# Chapter 10
# Remediation and Cleanup Options

## *10.1 Introduction*

The purpose of this chapter is to assist the user with a basic understanding of the types and availability of remediation technologies for mining and mineral processing sites. An understanding of the technologies available for mine site cleanup should help the site manager design a successful and cost-effective site management strategy.

Following a background section (Section 10.2) the chapter addresses four general topics: conventional technologies (Section 10.3); innovative/emerging technologies (Section 10.4); institutional (i.e., non-engineering) controls (Section 10.5); and sources of information regarding available technologies (Section 10.6).

Several appendices address innovative ways to clean up mining and mineral processing sites.

> Appendix B includes information and references addressing conventional and innovative remediation of Acid Mine/Rock Drainage.
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> Appendix G provides more specific information regarding conventional mine remediation technology.
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> Appendix H contains a discussion of innovative technologies in EPA's SITE Program that may be applicable at mining and mineral processing sites.
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> Appendix K includes Information and references to Best Demonstrated Available Technologies (BDATs) as developed under the RCRA Land Disposal Restriction program.
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> Appendix L presents efforts under the Mine Waste Technology program to find innovative remediation techniques.
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> Appendix M includes additional remediation references, addressing RCRA Corrective Action program, general groundwater remediation, and remediation of cyanide heap leach operations.

## *10.2 Background*

EPA, other Federal agencies, States, and Tribes have been managing investigations and cleanup activities at mining and mineral processing sites for over two decades. A large number of cleanup technologies have been successfully employed in the remediation and management of mining wastes. Because of the unique problems associated with the cleanup of mining and mineral processing wastes, new technologies, as well as new approaches to utilizing older technologies, are constantly being developed. Progress in understanding the behavior of contaminants has led to a series of new technologies being developed to address Superfund sites in general and mining and mineral processing sites in particular.

It is important that the site manager understand differences in the types of remediation technologies when evaluating them. Certain emerging technologies may be effective on a small scale but may not have been tested in a large-scale application. In other cases, the site manager needs to be aware that innovative technologies tested on one type of waste or media

may not be directly applicable to other types of mining and mineral processing site waste or media. For the purpose of this discussion, two broad categories of technologies (i.e., conventional and innovative/emerging) characterize the universe of available and applicable remediation solutions. A third category, institutional controls, will be discussed as it relates to more traditional non-engineering controls.

**Conventional Technologies.** These are technologies with a successful track record in mine site cleanup, or technologies that are considered standard practice for mine site management. Such approaches have been widely applied to remediation of mining and mineral processing sites, as well as other waste management units. Lime treatment for acid wastes is an example of conventional technology.

**Innovative/Emerging Technologies.** Two types of technologies are included in this category. Innovative technologies include processes or techniques for which cost or performance data is incomplete and the technology has not yet been widely applied. An innovative technology may require additional field scale testing before it is considered proven and ready for commercialization and routine application at mine sites. Emerging technologies typically are even earlier in the development process. While they are potentially applicable at mine sites, additional laboratory or pilot-scale testing to document effectiveness is highly recommended. Current initiatives at EPA and other Federal agencies encourage the consideration of innovative/emerging technologies in site remediation.

**Institutional Controls.** For the purpose of this discussion, institutional controls are non-engineering site management techniques or strategies used to protect human health and the environment. Examples of institutional controls include fencing, zoning, health education, easements and other deed restrictions, and interior cleaning (i.e., removing contaminated dust from interior of residences). These controls can be an integral part of an overall site management strategy.

Information addressing the conventional and innovative/emerging technologies includes the following (described below): a basic description, a relative-cost analysis, and a general effectiveness evaluation as described below. Exhibit 10-1, found at the end of this chapter, summarizes this information.

> General cost information is presented as well in the form of a comparison to the other technologies; cost information is based on 1998 data. The costs are presented as low, medium, high, or very high. These costs do not include site-specific considerations that may significantly impact the costs, including availability of power, materials, manpower and/or equipment.
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> The general effectiveness of the technology at mining and mineral processing sites is presented. Because the major contaminants of concern at most mining sites are metals, the effectiveness discussion for each technology on that contaminant class. Local site conditions can significantly impact the actual effectiveness at each mining and mineral processing site.

In many cases the remediation process will utilize multiple technologies to develop a treatment train (e.g., a series of technologies used in sequence in the remediation process). Conventional technologies, innovative/emerging technologies, and institutional controls may all be used in a integrated management strategy. As an illustration, a contaminated area may be bioremediated, with associated contaminated ground-water being pumped and treated chemically, followed by filtration, and solidification and landfilling of the sludge, utilizing fencing to restrict access to the landfill and contaminated area and creating an easement to access certain areas.

## *10.3 Conventional Technologies*

The fundamentals of conventional treatment, collection and diversion technologies are discussed in this section. In addition, those management techniques that remove the contaminant from the site, such as the sale of useable materials or decontamination of structures, are included as conventional technologies.

### *10.3.1 Treatment Technologies*

For the purpose of this discussion, treatment technologies are those technologies that either change the composition of the contaminant to form other compounds that are less dangerous to human health or the environment, or limit contaminant mobility by physical or chemical means.

**Chemical Treatment.** In chemical treatment, reagents are used to destroy or chemically modify organic and inorganic contaminants, converting hazardous constituents into less environmentally damaging forms. Typically, chemical treatment is used as part of a treatment train, either as a pretreatment technique to enhance the efficiency of subsequent processes or in post-treatment of an effluent. One of the common uses of chemical treatment at mining and mineral processing sites is the use of lime to neutralize acid rock drainage (ARD) and to precipitate the metals. The cost of chemical treatment ranges from low to high depending site conditions, including the chemicals that are used and the nature of the products that are produced by the chemical treatment. As an example, if the sludge that precipitates after the addition of lime is disposed as a solid waste, the additional cost of disposal would bring the cost into the high range. In many cases the operating and maintenance (O&M) costs will be significant over the life of the remediation.

Larger chemical treatment operations may benefit from a high density sludge (HDS) treatment system. A HDS process significantly reduces the volume of sludge compared to a basic lime treatment by recirculating sludge and lime. For example, at the Iron Mountain Mine site in California, a HDS treatment system reduced the costs associated with treatment by more than 15 percent while at the same time doubling the expected useful life of the on-site landfill and producing a more chemically and physically stable sludge.

**Stabilization.** Stabilization refers to processes that reduce the risk posed by a waste by converting the contaminants into a less soluble, less mobile, and, therefore, less hazardous form without necessarily changing the physical nature of the waste. [Site managers should be aware that the term “stabilization” is also used to describe interim remediation activities (e.g., capping) that may be used to stabilize a site in order to minimize further releases prior to actual clean up.] An example of stabilization as a treatment is the pH adjustment of a sludge which results in making the contaminants in the sludge less mobile. The cost of stabilization will be in the medium to high range depending on treatment required for stabilization. The effectiveness of stabilization is dependent on the nature of the materials to be stabilized and the subsequent storage or disposal. Cement-based stabilization is often used for many metals to comply with the treatment requirements of the Land Disposal Restrictions (LDRs).

**Solidification.** Solidification refers to processes that encapsulate waste in a monolithic solid of high-structural integrity. Solidification does not necessarily involve a chemical interaction between the waste and the solidifying reagents, but involves a physical binding of the waste in the monolith. Contaminant migration is restricted by vastly decreasing the surface area exposed to leaching and/or by isolating the waste within an impervious capsule. Encapsulation may address fine waste particles (microencapsulation) or large blocks or containers of wastes (macroencapsulation). There is, however, inherent risk that the stabilized solidified waste matrix will break down over time, potentially releasing harmful constituents into the

environment. An example of the solidification technology involves the use of cement to solidify contaminants into a large block. The cost of solidification ranges from medium to high depending of the steps required to encapsulate the waste. A simple encapsulation into a large concrete block would be an example of the medium end of the cost range. The effectiveness of solidification is dependent on the potential for the solid to break down over time and allow the encapsulation to be breached.

**Thermal Desorption.** Thermal desorption refers to treatment alternatives that use heat to remediate contaminated soils, sediments, and sludges. Thermal desorption is used to separate a contaminant from the containing media. The off-gas from the desorption unit typically must be further treated. Temperatures utilized for thermal desorption of metals is high enough that other contaminants, such as volatile organic compounds, may actually undergo thermal destruction, as discussed below. Thermal desorption is not commonly used at mining and mineral processing sites since the common contaminants at these sites, metals, are not easily heated to their gas-phase. The cost of thermal desorption is in the range of medium to high and the effectiveness at most sites is poor since there may be only a limited quantity of chemicals in the soils that can be easily heated to their gas-phase.

**Thermal Destruction.** Thermal destruction is a treatment alternative that uses heat to remediate contaminated soils, sediments, and sludges. Thermal destruction typically uses higher temperatures to actually decompose the contaminants, potentially with no hazardous contaminant residues requiring further management. Thermal destruction is not commonly used at mining and mineral processing sites since the process does not destroy metals, the most common contaminant. The cost of thermal destruction is in the range of medium to high and the effectiveness is limited to those materials that can be destroyed.

**Vapor Extraction.** Vapor extraction is an *in-situ* process that uses vacuum technology and subsurface retrieval systems to remove contaminant materials in their gas-phase. Vacuum extraction of vapors from contaminated soils and subsurface strata has been successfully employed to remove volatile compounds from permeable soils. Typically, sites considered for vapor extraction-based technologies are those where chlorinated solvents or petroleum products, such as gasoline and other fuels, have spilled or leaked into the subsurface. Vapor extraction is not commonly used at mining and mineral processing sites since metals that are the typical target contaminant are not in a gas-phase in soil. The cost of vapor extraction is in the range of medium to high and the effectiveness at most sites is poor unless a significant quantity of chemicals are present within the soils in the vapor phase.

**Solvent Extraction.** Solvent/chemical extraction is an *ex-situ* separation and concentration process in which a nonaqueous liquid reagent is used to remove organic and/or inorganic contaminants from wastes, soils, sediments, sludges, or water. The process is based on well-documented chemical equilibrium separation techniques utilized in many industries, including the mining and mineral processing industry. In the mine-site remediation, one type of solvent/chemical extraction technology (i.e., leaching) is used extensively, primarily because of the application of accepted mining and beneficiation technologies to the remediation field. The cost of solvent extraction is in the range of low to high depending on site characteristics, which include: the media necessary to extract the contaminants, the system to recover the solution with the contaminants, the process to remove the contaminants from the solution, and the handling and disposal of the spent waste or soil. The effectiveness of solvent extraction is good if the contaminants can be extracted by the liquid reagent.

**Soil Washing.** The *ex-situ* process of soil washing employs chemical and physical extraction and separation techniques to remove a broad range of organic, inorganic, and radioactive contaminants from soils. The process begins with excavation of the contaminated soil, mechanical screening to remove various oversize materials, separation to generate coarse- and

fine-grained fractions, and treatment of those fractions. Surficial contaminants are removed through abrasive scouring and scrubbing action using a washwater that may be augmented by surfactants or other agents. The soil is then separated from the spent washing fluid, which carries with it some of the contaminants. The recovered soils consist of a coarse fraction, sands and gravels, a fine fraction, silts and clays, and an organic humic fraction, any or all of which may be contaminated. The washed soil fraction may be suitable for redepositing on site or other beneficial uses. The fines typically carry the bulk of the chemical contaminants and generally require further treatment using another remediation process, such as thermal destruction, thermal desorption, or bioremediation. The costs of soil washing would range from medium to high similar to "soil flushing" discussed below, however the costs are impacted by the controlled method of recovering the liquid and the excavation costs to remove the soil. The effectiveness of soil washing is determined by the ability of the washing liquid to remove the contaminants.

**Soil Flushing.** The *in-situ* process of soil flushing uses water, enhanced water, or gaseous mixtures to accelerate the mobilization of contaminants from a contaminated soil for recovery and treatment. The process accelerates one or more of the same geochemical dissolution reactions (e.g., adsorption/ desorption, acid/base reactions, and biodegradation) that alter contaminant concentrations in ground-water systems. In addition, soil flushing accelerates a number of subsurface contaminant transport mechanisms, including advection and molecular diffusion, that are found in conventional ground water pumping. The fluids used for soil flushing can be applied or drawn from ground water and can be introduced to the soil through surface flooding or sprinklers, subsurface leach fields, and other means. When the contaminants have been flushed, the contaminated fluids may be removed by either natural seepage or a ground water recovery system. Depending upon the contaminants and the fluids used, the soil may be left in place after the soil flushing is completed. The cost of soil flushing ranges from medium to high depending on the means of applying the flushing fluid and the method of recovery of the fluids used. The effectiveness of soil flushing is dependent on the characteristics of the soil and the fluid used for flushing. If the fluid can mobilize the required contaminants and be recovered, the technology can be effective. There often is a problem, however, with either mobilizing the contaminants or recovering the fluid that limits the effectiveness. In contrast, another concern is that contaminants may be highly mobilized with the subsequent possibility of contaminating ground water.

**Decontamination of Buildings**. Decontamination of buildings and other structures through various extraction and treatment techniques may be necessary at certain mining and mineral processing sites. The purpose of decontaminating the structures may be to meet the requirements of historical preservation and/or to assist the community in attracting new industry. Decontamination may be as simple as pressure washing a building or more complex, involving partial removal techniques. As an illustration, if the contamination is a dust settled throughout the building, a simple washing may remove the contamination; if, however, the contaminant saturated wooden members of the structure, some of all the wood may have to be removed in order to decontaminate the building. The cost of decontaminating buildings and other structures is dependent on the techniques needed to complete the decontamination efforts. The effectiveness of decontamination of buildings is site specific and will be determined by what the contaminants are being addressed and how effective the technique is in removing them.

### *10.3.2 Collection, Diversion, and Containment Technologies*

Collection, diversion, and containment technologies are used at sites where treatment technologies cannot control the contaminants to an acceptable level. These engineering controls include technologies that contain or capture the contaminants to reduce or minimize releases. This section discusses some of the containment technologies available to site managers.

**Landfill Disposal.** Landfills are waste management units, typically dug into the earth, but including above ground units that are not exposed on the sides (i.e., not freestanding waste piles), that accept waste for permanent placement and disposal. While landfilling is a conventional disposal technology, it has had its share of recent innovations. Landfills may be lined to contain leachate, drained with a leachate collection system, and capped. The cost of landfills can range from medium to high at mining and mineral processing sites depending on the site conditions that impact the design, including low permeability cover, low permeability liner, leachate collection, and leachate treatment. The O&M costs of leachate treatment or cap maintenance can be significant. The effectiveness of the landfill is dependent on the design. A landfill that can isolate the waste is effective. Should the cap or liner be breached, however, the effectiveness will be greatly diminished. On-site landfills should be designed to meet site specific cleanup goals and address applicable regulatory considerations.

**Cutoff Walls.** Cutoff walls are structures used to prevent the flow of ground water from either leaving an area, in the case of contaminated ground water, or entering a contaminated area, in the case of clean ground water. Types of cutoff walls include: slurry walls, cement walls, and sheet piling.

> **Slurry walls** are basically trenches refilled with a material (e.g., bentonite slurry) that combines low permeability and high adsorption characteristics to impede the passage of ground water and associated contaminants. The cost of slurry walls is in the medium range, with depth being a factor on the cost due to equipment limitations. The effectiveness of slurry walls is dependent on the ability of the wall to get a seal on the bottom (i.e., by contact with an impermeable soil or rock layer) to keep the ground water from flowing under the slurry wall. Similarly, effectiveness is affected by construction of the slurry wall with no gaps or other points for by-pass.
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> **Cement walls** are similar to the slurry walls, except that instead of a low permeability clay-type slurry, a cement-based slurry is used. Construction may be by trench and fill as with the slurry wall construction. Alternately, construction may utilize a larger excavation in which forms are constructed to pour a concrete wall after which the excavated area around the wall is backfilled. The backfill may be with a high permeability material used to capture and channel the ground water flow (e.g., for recovery if contaminated, or to prevent its contamination). The cost of the cement walls is greater than the slurry walls especially if the wall is formed in place, with a cost range of medium to high. This increased cost however may buy an increase in effectiveness.
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> **Sheet piling** is a technology that is often used to install a cutoff wall. Sheet piling has been used in the past to funnel ground water to a treatment cell for treatment and is regularly used as a temporary cutoff wall during the remediation period. The cost of the sheet piling is in the medium to high range, with the high range utilizing a better mechanism to seal the joints between the sheets. The effectiveness of sheet piling is similar to the slurry wall, however there is a greater potential of the wall to have leaks at the joints.

**Pumping Groundwater.** A pump-and-treat process for addressing groundwater contamination is a combination of an extraction technology (pumping) and a subsequent treatment technology; this discussion focuses on the pumping portion of the combination. The treatment, which can vary by contaminant, could be any of the other technologies discussed above. The pump-and-treat technology has been the preferred method of remediating contaminated ground water. The cost of the pumping portion can range from medium to high, including, but not limited to, the number and spacing of wells, the volume to be pumped, and the depth to ground water. The long-term effectiveness of this procedure is limited for certain contaminants,

especially some metals, in certain soil types. Consideration must be given to such factors as desorption rates and chemical properties of the contaminants themselves.

**Capping.** Capping is typically used to cover a contaminated area or waste unit to prevent precipitation from infiltrating an area, to prevent contaminated material from leaving the area and to prevent human or animal contact with the contaminated materials. An example of preventing releases is the growing of vegetation on tailings to prevent fugitive dust from blowing off and being transported downwind. A example of preventing human contact is the removal and replacement of a specified depth of soil in a residential area which has been used to protect the residents from the contaminated subsoils.

Capping could include: surface armoring, soil/clay cover, soil enhancement to encourage growth, geosynthetic or asphaltic cover system, polymetric/chemical surface sealers, revegetation, concrete and synthetic covers. The cost of caps can range from low (e.g., planting grasses) to high (e.g., synthetic caps) depending on the cap selected. The cap may or may not be effective in achieving multiple performance objectives, for example; a cap designed to minimize erosion, however, may not be an effective cap to minimize infiltration and *vice versa*.

**Detention/Sedimentation.** Detention/sedimentationcontrols are used to control erosion and sediment laden runoff. “Treatment” generally consists of simply slowing the water flow and reducing the associated turbulence to allow solids to settle out. Settling may be allowed at natural rates; in other cases flocculants may be added to increase the settling rate. The settled sediments may be removed and disposed; if the sediment is contaminated then treatment may be required. The cost of detention and sedimentation is generally in the range of low to medium, depending on the O&M costs to remove the settled solids. The detention/sedimentation basins can be effective if they can be designed to allow the proper amount of settling time; however, in some cases the solids settle at a very slow rate and a portion of the solids leave the settling basin.

**Settling Basins.** Settling basins may be used to contain surface waters so that contaminated sediments suspended in the water column can be treated, settled, and managed appropriately. Dissolved contaminants and/or acid waters may be contained as well to allow for treatment or natural degradation (e.g., contained cyanide will degrade naturally). As the impoundment fills with the solids that have settled out, solids must be removed and disposed of in order for the impoundment to continue working effectively. The cost of operating settling basins is in the low to medium range, depending on the construction of the impoundment and dam. For example, a lined impoundment will cost more than an unlined impoundment. The O&M costs of the settling basin could be significant over the life of the basin to remove and dispose of any settled solids. Properly designed settling basins can be effective in removing suspended solids from surface waters.

**Interceptor Trenches.** Interceptor trenches are trenches that have been filled with a permeable material, such as gravel, that will collect the ground water flow and redirect it for either *in-situ* or *ex-situ* treatment. Interceptor trenches are often used to collect and treat ground water and prevent it from leaving a containment area, such as a landfill. The initial cost of interceptor trenches is low to moderate depending on the availability of materials. However, the O&M cost can be significant if the liquid flowing through the trench precipitates material that will plug the trench, thus minimizing the permeability and requiring the permeable material to be cleaned or replaced. Interceptor trenches are effective at capturing ground water flow if the permeability of the media in the trench is greater than the native material.

**Erosion Controls.** Erosion controls are those engineering controls used to eliminate or minimize the erosion of contaminated soils by either air or precipitation (i.e., stormwater or snow melt). Erosion controls include:

> **Capping or covers** (as discussed above), particularly in the form of revegetation, polymer/chemical surface sealers, armoring and soil enhancements. The caps or covers for erosion control, in general, are lower than the costs of caps to limit infiltration. The cost range of the erosion control caps is low to medium. The O&M costs of the cap could be significant, particularly if the cap or cover can be easily damaged. For example, if revegetation is selected, then the O&M costs will include revegetating areas where the vegetation does not grow, or is damaged by factors which could include natural conditions such as drought or insect invasion. The effectiveness of the caps or covers to prevent erosion is dependent on site conditions, however the caps or covers should generally prevent the erosion of soils by either water or air.
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> **Wind breaks** are used to minimize the erosion of soils and dusts by the wind and can include planting of trees and other vegetation to reduce the wind velocity, and/or the installation of fences. The cost of wind breaks is generally in the low to medium range. The effectiveness of wind breaks is dependent on the prevailing wind. In general, wind breaks are not as effective at eliminating airborne dust as the caps or covers.
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> **Diversions** (as discussed below) are used to control surface water around areas that have a high probability of erosion. An example of this would be construction of a diversion ditch to capture runoff which prevents the flow from reaching a steep slope, where it could cause erosion.

**Diversions.** Diversions are engineering controls that are used to divert ground water or surface water from infiltrating waste units or areas of contamination, thereby preventing the media from being contaminated and pollutants from leaching and migrating. Two types of diversions are run-on controls and capping:

> **Run-on controls** prevent surface water from entering waste units or areas of contamination and becoming contaminated. For example, surface waters may be diverted to avoid contact with stockpiled waste rock. This would prevent the water from becoming acidified. Examples of run-on controls would include retaining walls, gabion dams, check dams (both permanent and temporary), and diversion ditches. The costs of run-on controls are low to medium depending on the method used for the diversion. The use of run-on controls to divert surface water away from areas of contamination is effective in reducing the quantity of water that requires treatment.
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> **Capping** is the placement of synthetic liners or impervious earthen materials (typically clay) to prevent precipitation from infiltrating waste materials or severely contaminated areas and leaching contaminants into the ground water. This allows water to be captured and diverted elsewhere. The cost and effectiveness of caps are discussed above.

**Stream Channel Erosion Controls** are used to minimize the mobilization and transport of contaminated sediments by streams within the site. At many mining and mineral processing sites, historic transport of contaminated sediment into the stream has occurred. Many sites have areas where these sediments have been deposited along stream shores and beds. Stream channel erosion controls can be used to minimize the remobilization and transport of these sediments, often during periods of high flows. Technologies to control stream channel erosion often include both erosion controls and diversions such as channelization or lining of stream channels, diversion dams and channels (construction of diversion dams and or channels

to reduce flow to contaminated areas and ground water recharge areas, to reduce water velocity, trap sediment and divert clean water), riprap, and gabions. The cost of these controls can range from low (e.g., revegetation of stream banks) to high (e.g., diversion to an engineered channel) depending on the site conditions. Some of the technologies may be temporary until other remediations are completed. The O&M cost to the erosion controls could be significant, especially with damage from flood events.

### *10.3.3 Reuse, recycle, reclaim*

**Sale of Useable Materials.** Sale of materials that can be utilized by other is another management approach that the site manager may employ. The useable materials could include: finished product in the unlikely case that any remains on site; supplies of materials that remained unused at the site; feedstocks, ore or concentrate that remains on site; demolition debris for reprocessing; and/or waste materials for reprocessing. The cost from this technology may be either low or positive. In evaluating the cost of selling useable materials, the cost should be compared to the cost of disposal to ensure that the cost of selling the material minus any money received is actually less than the cost of disposal. Recycling or reusing these materials is an effective means of eliminating contaminants, although there generally are limited materials that should be sold.

**Remining/Reprocessing.** Remining is the process of taking mine "waste" material and running it through a process to recover valuable constituents. Remining typically utilizes the same mining and beneficiation processes discussed in Chapter 3 to extract metal contaminants from tailings or other waste materials. For example, tailings may be reprocessed to recover metals that remain, by any or all of the following methods: gravity separation (if there is a difference in the specific gravity of the desired mineral and the rest of the tailings), flotation, or leaching.

The cost of remining/reprocessing may range from profitable to high depending on the cost of the remining/reprocessing minus the value paid for the metals or other materials. The "new tailings" can be placed in an engineered containment facility which generally is more desirable than the existing facility, thereby minimizing the potential of releases to the environment. The "clean tailings" may also have other beneficial uses, depending on the characteristics of the tailings. The effectiveness of the remining and reprocessing can vary significantly depending on the site. In general, however, it is very effective for the portion of the waste that is reprocessed.

## *10.4 Innovative/Emerging Technologies*

The following treatment technologies are considered to be innovative/emerging technologies. The discussion is intended to provide examples; innovative and emerging technologies are continually evolving and information addressing these technologies will necessarily be obtained from individuals and organizations with ongoing characterization and remediation activities, investigations, or research.

**Bioremediation,** for the purpose of this discussion, refers to the use of microbiota to degrade hazardous organic and inorganic materials to innocuous materials. Certain bacteria and fungi are able to utilize, as sources of carbon and energy, some natural organic compounds (e.g., petroleum hydrocarbons, phenols, cresols, acetone, cellulosic wastes) converting these and other naturally occurring compounds to byproducts (e.g., carbon dioxide, methane, water, microbial biomass) that are usually less complex than the parent material. At metal contaminated sites, such as mining and mineral processing sites, the addition of biological nutrients has been demonstrated to stimulate natural microorganisms to operate a natural

process for biological attenuation and stabilization of heavy metals. The cost of bioremediation is in the range of medium to high; as the technology evolves the cost may decrease.

**Phytoremediation** is the use of plants and trees to extract, stabilize or detoxify contaminants in soil and water. The phytoremediation process generally describes several ways in which plants are used to remediate or stabilize contaminants at a site. Plants can break down organic pollutants or stabilize metal contaminants by acting as filters or traps. The three ways that phytoremediation works are: phytoextraction, rhizofiltration, and phytodegradation.

> **Phytoextraction**, also termed phytoaccumulation, refers to the uptake of metal contaminants by plant roots into stems and leaves. Plants that absorb large amounts of metals are selected and planted at a site based on the type of metals present and other site conditions that will impact the growth. The plants are harvested and either incinerated or composted to recycle the metals. The cost of phytoextraction is in the low to medium range depending on site conditions and the costs of disposal of the harvested plant material. The O&M costs may be significant if the plants need to be harvested for many years. The effectiveness of phytoextraction has been good for some metals where there are shallow, low levels of contamination; the technology is, however, considered innovative for most metals.
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> **Rhizofiltration** is used to remove metal contamination in water. The roots of certain plants take up the contaminated water along with the contaminants. After the roots have become saturated with metals, they are harvested and disposed. The cost of rhizofiltration is in the low to medium range depending on site conditions and the cost of disposal of the harvested plant material. The O&M costs may be significant if the plants need to be harvested for many years. The effectiveness of rhizofiltration is not yet determined as the technology is considered innovative.
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> **Phytodegradation** is a process in which plants are able to degrade organic pollutants. Phytodegradation is not currently used for inorganic contaminants.

**Vitrification.** Vitrification is a solidification process employing heat to melt and convert waste materials into glass or other crystalline products. Waste materials, such as heavy metals and radionuclides, are actually incorporated into the relatively strong, durable glass structure that is somewhat resistant to leaching. The high temperature also destroys any organic constituents with byproducts treated in an off-gas treatment system that generally must accompany vitrification. The cost of vitrification is very high and has not been commonly used at mining and mineral processing sites. The effectiveness of the vitrification is dependent on the material that is treated. If a glass like product can be made, the ability to isolate the waste is very effective.

### *10.5 Institutional Controls*

Institutional controls are non-engineered solutions (e.g., fencing and signing, zoning restrictions) that are used to protect human health and the environment by controlling actions or modifying behavior. Institutional Controls are part of risk management and a potential part of the response. Risk should be evaluated for present site conditions and the various alternative future uses. It is in this latter element that the risk levels of specific future land uses and institutional controls can be evaluated. Where residential exposures do not currently exist and may not occur in the foreseeable future, institutional controls may be adequate to protect against human health exposures (though active remediation still may be required for environmental risks). In general, Institutional Controls can include, but not limited, a number of activities as described below. The user is advised to consult the Institutional Controls: A

Reference Manual, US EPA Workgroup on Institutional Controls - Workgroup Draft 1998 and/or Institutional Controls: A Site Manager's Guide to Identifying, Evaluating and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups, Draft March 2000, OSWER 9355.0-74FS-P, EPA 540-F-00 for further details on institutional controls.

**Restricting Access** is often used to minimize access to areas where there may be an exposure. Erecting fenced, posting signs, utilizing guards or security services, and using fines for unauthorized access all may assist in restricting access. The cost of fencing can be significant if the area is quite large and O&M costs can also be significant if the fences need constant maintenance to repair damage, either from natural causes or breaches. Fences can be effective at restricting access; they may, however, in some circumstances encourage the curious to trespass. The cost of posting signs is low and maintenance costs are generally low. Effectiveness of the signs, however, is generally poor. While fining trespassers may be utilized, the cost of enforcement may be significant if additional guards have to be employed. The levying of fines generally has a limited effectiveness.

**Deed Restrictions/Notices** place legal restrictions on the use of and transfer or sale of the property and provide the prospective purchaser with a notification of any requirements that must be met on the property. The cost of implementing the deed restrictions/notices is low. The effectiveness of any of these deed restrictions/notices depends on the support of the local government and/or the entity (i.e., easement holder) authorized to enforce controls. In addition, the motivation to enforce these regulations may diminish as time passes after completion of the cleanup.

**Zoning or Other Regulations** restrict activities that could cause an exposure. The local government must enact and enforce the regulations. The cost of implementing the regulation is low, however the costs of enforcing the regulations can be very expensive, especially to a local government that may be depressed (i.e., because of a reduced tax base from loss of the mining enterprise being addressed). The effectiveness of any of these regulations or zoning requirements depends on the local government and community. The motivation to enforce these regulations may diminish as time passes after the completion of the cleanup. Examples of regulations include: restricting use of off-road vehicles in an area where the use could damage the remediation and allow contaminants to be released by erosion (e.g., air or surface water); speed limits for unpaved roads to limit the amount of dust that would be generated; or load limits on roads to keep the surface from breaking down. An example of a zoning regulation would include a regulation that would keep areas of the mining and mineral processing site industrial or commercial.

**Limited Future Development** in a remediated area would require that future development not damage the remedy or increase the exposure. The cost of implementing this is low; as with the cost of zoning, however, it requires the community and local government to accept the limitations. The effectiveness of this control is dependant on the local government willingness to mandate and enforce limitations.

**Regulatory Requirements** are those requirements that are needed to keep the remedy in place. They can be very important at a mining and mineral processing site that includes a residential community. Examples of regulatory requirements include drilling permits, excavation permits, or construction permits in areas where there is contamination at depth. The permits would ensure that all activities where contaminated soils are exposed would follow certain procedures to minimize any exposure or re-contamination of clean soils. The costs of implementing and managing these procedures would range from medium to high depending on how the permits are issued and tracked. The effectiveness of this system depends on the source of funding for the permit process and the willingness of the community and local government to accept the requirements.

**Procedures for Soil Disposal** are a set of procedures to handle and dispose of any contaminated soils that are removed during normal activities, such as repairs to infrastructure (e.g., roads and utilities) and development and expansion of existing houses and buildings. The cost of these procedures will vary depending on requirements for handling and disposal. In general, the costs would be anticipated to be in the medium to high range. The effectiveness of these procedures is dependent on the acceptance of the community. If the procedures are considered to be onerous or difficult, they probably will not be effective.

**Health Education Programs** are used to inform and educate the community of the risks from the contaminated media. This can be a difficult task in an established community that does not perceive a risk. The costs of the health education program can range from low to high depending on what is included in the program. For example, if health intervention and monitoring are included as part of the program the costs will be high. The effectiveness of the health education program is dependent on community acceptance.

**Interior Cleaning** is a more effective way to remove contaminated dusts and soils from a house. However, the cost of the cleaning every home can range from medium to high. If the sources of the dusts and soils have not been removed, the home can become recontaminated in a short time. Programs to encourage interior cleaning can assist in reducing the risk from contaminated dusts and soils that have entered the home, either via airborne dust or tracked in by people or animals. An example of such a program was employed at the Bunker Hill Superfund site in northern Idaho in which the program loaned vacuums with HEPA filters to local residents. The costs of the programs are generally low, however the effectiveness varies based on community acceptance.

## *10.6 Sources of Information and Means of Accessing Information Regarding Available Technologies*

Identifying innovative technologies or cross-applying technologies from conventional sites to mining and mineral processing sites can be difficult as the technologies and their applications are constantly changing and improving. It is extremely important that the site manager know how to access information regarding these technologies. One goal of this handbook is to provide the site manager with a roadmap to this information; the second goal is to encourage the site manager to build a network of contacts. A network of individuals and organizations that can answer questions and provide information regarding technologies is critical in the development of remediation alternatives. This network may include government, academic, and private sector entities. Former and current mine-site remediation managers are an extremely valuable source of practical information regarding problems encountered at mining and mineral processing sites and solutions, including both successful and unsuccessful methods. Program and enforcement staff at EPA Headquarters and the ten EPA Regional Offices, as well as State offices can assist site managers with understanding and addressing a variety of issues related to Superfund, Applicable or Relevant and Appropriate Requirements (ARARS), other standards, limitations, criteria, and other programs and initiatives. Other Federal agencies, including the Department of Energy, the Department of Defense, the Department of Agriculture, and the Department of Interior, are active in developing remediation technologies and assisting mining operations. Universities and university-led centers (e.g., combinations of government, academic, and private sector entities) are actively exploring new opportunities in remediation technologies. Finally, private sector entities are developing technologies, although the nature of their business may limit easy access to innovative technologies outside of a business relationship.

Building these contacts into a network will assist the site manager in addressing all aspects of the site investigation and cleanup. To help begin this process, Appendix I of this reference document includes a list of contacts for EPA staff working with mining and mineral processing related issues.

In addition, the Internet websites identified in Appendix J allows the user to electronically access a vast amount of data regarding remediation technologies and related topics. Other sources of information have been analyzed and collected in the appendices as well. These appendices are intended to provide the user with a guide to the many sources of information regarding remediation technologies that are currently available. Some of the sources of information available include: hotlines, libraries, universities and research centers, the Internet, computerized bulletin boards, and technical documentation.

EPA has developed a large number of areas with information of potential use in identifying remediation technologies. These include Web pages, a compendium of Superfund guidance and technical documents, rule-making dockets, and various media- and program-based offices (e.g., the Office of Water and the Superfund Office).

**Exhibit 10-1**
**Remediation Technologies Matrix**

| Technology | Type[1] | Media | Cost[2] | Effectiveness | Comments |
|---|---|---|---|---|---|
| Bioremediation | I/E | S | M-H | Innovative technology. | |
| Capping | C | S, sludges, wastes | L-H | Effective | |
| Capping (Erosion) | C | S, SW, A | L- M | Depends on site conditions, generally effective | O&M costs could be significant if the cap or cover is damaged. |
| Cement Walls | C | GW | M-H | Effective | |
| Chemical Treatment | C | SW, GW | M-H | Effective | O&M cost may be significant. |
| Decontamination | C | Structures | L-M | Depends on site conditions and contaminants | |
| Deed Restrictions | IC | Land | L | Depends on community acceptance | |
| Detention/ Sedimentation | C | SW | L-M | Effective | |
| Fencing | IC | | L-M | Fencing can be effective at restricting access if the fences are maintained. | O&M costs can be significant, particularly for long stretches of fence. |
| Fines | IC | S, SW, GW, A | L | Depends on community acceptance | |
| Health Education Programs | IC | S,A,GW,SW | M-H | The effectiveness of any health education program depends on the community acceptance. | Needs local enforcement and support to be effective. |
| Interceptor Trenches | C | GW | L-H | Effective in capturing GW if the permeability is greater than native material | Significant O&M costs if the GW materials precipitate and reduce the permeability, requiring the media to be replaced or cleaned. |
| Interior Cleaning | IC | S, A | M-H | Can be very effective for removing the exposure to contaminants in interior dust. | Re-contamination is possible if sources have not been remediated. |
| Landfill Disposal | C | S, Solid Waste | M-H | Effective as long as the cap or liner are not breached. | May have significant O&M costs to maintain cap or treat leachate. |

Type: C = Conventional; I/E = Innovative/Emerging; IC = Institutional Control
Media: S = Soil; GW = Ground Water; SW = Surface Water; A = Air
Cost: L = Low; M = Medium; H = High; VH = Very High

**Exhibit 10-1**
**Remediation Technologies Matrix**

| Technology | Type[1] | Media | Cost[2] | Effectiveness | Comments |
|---|---|---|---|---|---|
| Limited Future Development | IC | Land | L | Depends on community acceptance | |
| Phytoextraction, Phytodegredation | I/E | S | L-M | Has been successful for some metals | May be considered innovative. |
| Programs to Encourage Interior Cleaning | IC | S, A | L | The effectiveness depends on community acceptance. | Some community members will not participate. |
| Pump and Treat | C | GW | M-H | Depends on site conditions and contaminant characteristics | |
| Regulatory Requirements | IC | S | | The effectiveness depends on community acceptance. | Needs a source of funding to implement the permit issuing and tracking system. |
| Remining/ Reprocessing | I/E | S, Wastes | L-H | If all the material can be removed, this is a very effective technology; only a limited amount of material may, however, be available for remining. | Depends on the characteristics of the material to be reworked. Recovering salable metal may offset remediation costs. The time to reprocess large amounts of material could be significant and may not be acceptable. |
| Rhizofiltration | C | SW, GW | L-M | Innovative technology | |
| Run-on Controls | C | SW | L-M | Effective | |
| Sale of Useable Materials | C | feedstocks, wastes | L | Good | Limited to those materials that there is a market for. |
| Settling Basins | C | SW | L-H | Effective in removing suspended solids | May have significant O&M costs over the life of the dam. |
| Sheet Piling | C | GW | M-H | Effective | May have “leaks” in the wall |
| Signs | IC | S, SW, Waste Units | L | Signs have a very limited effectiveness | O&M costs can be significant if the signs keep “disappearing” |
| Slurry Walls | C | GW | M | Effective | May have “leaks” in the wall. |
| Soil Disposal | IC | S | M-H | The effectiveness depends on community acceptance. | Greatly depends on the handing and disposal requirements |

Type: C = Conventional; I/E = Innovative/Emerging; IC = Institutional Control
Media: S = Soil; GW = Ground Water; SW = Surface Water; A = Air
Cost: L = Low; M = Medium; H = High; VH = Very High

**Exhibit 10-1**
**Remediation Technologies Matrix**

| Technology | Type[1] | Media | Cost[2] | Effectiveness | Comments |
|---|---|---|---|---|---|
| Soil Flushing | C | S | M-H | Site conditions affect fluid's ability to mobilize contaminants | May be a concern with contamination of ground water. |
| Soil Washing | C | S | M-H | Site conditions affect fluid's ability to mobilize contaminants | |
| Solidification | C | S, sludges, wastes | M-H | Depends on the ability of the solid to break down over time. | |
| Solvent Extraction | C | S, wastes, sludges | L-H | Depends on the solutions' ability to extract contaminants | |
| Speed Limits | IC | A, S | L | The effectiveness depends on community acceptance. | Needs local enforcement and support to be effective. |
| Stabilization | C | S, sludges, wastes | M-H | Dependent on the nature of material to be stabilized. | |
| Stream Channel Erosion Control | C | SW | L-H | Effective | O&M costs can be significant. |
| Thermal Destruction | C | S, sludges, wastes | M-H | Poor for metals | Not common at most mining and mineral processing sites. |
| Thermal Desorption | C | S | M-H | Depends on site characteristics and contaminants | Not common at most mining and mineral processing sites. |
| Vapor Extraction | C | S | M-H | Depends on site characteristics and vapor phase contaminants | Not common at most mining and mineral processing sites. |
| Vehicle Limits | IC | S | L | The effectiveness depends on community acceptance. | Needs local enforcement and support to be effective. |
| Vitrification | I/E | S, Solid Waste | VH | Effective | Not common at mining and mineral processing sites. |
| Wind Breaks | C | S | L-M | Fair to good effectiveness | |
| Zoning | IC | S | L-M | The effectiveness depends on community acceptance. | Needs local enforcement and support to be effective. |

Type: C = Conventional; I/E = Innovative/Emerging; IC = Institutional Control
Media: S = Soil; GW = Ground Water; SW = Surface Water; A = Air
Cost: L = Low; M = Medium; H = High; VH = Very High