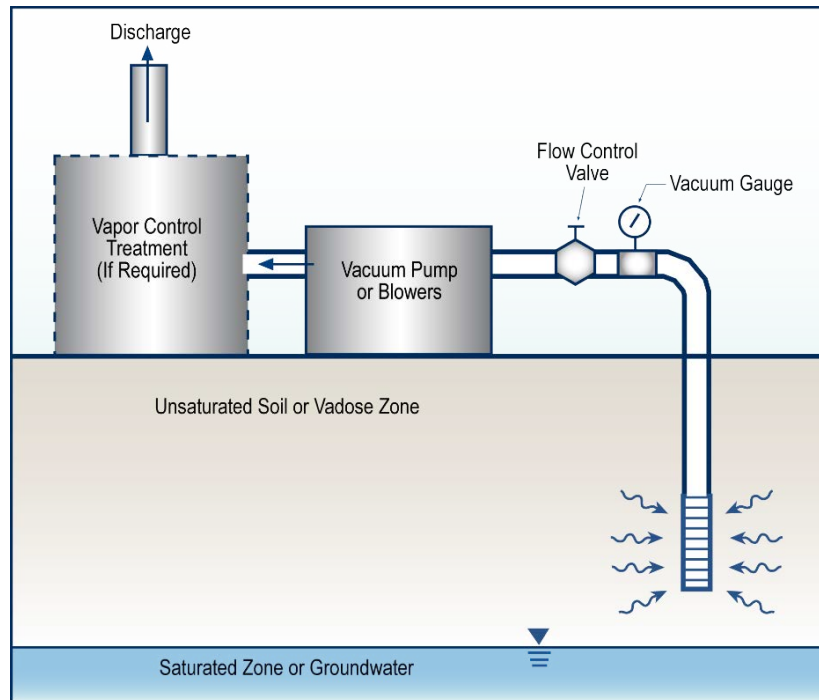
The basic components of an SVE system include an air/water separator, an inline filter, a blower (matched to the soil **permeability**), and an air treatment system (see [Section 8.10, Off-gas or Air Treatment Technologies](#)).

Exhibit 8–4 shows a typical SVE system. Some configurations use horizontal extraction wells placed in trenches instead of vertical wells. The only limit on

depth for these wells is the depth of the water table; SVE is effective only in soil above the water table.

SVE may be enhanced by the addition of heat or steam. The heat is transferred to the soil and the volatile constituents tend to evaporate for collection by a heat-resistant SVE system. Some temperatures may rise above the melting temperature for plastic well materials; therefore, all wells and **piezometers** need to be made of stainless steel to maintain their function through and after a thermal treatment.

EXHIBIT 8-4 Soil Vapor Extraction



8.8.2 Bioventing

In situ bioventing involves delivery of oxygen to contaminated unsaturated soils by forced air movement (either extraction or injection of air) to increase oxygen concentrations and stimulate biodegradation. It may use most of the same components as SVE, but it applies a smaller vacuum to produce a lower flow. During extraction, the blower discharge may require air treatment or may be discharged directly through a tall stack depending on concentrations and site location. In some situations, air or oxygen is injected into the soil at a slow rate, stimulating the bacteria in the soil to use contaminants as food. Bioventing can be used to treat aerobically **biodegradable** constituents. Bioventing has been proven effective in remediating releases of gasoline, jet fuels, kerosene, and diesel fuels.

Bioventing is typically used after the highest concentration source removal is completed. Bioventing is appropriate for the lower concentration phases of the remediation.

8.8.3 Enhanced Bioremediation

Bioremediation is a treatment process that uses naturally occurring **microorganisms** (such as, yeast, fungi, bacteria) to degrade (break down) hazardous substances into less toxic or non-toxic substances. Microorganisms eat and digest organic substances for nutrients and energy. (In chemical terms, organic substances are those that contain carbon and hydrogen atoms.) Certain microorganisms can digest organic substances, such as fuels or solvents, that are hazardous to humans. The microorganisms break down the organic contaminants into harmless products—mainly carbon dioxide and water. Although successful in situ biodegradation has been demonstrated in cold weather climates, low temperatures slow the microbial degradation rate. For contaminated sites with low soil temperature, heat blankets may be used to cover the soil surface to increase the soil temperature and the degradation rate.

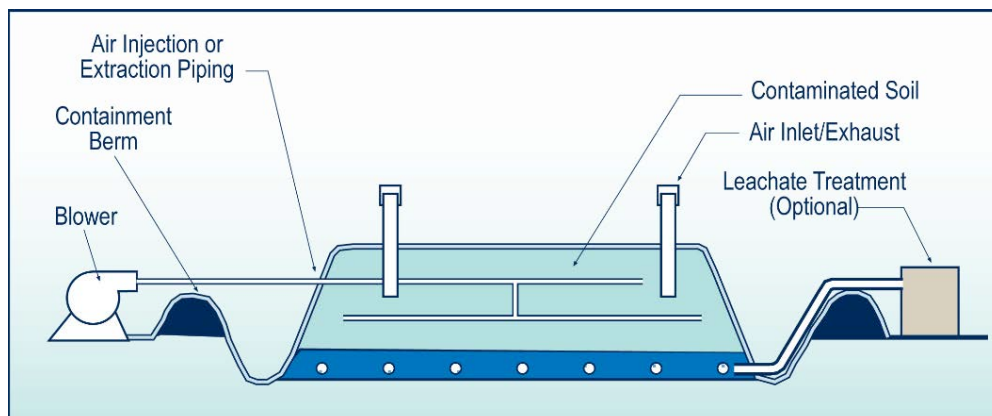
Enhanced bioremediation or biodegradation is a broad, general term that simply means adding something into the soil with the purpose of stimulating the bacteria to use the contamination as food. The term “enhanced biodegradation” or bio-stimulation for soil remediation usually involves adding nutrients to the soil in situ.

Nutrients are usually added to the soil by **percolating** or injecting water mixed with nutrients through the soil. An infiltration gallery or spray irrigation is typically used for shallow contaminated soils, and **injection wells** are used for deeper contaminated soils. When enhanced biodegradation involves the addition of supplementary microorganisms, the technology is termed **bioaugmentation**.

8.8.4 Biopiles or Biomounding

Soil biopiles or **biomounding** involves excavation and piling contaminated soil in heaps over a system of perforated piping. Air is supplied to the piping using blowers or is drawn through the pile using vacuum pumps. Microorganisms in the soil degrade the organic compounds in the contaminated soil. Moisture and nutrients are added to maximize bioremediation. Volatile contaminants are controlled easily if a vacuum is being used to pull air through the pile (see *Exhibit 8–5*).

EXHIBIT 8–5
Typical Biopile System



Biopiles have been proven effective in reducing concentrations of petroleum-related constituents. Depending on the state’s regulations for air emissions of

volatile organic compounds (VOCs), vapor controls may be required before venting exhaust to the atmosphere.

8.8.5 Phytoremediation

Phytoremediation is a process that uses plants (such as grasses or willow and poplar trees) to remove, transfer, stabilize, and destroy contaminants in soil and sediment. The mechanisms of phytoremediation include enhanced rhizosphere biodegradation, phytoextraction (also called phytoaccumulation), phytodegradation, and phytostabilization. Phytoremediation generally works best for contamination that is widespread, shallow, and low to medium levels of contamination. Phytoremediation can be used to clean up certain metals, pesticides, crude oil, and components of gasoline, diesel, and jet fuel. Different plants are selected for each application. Phytoremediation is a slow process but can be used where other technologies are not practical or are undesirable. This technology has the distinct advantage of being aesthetically pleasing, and beneficial to the environment.

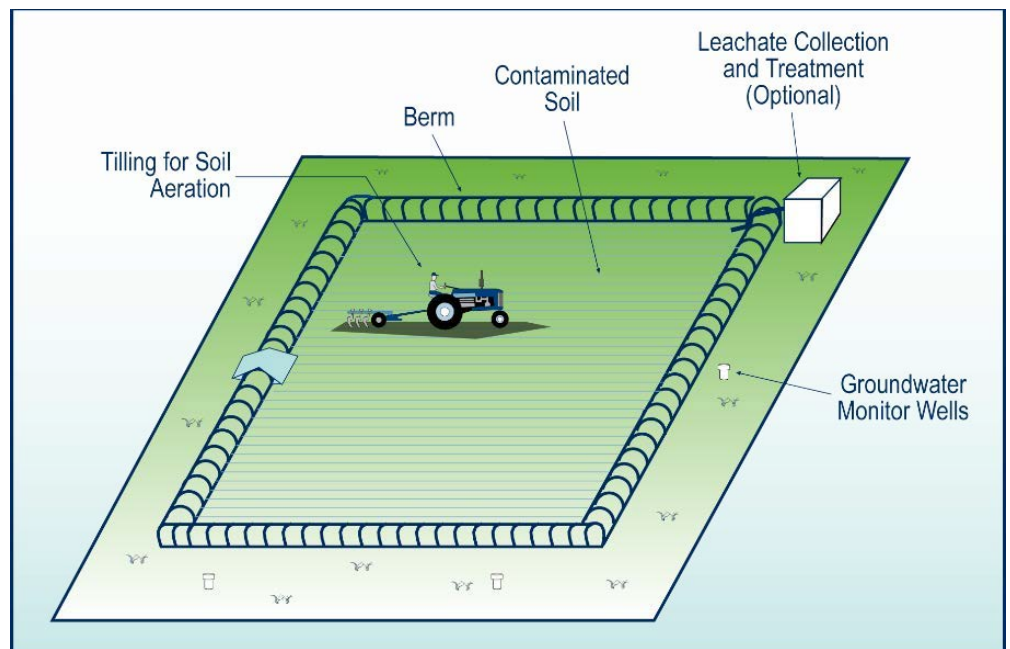
8.8.6 Landfarming

Landfarming or land treatment is a relatively simple treatment method. Contaminated soils are excavated and spread on a pad or liner with a built-in drainage system to collect any **leachate** (contaminated liquids that seep out of contaminant-soaked soil) (see *Exhibit 8–6*). The soils are periodically turned over or tilled to mix air into the waste. Moisture and nutrients are added to enhance bioremediation. Biodegradation (broken down by bacteria) accounts for most of the remediation, but **volatilization** (release of vapors) and **photodegradation** (broken down by light) can also enhance cleanup.

Landfarming, like biopiles, has been proven to be effective in reducing concentrations of petroleum-related constituents.

EXHIBIT 8–6

Landfarming Schematic

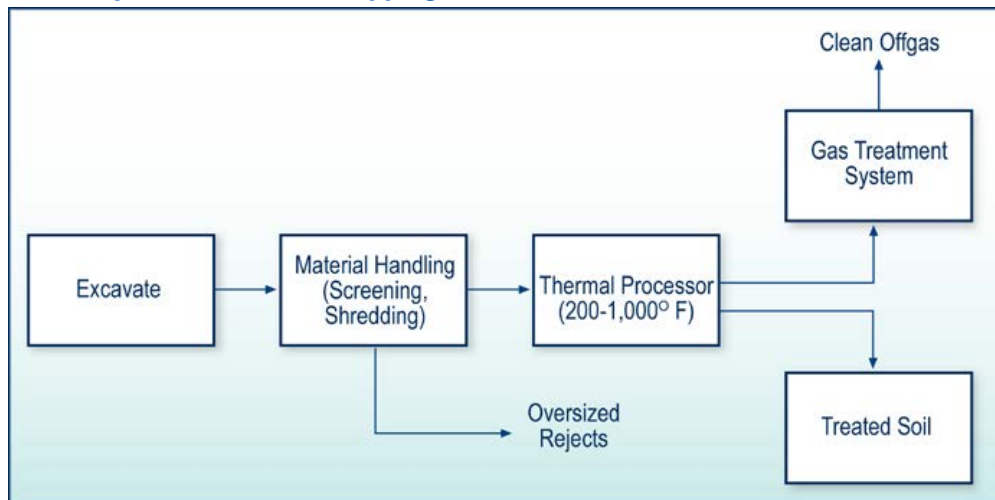


8.8.7 Low-temperature Thermal Stripping

Low-temperature thermal stripping is also known as **low-temperature thermal desorption**, thermal volatilization, and soil roasting (see *Exhibit 8–7*). The process involves feeding contaminated soil into a feed hopper, which falls into a thermal processor. Thermal processors are designed to heat soils to sufficient temperatures (200°F–1,000°F/93°C–538°C) to cause constituents to volatilize and **desorb** (physically separate) from the soils. Air pollution control equipment (such as an after-burner, catalytic oxidation chamber, scrubber, or carbon adsorption unit) is usually required to treat exhaust gases (vaporized hydrocarbons) prior to discharge.

EXHIBIT 8–7

Low-temperature Thermal Stripping



After leaving the desorber, soils are cooled, remoistened to control dust, and stabilized (if necessary) to prepare them for disposal or reuse. Treated soil may be redeposited on-site, used as cover in landfills, or incorporated into asphalt.

Low-temperature thermal desorption has been proven effective in reducing concentrations of petroleum products including gasoline, jet fuels, kerosene, diesel fuel, heating oils, and lubricating oils.

8.8.8 Excavation and Off-site Disposal or Recycling

Soil removal is an appropriate strategy if the area is small and shallow, and a quickly implemented cleanup is important. Excavation of contaminated soil is generally possible to a depth of 25 feet or more, depending on the equipment available and the water table depth. When contaminated soil is excavated, it must be either treated on-site or transported for off-site treatment or disposal.

You can landfill soil off-site if it's not heavily contaminated with petroleum and has no free liquids. Many municipal or solid waste landfills will accept this waste if it is non-hazardous. EPA exempts petroleum-contaminated soil and debris from the hazardous waste **toxicity characteristic** (D018 through D043) if it is being cleaned up under the UST regulations in 40 CFR 280. Check to see if state requirements also provide this exception. Other contaminants may need additional treatment before landfilling, depending on the landfill's permit. The landfill may be able to treat the soil at its facility prior to land disposal and include this cost in the disposal price.

Petroleum-contaminated soil can be incorporated into marketable products. Contaminated soil may be accepted by certain asphalt processing, cement production, and brick-making facilities.

8.9 Groundwater Remediation Technologies

At many sites, the focus of long-term remedial actions centers on the groundwater and restoring water quality. Some common groundwater treatment technologies include groundwater extraction and treatment (called pump and treat) or in situ methods, such as air sparging, chemical oxidation, thermal treatment, and monitored natural attenuation.

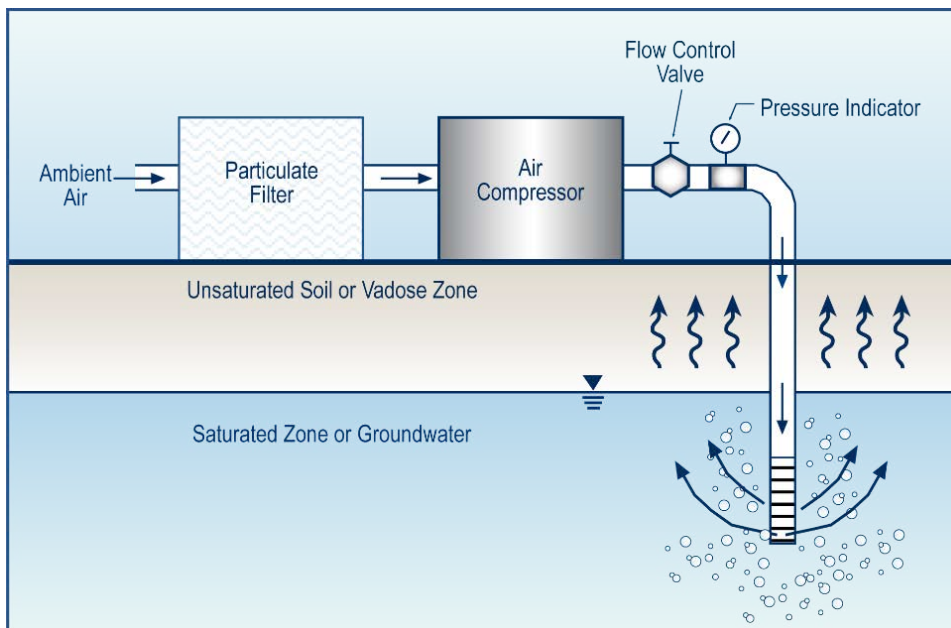
8.9.1 Pump and Treat

A pump and treat system is a common method for treating contaminated groundwater. With this technique, a system of extraction wells or trenches and pumps brings contaminated groundwater to the surface. The water is collected and sent through an aboveground treatment system, such as an **oil/water separator**, air stripper, biological treatment system, or granular activated carbon (GAC) system. There are regulatory considerations and possible permits for discharge of treated groundwater.

There are various kinds of extraction wells and pumps for groundwater recovery systems. An experienced hydrogeologist will establish the best locations and spacing of the wells. Belowground drains or interceptor trenches (sometimes called French drains) to collect contaminated groundwater are an alternative to extraction wells.

There is considerable EPA and state concern that pump and treat does not produce required cleanup levels in a reasonable time and that it is costly. Although often used in the past, it may not be your best long-term solution because the long-term costs can be significant. However, pump and treat does have an advantage of capturing or arresting the migration of a plume that could be threatening a downgradient receptor.

EXHIBIT 8-8
Air Sparging



8.9.2 Air Sparging

Air sparging is also known as in situ air stripping, groundwater sparging, and in situ volatilization. Air sparging is an in situ remedial technology that reduces concentrations of volatile constituents that are adsorbed to soils and dissolved in groundwater. This technology involves injecting pressurized air into the **saturated zone** (below the water table) via an injection well, called a sparging well. The air bubbling up allows volatile compounds dissolved in

the groundwater to migrate up into the unsaturated soil as a vapor (see *Exhibit 8–8*). In addition to its air stripping capability, air sparging enhances biodegradation by supplying oxygen to groundwater, which helps microorganisms digest organic substances. Air sparging using low air flow rates and the addition of nutrients is sometimes called biosparging.

Air sparging is often used together with SVE. When air sparging is combined with SVE, the SVE system mechanically extracts vapors that the sparging system has freed from the groundwater and prevents the dispersion of these vapors to any sensitive or potentially explosive surface receptors. Air sparging is effective in reducing concentrations of VOCs. Air sparging is generally more applicable to the lighter gasoline constituents (such as BTEX) because they readily transform from liquids into gases. Air sparging is less applicable to diesel fuel and kerosene.

For treatment of elevated concentrations in source areas, sparging requires soils that are sand-sized or greater (otherwise, the air cannot bubble up through the groundwater). Both vertical wells and horizontal wells are used to deliver the air, with horizontal wells having advantages in coverage and versatility. Horizontal wells can often be installed beneath structures or piping systems, where vertical wells might not have easy access.

8.9.3 In situ Chemical Oxidation

In situ chemical oxidation (ISCO) involves the introduction of a chemical oxidant for the purpose of reacting and transforming or breaking down groundwater contaminants into less toxic compounds that are more stable, less mobile, or inert. There are several different forms of oxidants that have been used for ISCO. The four most commonly used oxidants are permanganate (MnO_4^-), persulfate (S_2O_8), hydrogen peroxide (H_2O_2), and ozone (O_3). Chemical oxidation is primarily used to treat contaminants in the source area saturated zones and **capillary fringe**. Chemical oxidants are typically delivered via injection wells, infiltration galleries, and temporary injection points. A good chemist can assist with selecting the oxidant that works best against specific contaminants.

There are potential hazards using chemical oxidants because most are corrosive and highly reactive, with the potential to be explosive. Heat may be generated by the chemical reactions and excessive heat production may need to be addressed (it may damage or melt polyvinyl chloride or plastic wells). Proper worker protection is needed when handling these chemicals.

In addition, there are several regulatory requirements pertaining to chemical oxidation including approval of an oxidant injection permit from federal or state environmental agencies under their underground injection control programs. Chemical storage may trigger Emergency Planning and Community Right-to-Know Act (EPCRA) requirements (see [Chapter 12, Routine Reporting](#)).

8.9.3.1 Permanganate and Persulfate Oxidation

Potassium permanganate (KMnO_4), is the most common oxidant of the four and is available in a solid that must be mixed with water before injection. Another form is sodium permanganate (NaMnO_4), which is more stable and supplied as a liquid. Activated sodium persulfate ($\text{Na}_2\text{S}_2\text{O}_8$) is a relatively new form of oxidant.



These are strong oxidizers and typically only used in high concentration cases. It's not safe to apply these compounds if free product is present *unless the risk of uncontrolled oxidation is eliminated*. Often the most successful use of these oxidants is in otherwise difficult to treat settings, such as low permeability soils, heavier fuels, or hard to access locations.

8.9.3.2 Hydrogen Peroxide Infiltration

Hydrogen peroxide, injected or infiltrated into the saturated zone, serves as a source of oxygen to enhance bioremediation of organic-contaminated areas, including petroleum-impacted areas. Hydrogen peroxide is often delivered via extracted groundwater that is re-injected or re-infiltrated back into the subsurface. Subsurface persistence has been cited as a concern in some cases, but the liquid delivery adds an advantage in that its delivery can be incorporated into an existing water pumping system. Hydrogen peroxide is particularly effective when catalyzed by iron. The subsequent reaction between hydrogen peroxide and ferrous iron produces what is called Fenton's reagent.

8.9.3.3 Ozone Injection

Ozone is another powerful oxidant and may be injected into the ground in a dissolved phase or in a gaseous phase through the use of sparging wells. The instability of ozone requires that it be generated on-site. This can be accomplished using a simple process where electrical energy breaks apart oxygen molecules present in the air to react and make ozone. In situ decomposition of the ozone can lead to beneficial oxygenation and biodegradation of contaminants in addition to the oxidation reactions.

Vapor control equipment, such as an SVE system, may be needed if ozone injection rates are sufficient to emit fugitive ozone emissions into the **unsaturated zone** and atmosphere.



8.9.4 In Situ Thermal Treatment

Different in situ techniques can be used to apply heat to contaminated groundwater and soil. The heat can destroy or volatilize organic chemicals. As the contaminants change into gases, their mobility increases, and the gases can be extracted via SVE wells, which may require off-gas treatment depending on the state regulations and the site location. Alternatively, thermal treatment areas may be covered with an impermeable surface cover (such as concrete, asphalt, or a heavy-duty tarp) to keep the heat and steam underground. Such covers also help prevent the release of chemical vapors into the air. Thermal methods can be particularly useful for LNAPLs, especially less volatile oils. Heat can be introduced belowground by injecting steam and hot water or through electricity using electrical resistance heating and thermal conduction heating. Selecting the most appropriate heating technology is a site-specific decision that is influenced by subsurface permeability, contaminant properties, and the contaminant distribution.

In situ heating with steam couples subsurface injection of steam (or hot water) with multiphase extraction of soil vapor and groundwater. In practice, steam will also displace NAPL from a treatment area, which makes this heating approach the most effective for NAPLs with low volatility. Overall, the method is well-suited

for large sites with moderate to high permeability because heating is strongly controlled by the lateral distribution of steam in the treatment area. Treatment temperatures are pressure-dependent, but conditions over 212°F/100°C are feasible with this technology.

Electrical resistance heating (ERH) delivers an electrical current between an array of metal rods called “electrodes” installed underground. The heat generated as movement of the current meets resistance from soil converts groundwater into steam, vaporizing contaminants. Given the nature of this heating mechanism, ERH treatment temperatures are limited to the boiling point of water at local pressure conditions. The heating technology excels in fine-grained soils with low to moderate permeability.

When using ERH, the electrical current is prevented from traveling outside of the treatment area or to aboveground structures by using common electrical grounding techniques.

Thermal conduction heating (TCH), also referred to as in situ thermal desorption, supplies heat to the soil through electric heating elements encased in steel wells that are sealed from groundwater entry. A recent variation of TCH has coupled propane or natural gas combustion for in situ heating. Like ERH, multiple heaters are installed within the treatment area; similarly, TCH also works well in fine-grained soils with low to moderate permeability. Unlike ERH, the TCH process is capable of in situ treatment temperatures in excess of 212°F/100°C. In practice, as the contaminated area is heated, the contaminants are destroyed in situ, evaporated, or extracted and treated aboveground.

8.9.5 Monitored Natural Attenuation

Natural attenuation is a passive remedial approach that depends on natural processes to reduce contaminant levels in groundwater, and in soil to a lesser degree. This approach is often called monitored natural attenuation (MNA). The most important natural processes are aerobic biodegradation and volatilization. Other processes that can contribute are oxidation and/or reduction, sorption, dispersion, dilution, and radioactive decay. These processes tend to occur naturally without human intervention. Natural attenuation is also known as passive or **intrinsic bioremediation**.

MNA is usually not implemented as the main remedy until LNAPL (free product) has been removed to the maximum extent practicable. For UST releases, free product removal must be conducted per 40 CFR 280.64. As discussed previously, the removal of free product carries other practical benefits, such as shortening the expected time of remediation and minimizing cost. Likewise, understanding the CSM and MNA potential will lead to the optimization of the groundwater plume strategy (for example, an oxygen limitation might favor an oxidation approach).

Because petroleum hydrocarbons are readily broken down by aerobic bacteria and most groundwater sites are naturally replenished with oxygen, intrinsic bioremediation can be an important aspect of groundwater plume management for these types of releases. Naturally occurring degradation often exceeds, on a mass basis, the amount being degraded by sparging, or ISCO, or similar active remedies for large spills.

The major exceptions to this condition of naturally aerobic groundwater should be expected around shorelines or bays, or in heavily industrialized zones. At these locations, the natural replenishment of atmospheric oxygen may be suppressed, or the decaying organic matter in the soil may steadily consume the oxygen naturally present, leaving little if any for MNA. Under these conditions, other processes take on a greater importance. In addition to sorption, dispersion, and dilution, there are also other oxidation processes that can occur when oxygen is absent, involving nitrate (consumed), iron (made soluble, appearing), sulfate (consumed), and methane (produced). In the absence of oxygen, these processes are typically important to consider for MNA effectiveness.

Natural attenuation of groundwater requires routine monitoring to confirm that natural processes are reducing contaminant levels.

8.10 Off-gas or Air Treatment Technologies

Certain remedial technologies for soil and groundwater transfer the contaminants from those media to the atmosphere. In most areas of the U.S. and for most sites, some form of treatment will be required before these vapors can be discharged. In some cases, permits will be required for the air treatment systems. For example, air treatment systems typically represent at least 50% of the life cycle cost of most remediation projects and can consume over 75% of the energy used. For these reasons, the air treatment system selected and deployed should be understood and managed carefully.

Air treatment systems are based on three principles: adsorption, thermal oxidation (controlled burning), and condensation. Each has an optimum application based on concentration range and contaminant loading. The following sections discuss these general treatment types.

The primary remediation systems that will require air treatment are SVE (with or without air sparging) and air stripping of groundwater. The concentration ranges to be expected from each of these systems are the key to understanding the optimum air treatment system to use, or whether to start with one and plan to transition to another when concentrations have fallen. Planning this sort of staged treatment before installation of the initial system can make a future switchover relatively simple.

8.10.1 Air Treatment by Adsorption

Vapor-phase granular activated carbon (VGAC) is a common system used to purify waste gases from site remediation systems. VGAC is easy to operate, has low energy costs, and can be used over a wide range of concentrations. A VGAC system consists of containers of activated carbon (from 55-gallon drums to 10,000 lb tanks) that are typically connected as the final treatment step of a system. VGAC adsorption works most effectively when the incoming vapor stream is warm (100°F/40°C to 140°F/60°C) and of medium humidity. This is one of the reasons VGACs are placed downstream of blowers, as blowers tend to heat up and dry out the vapors they collect from the ground or from the discharge of an air stripper. Another reason is the air is near atmospheric pressure coming into and exiting the VGAC vessels, so collecting samples to verify compliance is simpler.

VGAC usually adsorbs hydrocarbon vapors at a rate of about 10 percent by weight (for example, it takes 500 lb of VGAC to adsorb 50 lb of hydrocarbons). A wide variety of contaminants, not just fuel components, can be adsorbed by the carbon.

8.10.2 Air Treatment by Thermal Oxidation

Hydrocarbons are readily oxidized, so burning vapors is a common method of air treatment for remediation systems. The two most common methods used are:

- Thermal oxidizers (THERMOX) are flares that burn the incoming vapor as fuel and frequently have a natural gas feed line to make up energy when the incoming concentrations decrease. They are simpler to operate than a catalytic oxidizer but more expensive at lower concentrations (because of supplemental fuel).
- Catalytic oxidizers (CATOX) use a heated catalyst to efficiently treat the fuel vapors, with either electricity or natural gas used to preheat the catalyst. These systems typically have higher capital costs than THERMOX units, but can cost-effectively treat to lower concentrations.

Both of these units require an external power supply and permitting prior to operation, but are highly efficient for relatively high concentration vapor streams. These also represent a well-understood technology, which can lead to expedited regulatory approval. Units are typically available on short notice.

If a mixed contamination source is to be treated, thermal options tend to be effective for **oxygenated fuels**, but sensitive otherwise. Any halogenated compounds (chlorinated, fluorinated), such as Freon or solvents, can be problematic; side-effects could include the formation of acids in the discharge or poisoning of the CATOX unit's catalyst.

8.10.3 Air Treatment by Condensation

For high vapor concentrations, condensation using a refrigeration cycle in which the incoming vapor is chilled to the point that the hydrocarbons form a liquid. The liquid can then be separated and then recycled or incinerated. A VGAC unit is typically used for the remaining vapor stream.

These units require a significant energy supply and are typically available on a leased basis for 6 or 12 months. They can be complex to run but include telemetry and remote operation options. Overall they work best during the initial stages at large spill sites, when the concentrations will stay high (greater than 5,000 parts per million by volume TPH) for many months. Condensation units are the most robust technology for mixed-compound air streams.





State Requirements

8.11 State Requirements

State petroleum assessment and cleanup programs, regulations, policy and guidance can evolve, so always check with your state agency for its remediation program requirements.

- Most states have developed their own programs for LUSTs, and some have programs for AST releases. The requirements vary widely between states and often are site-specific. These programs indicate what parameters to test for, what levels need corrective action, and what the cleanup level should be. Many programs also require that individuals performing the assessment be certified by the state agency. [Appendix E](#) lists state environmental agency contacts. Be aware that in a few states, the registration, testing and closeout of USTs are handled by the state Fire Marshal's Office or other department of state government.
- Most states have voluntary cleanup programs. Frequently these are coupled with the state Brownfields programs to encourage redevelopment of contaminated property.
- Most states have risk-based approaches based either on the ASTM RBCA standard, or their own risk-based process, for UST cleanups. This means the level of cleanup is based on many factors, and not necessarily one given value for all sites.
- Most states have cleanup levels for MTBE in groundwater. The remaining states are waiting for EPA to establish a national primary drinking water regulation or MCL for MTBE.
- States such as Missouri, Delaware, Maine, Michigan, New Jersey, and several others have begun establishing cleanup levels for other oxygenates in addition to MTBE. For instance, California and New Jersey have established drinking water and groundwater action levels for the oxygenate TBA, which is an intermediate of MTBE biodegradation and was used as a gasoline blending component circa 1975–85.
- California, Colorado, Illinois, Massachusetts, Minnesota, New York, Oregon, and Wisconsin have green remediation programs.
- Many states have their own state Superfund, which may include other contaminants that are not included under the federal Superfund. For example, in Hawaii, petroleum oils are included in the state Superfund.
- Many states have issued their own state cleanup standards. These standards are called by many different names and can be found in guidance documents or in regulations.
- Some states, such as New Jersey, New York, Pennsylvania, and Missouri, may require permit equivalents for CERCLA projects, despite the CERCLA exemption from permitting for remedial actions.

8.12 For More Information



For More Information

For Information On...	See...
Assessment and Cleanup Related Agencies	
EPA Federal Facilities Restoration and Reuse Office	www.epa.gov/fedfac
EPA Office of Underground Storage Tanks	www.epa.gov/UST
EPA Superfund Website	www.epa.gov/superfund
EPA Vapor Intrusion	www.epa.gov/oswer/vaporintrusion
EPA Site Characterization/Assessment	www.epa.gov/land-research/site-characterization-and-monitoring-technical-support-center-scmstsc
EPA Brownfields Program	www.epa.gov/brownfields
Triad Resource Center	www.triadcentral.org
DoD Strategic Environmental Research and Development Program (SERDP) and Environmental Security Technology Certification Program (ESTCP)	http://serdp-estcp.org/Program-Areas
Utility marking prior to digging	National “Call Before You Dig” Phone Number Dial 811 or www.call811.com
Documents and References	
Cleanup Levels	<p><i>Use of Risk-Based Decision-Making in UST Corrective Action Programs.</i> EPA OSWER Directive 9610.17. March 1, 1995. Available from www.epa.gov/sites/production/files/2014-02/documents/d9610.17.pdf</p> <p><i>Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites.</i> ASTM Standard E-1739-95(2005). American Society for Testing & Materials (ASTM). Philadelphia, Pennsylvania. (215) 299-5585.</p>
EPA Regional Screening Levels	www.epa.gov/reg3hwmd/risk/human/rb-concentration-table/Generic-Tables/index.htm
EPA RSL Calculator	https://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search
EPA Contaminated Site Cleanup Information (CLU-IN) and EPA Software (extent, flux, cost)	www.clu-in.org www.clu-in.org/software
EPA Green Remediation	https://clu-in.org/greenremediation/ and www.epa.gov/greenercleanups/epa-principles-greener-cleanups
SiteWise tool (jointly developed by the U.S. Army Corps of Engineers and U.S. Navy, in collaboration with Battelle).	www.clu-in.org/products/tins/tinsone.cfm?num=33952490
Sustainable Remediation Tool, (developed by U.S. Air Force Civil Engineer Center for use by the U.S. Air Force)	www.clu-in.org/products/tins/tinsone.cfm?num=66247610



Action Items

8.13 Action Items

Item	Date Started	Date Completed	N/A	Comment(s)
<i>Notify</i> regulatory agencies in the event that an environmental release is identified at your facility.			<input type="checkbox"/>	
<i>Hire</i> a qualified and capable consulting firm to initiate response actions, including the preparation of an investigation work plan and initial negotiations with your environmental agency.			<input type="checkbox"/>	
<i>Charter</i> the selected consulting firm to jointly confirm program values, project objectives, time-critical actions, performance criteria, lines of communication, initial CSM, and range of probable remedial actions.			<input type="checkbox"/>	
<i>Determine</i> the cause and extent of site contamination through field investigation and prepare a site investigation report for submittal to your environmental agency.			<input type="checkbox"/>	
<i>Obtain</i> permits for investigation and cleanup in sensitive areas such as wetlands, floodplains, and wildlife habitats, and for air and wastewater discharges.			<input type="checkbox"/>	
<i>Conduct</i> human health and ecological risk assessments to understand which receptors and pathways are important and how much cleanup is necessary.			<input type="checkbox"/>	
<i>Prepare</i> a proposed cleanup plan for submittal to your environmental agency, and negotiate the details prior to initiation of cleanup actions.			<input type="checkbox"/>	
<i>Choose and implement</i> a cleanup method that provides the optimum balance between effectiveness and life cycle cost.			<input type="checkbox"/>	
<i>Manage</i> site investigation and remediation wastes as hazardous waste, if appropriate.			<input type="checkbox"/>	
<i>Maintain</i> detailed records of all site investigation and remedial actions.			<input type="checkbox"/>	
<i>Install, operate, and maintain</i> pollution control and remediation systems for many years.			<input type="checkbox"/>	



CHAPTER 8
Appendices

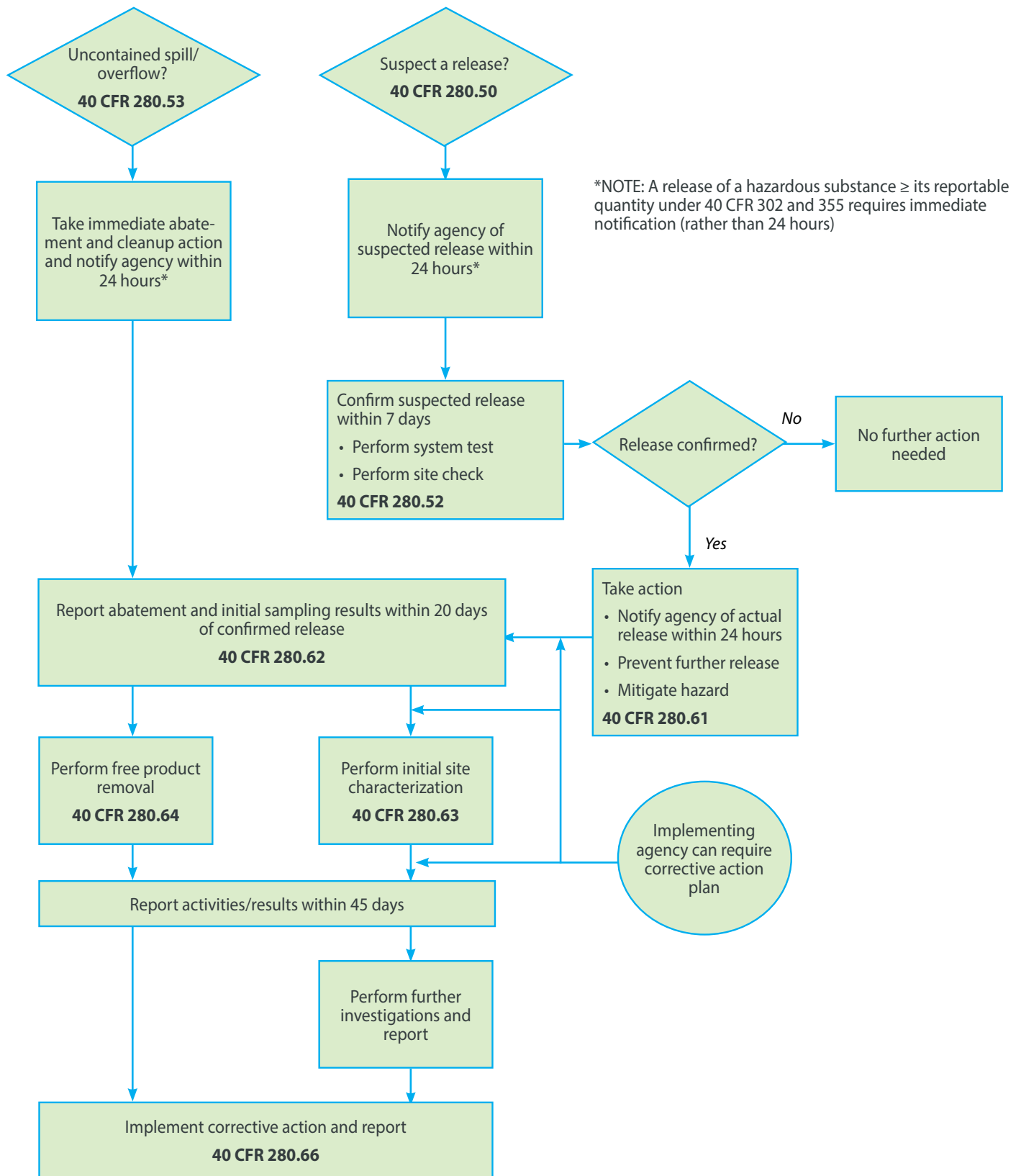


Appendix 8–1 Regulatory Flow Chart for UST Release Reporting, Investigation, Response, and Corrective Action

Appendix 8–2 General Comparison of Environmental Cleanup Process Under Three Regulatory Programs

**THIS PAGE LEFT
INTENTIONALLY BLANK**

Appendix 8-1: Regulatory Flow Chart for UST Release Reporting, Investigation, Response, and Corrective Action



**THIS PAGE LEFT
INTENTIONALLY BLANK**

Appendix 8-2: General Comparison of Environmental Cleanup Process Under Three Regulatory Programs

Elements of Program	RCRA Corrective Action	CERCLA (Superfund)	Brownfields
Responsible Agency	RCRA—authorized State	EPA Region or federal agency such as DoD	EPA, state or local government
Initiation of the Investigation Process	Required by a RCRA Part B Treatment, Storage, Disposal Facility permit or under an RCRA enforcement order	A hazardous substance may be released to the environment or a release or a threat of a release of a hazardous substance, pollutant, or contaminant into the environment that may be presenting an imminent threat to public health and welfare	Desire to redevelop property
Records Search	RCRA Facility Assessment	Preliminary Assessment	Due-diligence Assessment
Confirmatory Sampling	(Optional) A Phase I RCRA Facility Investigation or a Release Assessment may be conducted to determine if interim measures (conducted at the discretion of the implementing agency) are necessary	Site Inspection	Due-diligence Assessment through a Phase I Environmental Site Assessment and Phase II if needed
Interim Action (can occur during any point in the remedial process)	Interim or stabilization measures	Removal Action	Not Applicable
Site Scoring	Not applicable	Hazardous Ranking System scoring for National Priorities Listing determination	Not Applicable
Nature and Extent Determination	RCRA Facility Investigation	Remedial Investigation	Due-diligence Assessment through a Phase II Environmental Site Assessment
Alternatives Evaluation	Corrective Measures Study	Feasibility Study	Predevelopment, including identifying and refining development idea by assessing potential reuse and identifying sources of financing
Proposed Action	Fact Sheet or Statement of Basis	Proposed Plan	Securing the Deal, including negotiating contract terms, securing financing, and deciding how to manage environmental liability
Remedy Selection Decision Document	RCRA Permit Modification or Agreed Order	Record of Decision	Remedial Action Plan
Action Implementation	Corrective Measures Implementation	Remedial Design/Remedial Action	Remedial action and construction or land reuse development
Long-term O&M	RCRA Permit Modification Including Closure and Post-closure Care or Agreed Order	Long-Term Response Actions (LTRA); Operation and Maintenance; Institutional Controls; Five-year Reviews; Remedy Optimization	Long-term sustainable reuse, remedial system maintenance, and institutional controls may be negotiated with property owners as part of a deed of sale

**THIS PAGE LEFT
INTENTIONALLY BLANK**