Chapter II

Contamination, Assessment, and Cleanup

A. Introduction

In order to grasp both the problems posed by brownfields and the importance of solving those problems, it is critical to understand the contaminants found at brownfields, the phases of assessment, and the techniques used to cleanup sites.

Different types of contaminants require different restoration methods. Unfortunately, there is a lot of uncertainty over how to identify toxic substances, the best techniques for treatment, and the required level of cleanup. To make matters worse, the cleanup technologies employed at brownfields can be extraordinarily expensive.

In recent years, innovative treatment technologies have been introduced that are designed to decrease remediation costs. These lower costs have made the redevelopment of many brownfields economical.

B. Types of Contamination and Their Health Effects

Health and safety concerns about living and working near a particular brownfield are sometimes unfounded. However, this is not always the case. There is little question that the contaminants found on brownfields are potentially dangerous. The issue is whether or not the public will be exposed to them. If exposed to such substances, humans can suffer serious health consequences. Even if humans are not subjected to these hazards, they are extremely damaging to the environment.

The residues, tars, and byproducts of manufacturing plants, gas stations, pipelines, dry cleaners, and other industrial facilities are the root of the brownfields problem. Four general categories of contaminants are:

- Solvents
  Examples: Paint thinner, dry cleaning fluid, and parts degreaser.
  Sources: Garages, industry, homeowners, dry cleaners.
- Heavy metals
  Examples: Lead, Chromium, Cadmium, Arsenic, and Mercury.
  Sources: Metal finishing, metal plating, manufacturing, and foundries.
- Petroleum
  Examples: Gasoline, diesel, and motor oil.
  Sources: Underground storage tanks, gas stations, tank farms,

pipelines, and homeowners.

- Pesticides/Herbicides

  Examples: Bug killers (DDT), and weed killers (4-D)
  Sources: Homeowners, farmers, manufacturers, and exterminators.

A discussion of some of the most common and most hazardous substances found at brownfields is included in the **Appendix** at the end of this chapter. The substances chosen include the top ten from the **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Priority List of Hazardous Substances.** The Agency for Toxic Substances and Disease Registry (ATSDR) and EPA prioritize the substances frequently uncovered on National Priorities List (NPL) sites which threaten human health. This register of dangerous materials is based on[1]:

- Toxicity.
- Frequency of occurrence.
- Potential for human exposure.

There are two important points to keep in mind when reviewing the priority list. First, the priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their toxicity, frequency, and potential for human exposure at NPL sites. Second, the priority list does apply to all brownfield sites, since the data used is strictly from CERCLA sites on the NPL.

Along with the CERCLA Priority List of Hazardous Substances, ATSDR has been tabulating and recording substances to which people have been exposed to at hazardous waste sites. This information is displayed in the **Completed Exposure Pathway Site Count**. Any time a contaminant can come into contact with a population, it is called "completed exposure pathway" (CEP). Thus, a contaminant buried under eighty feet of dense soil is unlikely to affect a population and, as a result, does not represent a CEP. The CEP site count ranks substances according to their respective number of CEPs. In turn, contaminants high on this list are those which are most frequently in contact with populations[2].

For the purposes of this chapter, the CEP site count is important because it evaluates information from all sites (e.g., brownfields), not just NPL properties. Indeed, the NPL is biased towards sites with groundwater contamination; in fact, 85% of the properties on NPL have some level of groundwater contamination[3]. While this is an important area of contamination to consider, it is

[1]http://atsdr1.atsdr.cdc.gov:8080/97list.html. 1997 CERCLA Priority List of Hazardous Substances. January 5, 1998. 4:32 p.m.

[2]Division of Toxicology, Agency for Toxic Substances and Disease Registry, United States Department of Health and Human Services. 1997 CERCLA Priority List of Hazardous Substance that will be the Subject of Toxicological Profiles & Support Document. November, 1997. pg.37.

[3]http://www.epa.gov/swerosps/bf/ascii/aquifer.txt. November 12, 1997. 11:46 a.m.

equally important to review information on other areas of contamination. This is especially true for urban regions where groundwater may not be as important as other contaminants because it is not part of the drinking water supply.

The other major difference between the CEP list and the CERCLA Priority List of Hazardous Substances is that some of the substances on the former are not very toxic. Unlike the CERCLA list, toxicity is not a factor in determining CEP ranking; as a result, the prioritizations of the substances on these lists do not correspond. **For instance, some of the top substances found on the CEP list are ranked much lower on the CERCLA list. Examples include:**

- Trichloroethylene.
- Tetrachloroethylene.
- Chromium.
- 1,1,1-Trichloroethylene.
- 1,1-Dichloroethene.

See the **Appendix** at the end of this chapter for a description of ten of the worst chemical offenders found on NPL and lesser contaminated brownfields sites.

For additional information on the CERCLA Priority List of Hazardous Substances, CEP, or any of the substances on these lists contact[4]:

Agency for Toxic Substances and Disease Registry
Division of Toxicology
1600 Clifton Road, Mail Stop E-29
Atlanta, GA 30333
http://www.atsdr.cdc.gov/DT/mission.html
Phone 404-639-6300 or 1-888-42-ATSDR (1-888-422-8737)
Fax 404-639-6315

C. Site Assessment

The process of determining if a property is contaminated and, if so, with what, is called site assessment. Site assessment lays the foundation for how any remediation that is necessary will be carried out, what technologies should be used, and what level of cleanup is required. This is an extremely important process because most banks require some kind of environmental assessment before making a loan (lender attitudes toward brownfields is discussed in Chapter III). In fact, a section of the Uniform Residential Appraisal Report (URAR) form is devoted to environmental risks.

Assessment can be divided and categorized into any number of different sub-stages. One

[4]Much of the information to follow on the various types of contaminants is taken from ATSDR's web site: http://atsdr1.atsdr.cdc.gov:8080. This is a fantastic source of information.

common partition is the distinction between Phase I and Phase II environmental assessments.

Phase I Environmental Assessments

This investigation is meant to determine the present and past ownership of a site and to identify any chemical processes that took place there. The American Society for Testing and Materials (ASTM) has issued a comprehensive guidance on the purpose and scope of Phase I assessments. This is essentially an attempt to standardize the assessment process. This standardization has been met with mixed reviews. For example, some point out that standardized assessment requirements may not be appropriate for all situations. In addition, ASTM standards do not apply to wetlands, or to sites contaminated with asbestos or lead-based paint. Still, most agree that there are some general steps to a Phase I environmental assessment as outlined by EPA's Technology Innovation Office:

- Identify past owners and the uses they made of the property by conducting a title search and reviewing tax documents, sewer maps, aerial photographs, and fire, policy, and health department documentation related to the property.
- Review and analyze city government and other historical records to identify past use or disposal of hazardous or other waste materials at the site.
- Review federal and state lists that identify sites that may have environmental contamination; such lists include, but are not limited to: 1) EPA's Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) of potentially contaminated sites, 2) the National Pollutant Discharge Elimination System (NPDES) of permits issued for discharges into surface water, and 3) state records of "emergency removal" actions (for example, the removal of leaking drums or the excavation of explosive waste).
- Interview property owners, occupants, and others associated with the site, such as previous employees, residents, and local planners.
- Perform a physical or visual examination of the site, including examination of existing structures for structural integrity and asbestos-containing material.
- Test for the presence of various contaminants; for example, lead-based paint, asbestos, and radon in structures[5].

[5]United States Environmental Protection Agency. Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup, Second Edition. Washington, D.C. 1999. p 15. EPA 542-B-99-009.

The cost of conducting a Phase I assessment varies according to factors such as the number and availability of records required for evaluation. However, the cost for an assessment of a five acre commercial property is roughly $3,000[6].

A Phase I environmental assessment is extremely important because it can help protect someone who has unknowingly purchased a contaminated property. Under the "innocent landowner defense", a landowner must show that he/she, at the time of purchase, made "all appropriate inquiry" into the property's previous ownership and use it to attest that the landowner had no reason to know that hazardous substances were on his/her property. A Phase I assessment can assist in establishing the landowner's innocence (see "innocent land owner defense" discussed in Chapter III) if no contamination was found at the time of assessment. Another reason why these site characterizations are desirable is that Wall Street wants Phase I assessments for securitized loans.

There is a lot of debate over the validity of Phase I assessments. It is often very difficult to determine whether or not a site is contaminated without sampling. Thus, it is quite easy to overlook existing contamination during the course of this assessment. Some people feel that this stage in the assessment process is too weak, particularly given the importance it is given in determining liability.
Regardless of this controversy, if nothing suspicious is uncovered during a Phase I assessment, the site investigation stops.

Phase II Environmental Assessments

If a Phase I assessment reveals that the site may be contaminated with hazardous substances, a Phase II assessment is required. From a legal standpoint, this is important because the innocent land owner defense may not hold up for a purchaser who does not take the necessary steps to refute any likelihood of contamination. If a site has a known contamination problem, it is possible to combine a Phase I and a Phase II assessment.

On its own, a Phase II environmental assessment verifies the character of any contaminants that may exist on a site. Advances in detection technology have allowed for most contaminants to be easily detected in Phase II assessments. Phase II generally includes **taking soil and groundwater samples and, if applicable, samples of surface water and sediment**. These specimens are then sent to a laboratory for testing. During the process of sampling portions of the property, the cause of the contamination, precise location(s) and amount(s) of the substance(s), and potential health and environmental impacts are determined. Therefore, the migration pathways of contaminants also are examined during this phase, and a baseline risk assessment may be needed to calculate risk to human health and the environment[7]. Because

[6]Willard, Jane M. *Tailoring the Environmental Site Assessment.* The Real Estate Finance Journal. Fall, 1993. pg. 86.

[7]United States Environmental Protection Agency. Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup, Second Edition. Washington, D.C. 1999. p 19. EPA 542-B-99-009.

Phase II assessments demand scientific sampling and technical review, they are much more expensive than Phase I assessments.

The findings from the Phase I environmental assessment will guide the sampling process. For instance, if there used to be a gas station located on the adjacent property, the soil and groundwater should be tested for volatile organic compounds and other petroleum related substances. In general, Phase I discoveries such as discolored soil, USTs, old sewer systems, questionable prior owners, and the potential for PCBs compel a Phase II assessment. Anyone considering a Phase II assessment should **speak with a qualified consultant** before the tests are conducted. They will know what chemicals to look for and how to locate them[8].

Although there is no standard for Phases II assessments, they typically conclude with a report that recommends a cleanup approach. The results of this phase, which are detailed in the report, can be critical for:

- Establishing cleanup goals.
- Deciding on future land use restrictions.
- Determining which technologies to utilize.
- Understanding what the remediation risks are.
- Developing a restoration strategy and time-line.

Some consider this report and recommendation stage as a Phase III assessment. Either way, the goals are the same. Sometimes initial sampling does not reveal the horizontal and vertical migration of contaminants in soil and groundwater. In such cases, additional testing is required. Costs can range from $10,000s to $100,000s.

I. *<u>Key Questions</u>*
If there is evidence of potential or actual contamination on the property, there are several factors that should be considered during the site investigation.*

- *What agency will be responsible for managing oversight of each phase?*
- *What technologies are available to facilitate site investigation and to support data collection relevant to the goals of the project?*
- *Can the need for cleanup be assessed fully and accurately from the information gathered during the site assessment or from a previous site investigation?*
- *What issues has the community raised that might affect the site investigation?*
- *What are the potential exposure pathways? Who or what could be affected by the contamination or the efforts to clean up the contamination?*

---

[8]Youngblood, Lisa G. *Environmental Traps for the Commercial Lessee*. <u>The Practical Real Estate Lawyer.</u> September, 1996. pg. 68.

- *What happens if significant contamination is found and/or poses a "significant threat" to local residents?*

- *What happens if the contamination is originating from an adjacent or other off-site source, or from a naturally occurring source?*

- *Are the infrastructure systems (roads, buildings, sewers, and other facilities) contaminted? Could they be affected by efforts to clean up contamination?*

*Questions adapted from EPA's Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup. Visit **http://www.epa.gov/swertio1/index.htm** for more information on the publication.

What follows is a discussion of the revised approach EPA recommends for evaluating environmental problems, cumulative risk assessment. This new strategy is being applied to numerous EPA projects, including brownfields work.

Cumulative Risk Assessment

In the past, assessments have been isolated and segregated. Reviews of brownfields would focus separately on each contaminant found at a site, on one environmental pathway, and primarily on one potential health effect, cancer. In prior years,

> EPA has assessed risks and made environmental protection decisions based on individual contaminants - such as lead, chlordane, and DDT - with risk assessment from these chemicals often focused on one source, pathway, or adverse effect[9].

In comparison, the cumulative style of assessment describes and quantifies risks from multiple contaminants. It explains how a risk manifests itself. Who is more vulnerable to the contaminant, and why. For example, the specifics of the different potentially affected populations, such as age and gender trends, are critical to cumulative risk assessment.

> In recent years, EPA's risk assessment emphasis has shifted increasingly to a more broadly based approach characterized by greater consideration of multiple endpoints, sources, pathways, and routes of exposure; community-based decision making; flexibility in achieving goals; case-specific responses; a focus on all of the environmental media; and significantly, holistic reduction of risk. This more complex assessment involves cumulative risk assessment. It is defined in each case according to who or what is at risk of adverse effects - from identifiable

[9]http://www/epa.gov/swerosps/bf/html-doc/cumulrsk.htm. November 12, 1997. 11:30 a.m.

sources and stressors - through several routes of exposure over varied time frames.[10]

An extremely important consideration in the risk assessment process is exposure. Although some substances found at brownfields may be extremely toxic, they may be buried deep beneath the surface and, as a result, humans may never be exposed the dangers they pose. In contrast, less toxic substances that humans are exposed to on a regular basis are far more dangerous. For example, people are unlikely to ever come into contact with a deposit of arsenic buried in fifty feet of clay, but everyday millions of people are exposed to benzene while filling up their cars with gas. For brownfields, the question is: what is an acceptable risk? **EPA Baseline** is one additional cancer case per one million people exposed. Most people agree that this standard is far too strict. Some have suggested that one additional cancer case per ten thousand people exposed might be a more appropriate standard.

What follows is an outline adapted from the EPA Guidance on Cumulative Risk Assessment. This silhouette is designed to summarize the **six components of a holistic approach to assessing risk**. It is has been altered slightly to conform to the unique issues surrounding brownfields. The issues mentioned here are intended to guide those undertaking a site assessment.

A) **Population**. Who, what, and where is the risk?

1) Humans
   a. Individuals
   b. Population subgroups
      - Highly exposed subgroup (e.g., geographic area, age group, gender, economic status, racial or ethnic group)
      - Highly sensitive subgroup (e.g., asthmatics, age, gender)
2) Ecological Entities
   a. Groups of individuals
   b. Populations
   c. Multiple species
   d. Habitats or ecosystems
3) Landscape or Geographical Concerns
   a. Groundwater aquifers
   b. Watersheds
   c. Airsheds
   d. Regional ecosystems
   e. Recreational lands

B) **Sources**. What are the relevant sources of contamination?

1) Single source: Point sources (e.g., industrial or commercial discharge)

---

[10] Science Policy Council, United States Environmental Protection Agency. Guidance on Cumulative Risk Assessment. July 3, 1997. http://www.epa.gov/swerosps/bf/html-doc/cumrisk2.htm. January 21, 1998. 4:29 p.m.

2) Multiple sources: Combination of point sources (above), non-point sources (e.g., automobiles, and consumer use releases), and natural sources (e.g., flooding)

C) Stressors. What are the contaminants/chemicals?

1) A single chemical

2) Structurally related class of chemicals

- Individual substances (one substance present at different points in time)
- Mixture of substances (multiple substances present at one time)

3) Structurally unrelated chemicals with similar mechanisms of impact or health effect.

- Individual substances
- Mixture of substances

4) Chemicals with different structures as well as different mechanisms of impact and health effects.

D) Pathways and Routes of Exposure. How can one be exposed?

1) Pathways (more than one may apply)

a. Air
b. Surface water
c. Groundwater
d. Soil
e. Solid waste
f. Food

2) Routes of human and single species exposures

a. Ingestion (food and water)
b. Dermal (absorption through the skin for animals, including humans, and uptake for plants)
c. Inhalation

3) Routes of community exposure

a. Direct contact
   - Proximity to contamination
   - Spills

E) Endpoints. What are the potential effects?

1) Human health effects (based on animal studies, morbidity and disease registries, laboratory and clinical studies, or epidemiological studies or data)

a. Carcinogenic
b. Neurotoxicologic
c. Reproductive disfunction
d. Developmental
e. Cardio-vascular
f. Immunologic
g. Renal
h. Hepatic
i. Other

2) Ecological Effects

a. Populations or species
   - Loss of fecundity
   - Reduced rate of growth
   - Acute chronic toxicity
   - Change in biomass
b. Community
   - Loss of species diversity
   - Loss of keystone species
c. Ecosystem
   - Loss of function (e.g., photosynthesis)
   - Loss of habitat structure
   - Loss of a functional group of organisms

F) Time Frames. What are the relevant time frames (e.g., frequency, duration, intensity, and overlap of exposures)?

1) Acute
2) Subchronic
3) Chronic or effects with a long latency period
4) Intermittent

One should be able to assess some of these six determining factors, or parts of them, through a Phase I environmental assessment, however, for a complete evaluation of all of these factors, a more thorough inquiry will probably be required. Thus, the procedures necessary to complete a cumulative assessment and reach a holistic level of understanding of a specific site will depend on its particulars. This is why one can not attach a universal technique for investigating each of the factors outlined above that applies to all brownfields.

D. Cleaning up Brownfields

The challenge of restoring each contaminated property is to clean it up as quickly, cheaply, and effectively as possible, while reusing the land in fashions that serve the distinct needs of the local community. This part of the remediation effort utilizes the data collected during Phases I and II.

By the cleanup stage, technologies should have been reviewed as potential cleanup resources. When deciding which technology to use, consider:

- Effectiveness.
- Speed.
- Expense.
- Land use.
- Exposure pathways.
- The medium in which the contaminant is located (e.g., soil, air, surface water, or groundwater).

There is a diversity of treatment technologies from which to choose, each with different advantages and disadvantages. The biggest problem associated with these cleanup alternatives is that many of them are expensive. This is a major barrier to the reuse of brownfields, as cleanup expenses may be beyond the means of many firms. Even sites with relatively small amounts of contamination have high redevelopment costs. In order to gain a more complete understanding of exactly how much these treatment techniques can cost, what contaminants they can remediate, and how they work, several examples will be examined. In order to lay the foundation for this discussion, a brief review of how risk-based approaches to cleanup can direct a remediation initiative is required.

Risk-Based Corrective Action (RBCA)

Generally, it is not difficult and is relatively inexpensive to remove or treat the first 80% of the contamination found on a site - it is the last 20% that is difficult and expensive. The question is: do we need to remediate the last 20% in all situations? Risk-based corrective action (RBCA) is an attempt to answer that question. It calculates the level of cleanup required by evaluating future land use(s), as well as potential pathways, susceptible populations, and the urgency of cleanup. According to a 1995 study by the congressional Office of Technology Assessment, 42 states use risk-based assessment techniques to determine the required level of cleanup[11]. This is a practical way to **cut costs** without sacrificing safety.

Future land use assumptions allow the baseline risk assessment and the feasibility study to focus on the development of practicable and cost-effective remedial alternatives, leading to site activities which are consistent with the reasonably anticipated future land use[12].

Land Use

As the prior quote indicates, in order to make the best decision about which treatment technologies are appropriate for a given site, it is extremely important to consider how the land will be used. This will determine the level of cleanup required at the site and, as a result, the type of technology required.

How Do I Know What The Future Uses Will Be?

The key to answering this question is understanding that the remedy and restoration process does not determine the type of use, rather the type of use determines the type of cleanup. The use of the land is determined **before** cleanup begins[13]. Issues that affect future land uses or should be

[11]Wright, James G. Risks and Rewards of Brownfields Redevelopment. Cambridge, MA. Lincoln Institute of Land Policy. 1997. pg. 19.

[12]http://www.epa.gov/swerosps/bf/html-doc/landuse.htm July 18, 2002

[13]Where anticipated future land use is uncertain, multiple uses should be considered in developing remedial action objectives. This results in a range of cleanup alternatives which can allow for different types of land use.

considered when making such a decision are:

- Current land uses and land use plans.
- Current zoning and zoning laws.
- Environmental justice issues (discussed below).
- Existing infrastructure (e.g., transportation, utilities).
- Development patterns (historic and current) and market demand.
- Proximity to wetlands, flood plains, special ecosystems, species, etc.
- Current institutional controls (discussed in more detail later in this chapter).
- Federal / state land use designations (e.g., state recreational areas).
- Location relative to industrial, commercial, residential, recreational, or agricultural areas[14].

For example, it is reasonable to assume that a given piece of property will be used for industrial purposes in the future if it is currently an industrial site, the surrounding area is zoned for industrial use, and the land use plan indicates that the site is expected to be used in a similar manner in the future.

The Residential Standard for Cleanup

Sites dedicated to residential use demand the highest level of cleanup, because this land use involves the greatest likelihood of exposure. In the past, EPA has applied a standard for residential reuse that was too stringent for commercial and industrial uses. The application of residential standards to all reuse projects was a major stumbling block. By using risk-based standards this hurdle can be overcome[15].

Risk-Based Decision-Making in Underground Storage Tank Cleanup

The Resource Conservation and Recovery Act (RCRA) Corrective Action program (discussed in Chapter III) uses risk-based corrective action to determine priorities, cleanup standards, and site management requirements. As described earlier in this chapter during the discussion of cumulative risk assessment, applying one standard without considering the extent of actual or potential exposure is inefficient economically and may be dangerously insufficient in terms of protecting human health and the environment. These problems have become all the more serious as the number of releases from underground storage tanks (USTs) has increased. Some recent statistics drive home this point:

- *As of September 30,2001 there were 418,918 reported nation-wide UST releases.*
- *370,243 sites had initiated some kind of remediation.*
- *268,833 cleanups had been completed.*

Some states that have implemented risk-bases corrective-action (RBCA) programs in order to

---

[14]http://www.epa.gov/swerosps/bf/html-doc/landuse.htm July 18, 2002

[15]http://www.epa.gov/swerosps/bf/html-doc/landuse.htm July 18, 2002

help prioritize and organize their respective cleanups efforts include:

- *Texas*
- *Ohio*
- *Illinois*
- *Hawaii*
- *Massachusetts*
- *New Jersey*[16]

Treatment Technologies

"Treatment technologies are chemical, biological, or physical processes applied to hazardous waste or contaminated materials to permanently change their condition"[17]. These remediation tools can either remove, control, reduce, or alter the state of contaminants. Essentially, there are two categories of technologies: first, traditional land disposal and contaminant containment techniques, and second, innovative treatment technologies[18].

Land Disposal and Containment Techniques

When CERCLA was passed in 1980, the initial approach to remediating contaminated properties was either to remove the source of the problem or to contain it. Noticeably absent from this approach is any mention of "treating" the contaminant. In other words, relatively little is done to the contaminant itself, rather, the exposure pathways to the surrounding populations are cut off. There are two ways to achieve this end: one, remove the hazardous substances and store them at a safer location, and two, leave the substances where they are, but control them.

Excavation

Before 1984, excavation was the most frequently used remediation technique[19]. As will be described later in this chapter, it is still a component of many remediation efforts which combine excavation with treatment. Remediation techniques that require some excavation are referred to

---

[16] United States Environmental Protection Agency, Office of Solid Waste and Emergency Response. OSWER Directive 9610.17. March 1, 1996. Use of Risk-Based Decision-Making in UST Corrective Action Programs. http://www.epa.gov/swerust1/directiv/od961017.htm

[17]United States Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office. A Citizen's Guide to Innovative Treatment Technologies. April, 1996. EPA 542-F-96-001.

[18]Most of the information to follow on specific types of treatments is from either EPA Citizen's Guides on treatment technologies or the Remediation Technologies Screening Matrix and Reference Guide. EPA 542-B-93-005.

[19]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide. www.frtr.gov/matrix.html. EPA 542-B-93-005.

as “ex situ.” Originally, however, it involved moving hazardous substances to treatment and/or disposal facilities, rather than remediating the contaminated soils on site. This technique can be used on a diversity of contaminants, but most contaminants have to meet specific treatment standards before they can be relocated. The specific type of contaminant and its concentrations significantly affect any Land Disposal Restrictions (LDRs) that apply to its excavation.

Excavating soils containing hazardous substances is generally one of the more expensive remediation options. **To excavate 18,200 metric tons of contaminated soil would take roughly two months and would cost anywhere from $300 to $510 per metric ton to remove, relocate, and dispose of at a permitted RCRA facility**[20]. Of course, this may vary according to the availability of appropriate transportation containers, the type of contaminant, and the method of excavation. In addition, the distance between the site and the disposal location will effect costs.

Sometimes, however, it is more dangerous to move a contaminant than it is to leave it. Occasionally, when hazardous materials are unearthed and transported they become airborne, increasing the number of exposure pathways. In turn, some level of treatment is often required prior to excavation. For example, some have elected to use liquid nitrogen (LN2) to freeze both the soil and the contaminants before excavation begins. These treatments increase remediation costs.

Contaminant Containment

Even with such creative ideas such as liquid nitrogen freezing, in certain scenarios, it may be best to leave the substance where it is, prevent it from spreading, worsening, and affecting the local population. This approach is based on “engineered barriers.” A barrier may be natural or man-made, but either way, it must meet approved engineering standards. An institutional control (to be discussed later in this chapter) typically accompanies an engineered barrier, even when ownership of the property changes. These documents detail the rules and regulations regarding the maintenance of such protective devises.

The type of barrier used depends on the exposure pathway to be intercepted. The two most frequently used barriers are caps and slurry walls.

Caps

Caps are horizontal barriers that cover the contaminated area. They can serve two separate purposes. First, caps can halt the infiltration of water. By obstructing water from seeping into the soil, they prevent contaminants from leaching out of the soil and into the groundwater. Second, they can prevent the upward migration of soil (dust) and vapors into the air; thus, decreasing the likelihood of ingestion or inhalation of contaminants. While three feet of clean soil may be sufficient to for this purpose,

[20]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide. www.frtr.gov/matrix/section4/4_28.html. EPA 542-B-93-005.

generally caps are made of one of the following:

- Clay
- Asphalt
- Concrete
- Materials with similar repellent properties

Sometimes, caps can be put to productive use. For example, a roadway or a parking lot might be constructed over contaminated land.

Slurry Walls

Slurry walls can be implemented in conjunction with caps. Slurry walls are **vertical barriers** that prevent the horizontal movement of groundwater or soil. They are usually trenches filled with slurry, which is a blend of bentonite and water, although sheet piling and cement may be added for additional strength. "The slurry hydraulically shores the trench to prevent collapse and forms a filter cake to reduce groundwater flow"[21]. Slurry walls are often used where the waste mass is too large to clean up and where there is an imminent threat to a source of drinking water. The walls usually extend no deeper than 100 feet into the soil and are between two to four feet thick.

Because they obstruct contaminated groundwater or divert it away from drinking water intake, slurry walls are not meant to protect against any specific agents. Factors that **may affect the design and appropriateness of slurry walls are**:

- The density of the soil.
- The availability and grade of bentonite.
- The total size of the contaminated area.
- The characteristics of the backfill material.
- The maximum allowable permeability of the wall.
- The physical layout and topography of the brownfield.
- The compatibility of the hazardous wastes and the components of the slurry wall. These barriers may decay over time and may not be able to withstand strong acids, bases, salts, and some organic chemicals[22].

Not including the costs associated with testing, one can expect to spend between $540 to $750 per square meter[23] for the design and installation of a bentonite slurry wall in soft to medium grade soil.

[21]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide. http://www.frtr.gov/matrix2/section4/4-53.html. EPA 542-B-93-005.

[22]Ibid.

[23]Ibid.

Innovative Treatment Technologies

Some have questioned the sustainability of, and the costs associated with, relocating rather than treating contaminated materials. It was in this vein that the **Technology Innovation Office (TIO)** of the EPA was created in 1990. Its mission is to advance the use of new technologies for characterization and remediation. In short, to develop innovative treatment technologies for contaminated properties.

"Innovative treatment technologies" are not yet used routinely, however, most brownfields remediation efforts use some kind of innovative treatment technology. The term "innovative" does not mean that these technologies are unproven, rather that they propose a unique approach to remediation on which there is not much cost nor applicability information. The search for these creative technologies is driven by the need for more cost effect, efficient, timely, and safer remediation techniques. On the whole, innovative treatment technologies:

- Can be cost-effective, sustainable solutions.
- Are frequently favored by area neighborhoods.
- Are sensible alternatives to land disposal, and hazardous waste control techniques[24].

There are now numerous informational resources easily accessible via the internet that help brownfield decision makers obtain information on brownfields cleanup technologies. From organizations that provide technical assistance to cost-effective, innovative technologies to remediation case studies, these online resources are facilitating the understanding of complex brownfields cleanup issues. The following are web sites and descriptions for various publications, centers, and organizations dealing with multiple facets of brownfields remediation.

[24]United States Environmental Protection Agency. Tool Kit of Information Resources for Brownfields Investigation and Cleanup. EPA 542-B-97-001.

Sources of Support/ Outreach

Brownfields Technology Support Center (TSC). *EPA's Brownfields Technology Support Center (TSC) coordinated through TIO provides information about the range of new innovative treatment technologies and offers technical assistance. Communities, local and state governments, and other brownfield decision makers can access unbiased assessments and supporting information about innovative treatement technologies relevant to specific sites. Also, the TSC provides a range of technical assistance from developing strategies for streamlining site assessment and cleanup to plan and document evaluation. Requests for TSC assistance can be submitted at* ***http://brownfieldstsc.org or call 1-877-838-7220.***

EPA Cooperative Agreement with Public Technologies, Inc. (PTI). *This site provides information on characterization and remediation technologies. Some points of interest on this site include: highlights of hot technologies; case studies on cities successfully employing innovative technologies; and profiles of cutting-edge researchers and local government leaders who are using charcacterization and remediation technologies to a good effect.* ***http://www.brownfieldstech.org****.*

Hazardous Substances Research Centers (HSRCs). *HSRC programs provide free technical assistance to communities with environmental contamination programs. Technical Assistance to Brownfields (TAB) draws on the expertise of faculty of over 25 U.S. universities to assist in leadership and risk assessment training, site assessment workshops, and cleanup alternatives.* ***http://www.toscprogram.org.***

Information Resource

Technology Innovation Office's Hazardous Waste Cleanup Information Web Site. *This site provides comprehensive information on remediation, site characterization, partnerships, and international updates. Vendor support and publications are also available.* ***http://www.clu-in.org.***

Federal Remediation Technologies Roundtable (FRTR). *FRTR documents the cost and performance of clean-up technologies through the analysis of over 200 case studies. These case studies, including Superfund, RCRA, and state sites, are searchable by technology, contaminant, and media.* ***http://www.frtr.gov.***

EPA Remediation And Characterization Innovation Technologies (EPA REACH IT). *REACH IT , a free information service, allows environmental professionals to search, view, download, and print information about innovative technologies. Continuously updated by EPA and vendors, it provides vendor information on nearly 1,300 treatment and over 180 characterization technologies.* ***http://www.epareachit.org.***

Groundwater Remediation Technologies Analysis Center (GWRTAC). *GWRTAC compiles,* *analyzes and disseminates information on innovative ground-water remediation technologies. It also prepares reports on these technologies and maintains an active outreach program.* ***http://www.gwrtac.org.***

Interstate Technology and Regulatory Cooperation (ITRC). *ITRC is a state-led national coalition of personnel from the regulatory and technology programs of more than 25 states, three federal agencies, and tribal, public, and industry stakeholders. The organization's goal is to reduce barriers and speed interstate deployment of better, more cost-effective, innovative environmental technologies. ITRC produces guidance documents, each of which deals with a specific type of technology.* ***http://www.itrcweb.org****.*

Remediation Technologies Development Forum (RTDF). *Established by EPA in 1992, RTDF fosters public and private sector partnerships to develop and improve environmental technologies needed to address cleanup problems in the safest, most cost-effective manner. Technical documents on various environmental technologies such as bioremediation, inert soil-metals, phytoremediation, permeable reactive barriers and others are available at* ***http://www.rtdf.org****.*

EPA's ***Superfund Innovative Technology Evaluation (SITE)*** *program. The SITE Demonstration Program encourages the development and implementation of 1) innovative treatment technologies for hazardous waste site remediation and 2) monitoring and mearsurement.* ***http://www.epa.gov/ORD/SITE.***

Field Analytical Technology Encyclopedia (FATE). *FATE is an on-line encyclopedia containing information on field analytical technologies for hazardous site clean up. It covers multiple technology classes, from colorimetric indicator tests to X-ray fluorescence.* ***http://fate.clu-in.org.***

Road Map to Understanding Innovative Technology Options for Brownfields Investigation and Cleanup, Third Edition (EPA 542-B-00-001)*. This document provides information on how to identify and select innovative characterization and cleanup technologies for brownfields redevelopment. Select "publications" at* ***http://brownfieldstsc.org*** *to view the document.*

Assessing Contractor Capabilities for Streamlined Site Investigations (EPA 542-R-00-001). *The purpose of this document is to assist brownfield decision makers as they interview vendors to determine their qualifications to provide streamlined and innovative strategies. Select "publications" at* ***http://brownfieldstsc.org*** *to view the document.*

Citizen's Guides to Understanding Innovative Treatment Technologies*. These guides are resources designed to explain, in basic terms, the operation and application of the most frequently used innovative treatment technologies for remediating sites. The guides, available in both English and Spanish, present success stories about sites at which innovative treatment technologies have been applied. Select "publications" at* ***http://www.epa.gov/swertio1/index.htm*** *, then "Publications on Remediation" to view the document.*

__The Los Alamos National Lab__ for a comprehensive list of brownfields sites at __http://www.lanl.gov__. Of particular interest may be "The Environmental Technology Cost-Savings Analysis Project." This has information on the cost of each cleanup effort and the types of contaminants encountered. The sites are categorized by the type of treatment used.

What follows is a discussion of several of the more well known innovative treatment technologies.

Solvent Extraction

Solvent extraction utilizes a solvent (a fluid that can dissolve another substance) to remove contaminants so that they can be easily recycled or destroyed by another process. Thus, solvent extraction in and of itself does not terminate hazardous substances. Typically, an organic chemical such as propane, butane, or liquid carbon dioxide is the solvent. It is commonly used in combination with other technologies, such as solidification/stabilization, incineration, or soil washing, depending on site-specific conditions.

Solvent extracts can be used to treat sediment, soils, and sludges that contain organic compounds, not inorganics such as acids, bases, salts, and heavy metals. **The organic compounds found in brownfields are typically associated with metal degreasing, paint wastes, synthetic rubber processes, gasoline refinement, and wood preserving manufacturing processes**. Examples of substances that can be treated by the solvent extraction process include:

- PCBs.
- Petroleum wastes
- Volatile organic compounds (VOCs).
- Halogenated solvents, solvents containing substances such as bromine, chlorine, or iodine.

Basically, **the process** goes like this: the contaminated materials and solvent are mixed in an extractor, where the organic contaminant dissolves into the solvent. The solvent, now containing the hazardous substance, is placed in a separator. Here the contaminant is extracted from the solvent for treatment and eventual disposal or recycling. The solvent can then be reused.

This technology usually **costs between $110 and $440 per metric ton**[25].

[25]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide http://www.frtr.gov/matrix2/section4/4-17.html. EPA 542-B-93-005.

Pros of Solvent Extraction	Cons of Solvent Extraction
Separates contaminants so they may be treated individually	Unintentional extraction of organically bound metals can restrict how the highly concentrated contaminants can be handled and separated from the solvent
The technology can be transported to the site	Some of the solvent may remain in the treated material, thus the toxicity of the solvent is critical
It can process as much as 125 tons of waste per day	Certain soils and moisture levels can make extractions
It is designed not to emit anything into the air	Detergents and emulsifiers can make extraction difficult

Thermal Desorption

Thermal desorption can only be used on contaminants with low boiling points and, like solvent extraction, it does not treat the contaminants. Contaminated soils are heated until the contaminants with low boiling points turn to gas. Now separated from the soils, the gaseous contaminants are collected and treated by a separate air emissions treatment system.

Thermal desorption is used to separate volatile, semi-volatile organic compounds (SVOCs), and other organics such as **PCBs, PAHs, and pesticides from refining byproducts, wood treatment, paint, and coal tar wastes**.

It can take just over four months to clean up a site with approximately 18,200 metric tons of contaminated soil. The costs of thermal desorption vary according to the temperature required to vaporize the contaminants, but generally range between **$45 and $330 per metric ton**[26].

Pros of Thermal Desorption	Cons of Thermal Desorption
240 tons of contaminated soil can be treated per day	It does not work for soils contaminated with metals (except mercury)
When separating contaminants with low boiling points, the low temperatures require less fuel than other methods of extraction, making it less expensive	Wet soils will require more fuel, as there is more to vaporize
	Soils containing silt and clay can produce dust when heated, this can damage air treatment equipment
	Packed soils may insulate the contaminants from the heat, thus they may not vaporize

[26]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide http://www.frtr.gov/matrix2/section4/4-26.html. EPA 542-B-93-005.

	Soils with strong acids may corrode the equipment
	Large particles can increase the cost and limit the applicability

Natural Attenuation

Natural attenuation uses natural processes either to reduce the amount or concentration of contaminants, or to contain the spread of contaminants. Sometimes referred to as intrinsic remediation, bioattenuation, or intrinsic bioremediation, this is an **in situ** approach, which means that the contaminants are left in place during remediation. Natural attenuation is not appropriate for all sites and is often used on groundwater in combination with other cleanup devices that control or remove the source of the hazard.

There are two types of natural attenuation: **destructive and non-destructive**. Biodegradation, also known as bioremediation, is a kind of destructive natural attenuation where microorganisms destroy, or reduce the amount of, the target contaminant (this will be discussed in more detail later in this chapter). The non-destructive versions either reduce the concentration of the hazardous substance through dilution or dispersion, or prevent the migration of the contaminant through adsorption. During dilution and dispersion, surface water or ground water mixes with the contaminated area, decreasing the concentration of the hazardous agent. Absorption is when a contaminant binds to soil particles, preventing its migration. It is important to recognize that these are proactive remediation approaches. In comparison with other techniques that rely on advanced technologies, all versions of natural attenuation focus on verifying and constantly evaluating natural processes.

Petroleum contaminants from defective underground storage tanks (USTs) are usually good candidates for a natural approach. Biogradation is one of the few remediation techniques that can keep up with the highly mobile hydrocarbons that USTs leak. In addition, these petroleum products are among the easiest for natural processes to destroy.

The effectiveness of natural attenuation for a given brownfield depends on:

- **The type of contamination** (e.g., petroleum products).
- **The physical and geologic characteristics of the soil** (areas with limestone and fractured bedrock often contain a variety of soils and are not good locations for natural attenuation).
- **The chemical and biological composition of the soil and ground water** (swampy areas are generally good for natural attenuation because they contain high levels of organic matter).

Pros of Natural Attenuation	Cons of Natural Attenuation
Relatively inexpensive, as no energy source or special equipment is necessary	Requires careful review and continuous monitoring of site conditions and level of contaminants
In some situations the site can be used while cleanup is occurring	Typically a slow process, contaminants may spread before degraded
No excavation is required	Until complete, the resulting products may be more dangerous than the original hazard

Bioremediation

Bioremediation uses yeast, fungi, bacteria, or other microorganisms to convert contaminants into less hazardous substances. These organisms can eat and digest some substances that are toxic to humans. In most cases, the outputs of these organisms are water and carbon dioxide. **Fuels, non-halogenated volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs)** are frequently the target of these microorganisms.

Bioremediation technologies improve the health and increase the populations of the microorganisms. This is accomplished by creating an ideal environment for them to convert as much hazardous material as possible. In some cases, microorganisms found on the property are capable of producing the necessary results, all that is needed is proper oxygen and nutrient levels. On other sites, however, microorganisms may have to be imported.

However, not all bioremediation is in situ. Some bioremediation efforts are ex situ, meaning that the soil or groundwater to be treated is excavated prior to treatment. The costs associated with this strategy depend on the contaminants and their concentrations. For example, a bioreactor unit with a surface area of 9,300 to 13,900 square meters can cost between $80,000 to $85,000.

Pros of Bioremediation	Cons of Bioremediation
Cost effective	The intermediate products can be more hazardous than the original contaminants
Techniques can frequently be conducted on-site, limiting transportation costs and dangers associated with contaminant transport	Metals, chlorinated organics, and inorganic salts are toxic to microorganisms
Natural process	

Phytoremediation

Phytoremediation is the use of flora to restore contaminated properties. Some of these plants can actually destroy contaminants, while others act as filters and contain hazardous substances. The hazardous substances that can be treated by phytoremediation include:

- Metals
- Pesticides

- Solvents
- Explosives
- Crude oil
- PAHs

There are a number of different ways that plants can be used to treat these substances. For instance, during "phytoextraction" plants pull in metal contaminants such as nickel and copper through their roots. Specific plants are selected based on the kinds of metals that they absorb. Some plants that may be appropriate include:

- Alfalfa
- Juniper
- Fescue
- Clover
- Duckweed
- Parrot feather
- Poplar trees

Eventually, the plants are harvested and often incinerated. The ash is then deposited in a hazardous waste landfill. The volume of this deposit is roughly 90% less than it would have been if the soil was excavated. This is just one example of several types of phytoremediation options.

Pros of Phytoremediation	Cons of Phytoremediation
Aesthetically pleasing	May only work on shallow contamination
Selective enough to take care of the last remnants of contaminants left behind by mechanical methods	Further study is needed on animals that feed off these plants, of discarded foliage, and use of these plants for mulch or fire wood
Passive technique	Slow process
Can be used on wide variety of contaminants	Only appropriate for low levels of contamination
Driven by solar power, photosynthesis	

Soil Vapor Extraction and Air Sparging

Soil vapor extraction (SVE) is capable of removing volatile and select semi-volatile compounds from contaminated groundwater. It is a vacuum system of underground wells that pulls out contaminants in their gaseous form. Because the system can only remove contaminants in their vapor form, only those hazardous substances that tend to evaporate easily can be removed by this technique. Still, **SVE is the most common innovative technology used at Superfund sites**.

Air sparging does what SVE can not. Specifically, SVE can not remove contaminants in or below a site's groundwater level. Air sparging involves pumping air into this moist level in order to flush the contaminants up into the drier layers of soil where SVE can pull them in. Brownfields may not require air sparging if there is no contamination in or below the water table.

Both of these techniques work most effectively and quickly when the soil from which the hazardous materials are to be removed is course and grainy, like sand or gravel. Once separated from the ground, the contaminants are often treated using carbon absorption, condensation, or catalytic oxidation.

The Remediation Technologies Screening Matrix and Reference Guide suggests that using both of these technologies can cost anywhere between $371,000 to $865,000 per hectare ($150,000 to $350,000 per acre) of plume to be attended to.

Pros of SVE and Air Sparging	Cons of SVE and Air Sparging
Effective in combination with other technologies	SVE only works above water table (can be resolved with air sparging)
Low maintenance, no excavation required (although ex situ SVE is an option)	May not be effective in densely packed soil
Technologies are reasonably simply to install	
Safe	
SVE and air sparging aid bioremediation by increasing air flow	
The extracted gases and byproducts must be treated (con), but this costs less than excavation methods (pro)	

In Situ Soil Flushing

In situ soil flushing is a technique that is primarily used to treat radioactive contaminants, fuels, pesticides, VOCs and SVOCs. Water or a water solution containing either acids (e.g., nitric acid) or bases (e.g., sodium) is injected into the soil through wells. **The water, or solution, then flows through the contaminated soils, picking up the contaminants as it goes**. Acidic solutions are used on some hazardous metals and organic compounds, and basic solutions are used on substances such as phenols. The water is then pulled out of the ground through extraction wells that are on the other side of the contaminated area. The number, placement, and depth of the wells depends on the geography of the property.

Once the waste-filled water has been pumped out of the soil, it is treated. The water, or solution, often can be separated from the contaminants and reused.

Pros of In Situ Soil Flushing	Cons of In Situ Soil Flushing
Technology can be transported to the site	Extensive knowledge of site geology is required
The technology can be tailored to treat specific contaminants	The flushing solutions may create contamination if not entirely removed

Because it is in situ, no need for excavation	There is the potential to wash the contaminants beyond the extraction wells
	Dense soils are difficult to treat
	Each treatment is designed for a specific contaminant, not the best option for sites with multiple contaminants
	For fuels, VOCS, and SVOCs it is less cost effective than some alternatives

The preceding list of treatment technologies in no way represents the full scale of options. There are many more techniques that may better serve the unique needs of a given brownfield. One who is looking into redeveloping a contaminated property and wants to learn about the cleanup measures that would be required, the tools necessary, and/or the cost to be expected should contact his or her state department of environmental protection (DEP). Most states have been given some level of authority in determining remediation requirements. They should also have information on environmental remediation consulting firms.

The table below is a summary of some of the treatment information discussed in this chapter. While it is intended for general use only, price ranges and cleanup times have been provided where possible. This data may not reflect the unique needs of specific sites. Refer to the Remediation Technologies Screening Matrix and Reference Guide for more specific information on these and other types of remediation techniques.

	Contaminants	Cost	Time to Complete
Excavation	All	High ($300 - $510 per metric ton)	Short
Caps (containment)	All	$175,000 - $225,000 per acre	Insufficient information
Slurry Walls (containment)	All	Moderate ($540 - $750 per square meter of wall)	Short
Solvent Extraction	PCBs, VOCs	Moderate ($110 - $440 per metric ton)	Moderate (125 tons of waste processed per day)
Thermal Desorption	PCBs, PAHs	Low ($45 - $330 per metric ton of soil treated)	Short (240 tons of soil treated per day)
Natural Attenuation	Petroleum Products	Low	Long
Bioremediation	Halogenated VOCs and SVOCs, fuels	Low	Long
Phytoremediation	PAHs, metals, pesticides, oil	Low	Long

Soil Vapor Extraction and Air Sparging	VOCs and SVOCs	Low ($150,000 - $360,000 per acre)	Moderate
In Situ Soil Flushing	VOCs, SVOCs, fuels, radioactive contaminants	Low	Insufficient information[27]

E. Institutional Controls

One of the topics that a consultant and EPA will undoubtedly go over is long-term post-remediation responsibilities. These obligations are referred to as institutional controls. **They are legal mechanisms for imposing restrictions and conditions on land use**. Institutional controls are often necessary when some level of contamination remains on a site after remediation.

Thus, if a site was remediated according to risk-based correction standards which took land use into account, institutional controls might dictate that the site may not be used for another purpose without further cleanup. Or, if a slurry wall is breached, these controls may direct the appropriate response action. In either case, exposure pathways have been opened. Clearly, these regulations can be critical to the long-term protection of the general public and the environment. Institutional controls may take the form of:

- Restrictive covenants and deed restrictions.
- Negative easements.
- Ordinances adopted and administered by a unit of local government.

How Do They Work?

Institutional controls are contained within a "No Further Remediation Letter" (NFL). Such letters may include copies of deed restrictions and maps which illustrate the areas where contaminants still reside in potentially dangerous levels. The letter is typically approved by an EPA office and then filed with the local county recorder's office. This assures that future users of the property are aware of the contaminants and that future uses will conform to the level of remediation conducted. For example, institutional controls may:

- Prohibit the installation of potable wells.
- Restrict land use to industrial or commercial development.
- Order owners to maintain the integrity of caps and other engineered barriers.
- Make owners conduct a site safety plan if new exposure pathways have developed.

[27]United States Environmental Protection Agency. Remediation Technologies Screening Matrix and Reference Guide. http://www.frtr.gov/matrix.html. EPA 542-B-93-005.

How restrictive these controls are is **determined by**:

- The volume and concentration of the remaining contaminant(s).
- The toxicity of the contaminant(s).
- The location of the contaminant(s).
- Potential pathways.
- Site geology.

Sites that are **likely to have institutional controls** attached to them are those,

- With engineered barriers (e.g., caps and slurry walls).
- Where the point of human exposure is located at a place other than at the source (e.g., a spreading plume).
- Which were remediated according to industrial or commercial land use safety requirements (sites restored to acceptable residential levels probably will not require institutional controls).

Institutional controls are permanent. They command compliance throughout the life of the property. However, at some point, if the owner wants to have these controls lifted, he or she may conduct additional response actions. Obviously, these regulations are essential to the sustainability of brownfields restoration. They require long-term recognition of the potential environmental and human safety hazards associated with their reuse.

F. Conclusion

This chapter has made several things clear. One, there is a variety of extremely dangerous brownfield contaminants. Two, a cumulative approach to risk-assessment is critical to understanding which properties are the most hazardous and how they should be restored. Three, availability of a diverse and cost effective group of treatment technologies is essential to our nation's effort to rehabilitate brownfields. And four, institutional controls are a necessary component of promising long-term environmental protection and human safety.

This information provides the underpinnings for motivating non-profit, and private and public sector involvement in restoring brownfields. An awareness of the contaminants and how they can be treated allows these groups to understand the importance of solving our brownfields problem. Unfortunately, those who are fully aware of these details and are interested in rehabilitating contaminated properties have come across a major obstacle: the liabilities associated with brownfields.

This barrier to the productive reuse of brownfields is the subject of the next chapter.

Appendix

The following is a list of some of the worst chemical offenders found on NPL and lesser contaminated brownfields sites. However, descriptions are limited to the top ten from the CERCLA list because those pose the greatest threat to human health. In addition, information on asbestos (number 86 on the CERCLA list) is provided due to its prevalence at brownfields.

Arsenic

Arsenic is the number one contaminant on the CERCLA Priority List of Hazardous Substances. Organic and inorganic arsenic can be either manmade or natural. Arsenic occurs in an inorganic form when it is combine with oxygen, chlorine, or sulfur; this is when it is most toxic.

Exposure: While humans can be exposed to harmful natural sources of arsenic through drinking water contaminated by natural mineral deposits. Exposure can also be linked to industrial manufacturing processes. Sources of arsenic discovered at brownfields include:

- ***Waste-chemical disposal sites***. If this substance is not contained properly, it can get into the water.
- ***Smelting***. Manufacturers of copper and other metals release inorganic arsenic into the air.
- ***Fossil fuels***. Arsenic is also released during the combustion of oil, coal, gasoline, and wood.
- ***Pesticides***. The most common use of arsenic in the Unites States is for pesticides. Facilities that produce these plant and animal killers are frequently contaminated with arsenic.

Potential Health Effects: Arsenic usually enters the body orally either in food, water, soil, or the air. Humans are exposed to minimal levels of arsenic on a daily basis, these less dangerous doses are processed by the liver and excreted. However, those subject to high levels of arsenic may experience serious health problems as the substance begins to accumulate in the body. Large doses can result in death. Lower levels of exposure can produce health problems such as:

- Irritation of the digestive tract (pain, vomiting, and diarrhea).
- Decreased red and white blood cell production.
- Heart abnormalities.
- Liver and kidney damage.
- Nerve malfunctions leading to “pins and needles” in the extremities.
- Skin irregularities such as spots and corns.

Treatment: Thermal desorption and soil washing may be appropriate treatment techniques (described in detail later in this chapter).

Lead

Lead is second on the CERCLA Priority List of Hazardous Substances. It is one of the most commonly reported contaminants of brownfields sites and has been found on over half of NPL sites. It occurs naturally and can be found in all parts of the environment. It can get into the air, where it attaches to dust and is carried long distances. Rain brings these contaminated dust particles back to ground level, and heavy rain can force the substance into subsurface water supplies.

Industries use lead for a variety of things, but it is mainly used for manufacturing storage batteries, and the production of paint, gasoline additives, solder, pipes, and ammunition.

Exposure: Lead is released into the air during iron and steel production, smelting, municipal waste incineration, lead-acid-battery manufacturing, and lead-based paint burning. It can also get into the water of buildings and facilities that use lead plumbing. Some industries that use lead also excrete contaminated wastewater. Soil can be contaminated from municipal and hazardous waste dumps that contain lead-wastes, and from contaminated fertilizers.

Potential Health Effects: Not much lead can pass through the skin, but it can be inhaled, as well as ingested via drinking water and food. Regardless of how the substance enters the body, very little of it leaves. **Some lead is stored in the body each time one is exposed to it**. Most of this lead accumulates in bones.

Lead is particularly dangerous for unborn and young children. Fetuses exposed to lead through their mothers can suffer from premature birth, low birth weight, and abortion. Young children may put pieces of paint, or contaminated dirt and dust into their mouths. This is particularly a problem in some older buildings and housing projects which were built before contractors switched to safe painting products. The **effects on young children** include:

- Low intelligence scores.
- Slow growth.
- Problems hearing.

In adults as well as children, exposure to high levels of lead can cause brain and kidney damage. In men, lead can trigger high blood pressure, and damage the reproductive system.

Treatment: In situ flushing (described in detail later in this chapter) and treatment walls are frequently used on sites with lead contamination.

Mercury

Mercury also occurs naturally and can be found in both organic and inorganic forms. Once released into the environment, it can stay there for a long time. While air should contain roughly 2.4 parts of mercury per trillion parts of air (ppt), near industrial sites, it has been recorded at levels as high as 1,800 ppt. Similarly, mercury levels in water do not naturally exceed 25 ppt, but, mercury has been found in excess of 200 ppt at some Superfund sites. Levels greater than 500 ppt have been found in some drinking water wells near Superfund sites.

Exposure: Chemical, metal, electrical equipment, automotive part, and other manufactures can produce dangerous amounts of mercury. The water and air near toxic waste sites and spills generally has high levels of this substance. In its organic form, mercury can enter the body in the form of vapor inhaled, or contaminated foods ingested. Inorganic mercury can be found in both food and drinking water. In addition, both organic and inorganic mercury can get into the body through the skin. As stated on the Agency for Toxic Substances and Disease Registry's web site (atsdr1.atsdr.cdc.gov:8080/ToxProfiles/phs8916.html):

Exposure to above normal levels of mercury at NPL sites may occur though drinking water contaminated with inorganic mercury salts. Some sites may have such high amounts of mercury in the soil or in containers that breathing mercury vapor may be a problem. Once mercury has entered the body, it may be months before all of it leaves.

Potential Health Effects: Depending on the form of mercury to which one is exposed, there is a number of different negative health implications. **The primary effects of long-term exposure to organic or inorganic mercury is damage to the brain and the kidney, and to a developing fetus**. Inhaled mercury vapors can cause brain damage, while inorganic mercury salts ingested in food and water can hurt the kidneys. Eating food that is contaminated with organic mercury can result in brain damage and seriously harm a fetus.

Treatment: Depending on the specific conditions of the site, soil washing may be an effective treatment for mercury contamination.

Vinyl Chloride

Vinyl chloride is fourth on the CERCLA Priority List of Hazardous Substances. **It is a colorless gas that is not produced naturally**. It is released into the air and discharged in wastewater from plastics industries, primarily polyvinyl chloride manufactures (PVC). This hazardous substance is also released during the natural course of evaporation at chemical waste storage sites.

Exposure: Vinyl chloride can enter drinking water when factories release wastes containing it into bodies of water or when it leaks into underground water supplies from chemical storage facilities.

It can get into the human body by inhaling contaminated air or drinking contaminated water. This is a problem for people who live in communities with vinyl chloride plants and for those who live near waste disposal facilities. Concurrently, it can also enter the body if one eats food that has been contaminated by it.

Potential Health Effects: This substance can cause liver cancer and, according to the U.S. Department of health and Human Services, it is a known carcinogen.

Short-term exposure to high levels of vinyl chloride can cause serious health problems such as:

- Dizziness.
- Lack of muscle coordination.
- Headaches.
- Unconsciousness.
- Death.

Another health concern associated with this gas is **vinyl chloride disease**. This disease causes major liver and lung damage, poor circulation in the extremities, thickening of the skin, and blood abnormalities.

Treatment: Soil vapor extraction and air sparging (described in detail later in this chapter) are treatment options.

Benzene

This is the fifth substance on the CERCLA Priority List of Hazardous Substances. Benzene is an industrial chemical made from coal and oil. In its purist form, benzene is a clear liquid. It is used to make industrial chemicals, plastics, detergents, pesticides, and is a **component of gasoline**.

Exposure: It is frequently discovered in high levels at **gasoline filling stations, chemical spills, around Underground Storage Tanks (USTs),** in wastewater, and in groundwater adjacent to landfills containing benzene. Benzene is also emitted into the air by chemical manufacturing plants, recovery plants for coke oven by-products, and petroleum refineries.
Potential Health Effects: Breathing high levels of benzene can cause death, and in lower dosages dizziness and headaches. Extended exposure to this substance can cause:

- Leukemia (cancer of the tissues that form white blood cells).
- Anemia.
- Internal bleeding.

Treatment: There is a plethora of treatment options for remediating areas contaminated with benzene: in situ soil flushing, natural attenuation, thermal desorption, as well as soil vapor extraction and air sparging.

Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic Aromatic Hydrocarbons (PAHs) is a category of contaminants that includes several major brownfields chemical offenders, such as **benzo[a]pyrene and benzo[b]fluoranthene**. They are described here because, as their names suggest, they are related to benzene. Much like benzene, PAHs are associated with gasoline and fossil fuels. Specifically, **PAHs are chemicals that result from the incomplete combustion of substances such as coal, oil, and gas**.

They can be found in the air attached to dust, in soils and sediments, in crude oil, coal, coal tar, creosote, and road and roofing tar.

Exposure: One can be exposed to PAHs by inhaling contaminated dust particles that may get swept into the air at sites where, for example, coal and gasoline have been burned. Other problem properties include old manufactured-gas, wood-preserving facilities, coal-tar production plants, coking plants, bitumen and asphalt production plants, coal-gasification sites, smoke houses, and municipal trash incinerators.

As indicated by the Agency for Toxic Substances and Disease Registry, PAHs can also be absorbed through the skin:

> PAHs enter your body quickly and easily by all routes of exposure. The rate at which PAHs enter your body is increased when they are present in oily mixtures. They go to all the tissues of your body that contain fat, and tend to be stored mostly in you kidneys, liver, and fat, with smaller amounts in your spleen, adrenal glands, and ovaries[28].

Potential Health Effects: The Department of Health and Human Services has determined that some PAHs may be reasonably suspected to be carcinogenic, as they have caused tumors in laboratory animals. In addition, they are thought to be harmful to the skin, body fluids, and the immune system. The offspring of pregnant mice fed benzo[a]pyrene, a kind of PAH, had birth defects and low body weights[29].

Treatment: Potential remediation techniques include bioremediation, phytoremediation, soil washing, solvent extraction, thermal desorption, as well as soil vapor extraction and air sparging.

[28]http://www.atsdr.cdc.gov/tfacts69.html

[29]http://www.atsdr.cdc.gov/tfacts69.html

Polychlorinated Biphenyls (PCBs)

"PCBs are a family of man-made chemicals that contain 209 individual compounds with varying toxicity"[30]. PCBs are exceptional insulators and are nonflammable. Because of these characteristics, they have been used in transformers, capacitors, and a variety of electrical equipment. PCBs are no longer manufactured in the United States, but they still are significant environmental and human health problems because they are still in circulation.

> **Exposure:** Exposure to PCBs primarily comes through contaminated soil and water. While PCBs are found in the air, most of these contaminants are released through the natural evaporation process in soils and bodies of water. Precipitation quickly returns airborne PCBs to ground level. PCBs are found in transformer fluids and old fluorescent light fixtures. They frequently are leaked into the environment at **faulty toxic waste sites as well as municipal waste sites**, which are not capable of containing them (PCBs are supposed to be discarded in hazardous waste landfills).
>
> While PCBs can enter the body through breathing polluted air and skin contact, the most common means of exposure is through eating contaminated food, particularly fish.
>
> **Potential Health Effects:** Even though they have not been manufactured in the United States since October 1977 when they were banned, PCBs still pose a threat to human health and the environment because of their longevity. In specific, **PCBs can cause cancer, liver damage, skin inflammations such as rashes and lesions, and major reproductive complications due to their effect on hormones**.
>
> **Treatment**: PCBs can be treated with soil washing, solvent extraction, thermal desorption, and in situ soil flushing.

Cadmium

Cadmium is often found in combination with oxygen, chlorine, or sulfur. The resulting compounds are generally solids. It is typically created through the smelting of ores such as zinc, lead, and copper. It is used in the metal plating, batteries, plastics, and pigment industries.

> **Exposure:** Cadmium accumulates in the body. Because it is not naturally expelled from the body, several low dosages can build up to create significant health effects. This exposure can occur through eating contaminated food, and drinking contaminated water. Cadmium can seep into the water and the soil from pipes, solder, and chemical waste facilities. However, only 1% to 5% of the cadmium taken in through the mouth is adsorbed into the blood. In contrast, 30% to 50% of the cadmium inhaled ends up in the blood stream. The burning of fossil fuels, municipal wastes, and smelting are the primary sources of cadmium released into the air.

[30] http://atsdr1.atsdr.cdc.gov:8080/ToxProfiles/phs8821.html. January 6, 1998. 10:20 a.m.

Potential Health Effects: Cadmium is known to adversely affect the liver, the testes, the nervous and immune systems, as well as blood. The specific effects of exposure vary according to the type of exposure. Emphysema and lung cancer are associated with inhalation. While vomiting and diarrhea can be a byproduct of ingesting this hazardous substance. Kidney stones, skeletal damage, and high blood pressure can result from either inhalation or ingestion.

Treatment: For brownfields with cadmium contamination, soil washing may be an appropriate remediation technique.

Asbestos

Asbestos is one of the most common hazardous substances found at brownfield sites. Technically, the term "asbestos" refers to amosite, chrysotile, crocidolite, tremolite, actinolite, and anthophyllite. This group of fibrous minerals can be discovered in natural soils and rocks. Because they are nonflammable, these fibers are **used in a number of insulating and manufacturing products such as**:

- Roofing shingles.
- Ceiling tiles.
- Cement products.
- Textiles.
- Gaskets.
- Coatings.
- Packaging.
- Automobile parts (e.g., the clutch, the brake, and the transmission).

Exposure: As the things that contain asbestos begin to wear down and degrade, it is released into the air. Some of the fibers can remain suspended for long periods of time. Once asbestos particles settle, they remain in the upper levels of the soil. These fibers do not travel through the soil and do not break down into other substances; as a result, they can persist for several decades.

Because it is primarily an airborne contaminant, exposure to asbestos occurs through breathing contaminated air. Old buildings that relied heavily on its insulating properties are common sources of contamination. As they decay and are eventually torn down or renovated, asbestos is released into the environment. Waste facilities that contain asbestos are also frequent offenders.

Potential Health Effects: As the main exposure pathway is inhalation, the lungs are the part of the body most affected by asbestos. **Asbestosis** is a respiratory disease associated with exposure. Those who develop this disease suffer from scar-like tissues in the lungs and in the membrane that surrounds the lungs which can lead to coughing, heart enlargement, and troubled breathing. Asbestosis can culminate in disability or death.

Asbestos is also a known **carcinogen**. Specifically, there are two types of cancer caused by inhaling asbestos: lung cancer and mesothelioma. The later is a cancer that grows in the membrane around the lungs and internal organs. Frequently, both types of cancer are fatal.

Treatment: Asbestos is often found in existing buildings. In these cases, the asbestos will have to be physically removed before renovation or demolition begins. If asbestos is discovered in the soil, soil washing may be an effective remediation approach.