Chapter 3
Environmental Impacts from Mining

3.1 Introduction

This chapter introduces site managers to the types of impacts mining and mineral processing operations can have on the environment. Knowledge of these impacts will be important during site scoping, characterization, and alternative selection. This background information provides valuable insight into the contaminants that may be present, potential threats to human health and the environment, and feasibility of response actions. There are thousands of inactive and/or abandoned mine sites on federal, state, tribal and private land. While the majority of these sites are not believed to present significant environmental problems, there are, nonetheless, many sites that do create significant impacts. In addition to the impacts of individual mine sites, the cumulative impact of multiple sites within a historic mining district often has the potential to impair beneficial uses of local surface and groundwater.

Highlight 3-1
Major categories of mining impacts:

- Acid Drainage
- Metals contamination of ground/surface water and sediments
- Sedimentation
- Cyanide
- Air emissions and deposition
- Physical impacts

A variety of environmental impacts may occur at an abandoned mine site. Highlight 3.1 lists the major categories of abandoned mine site impacts. Leading the list is acid generation, which is one of the largest problems from hardrock metal mining. This chapter describes those that are specific to mine sites. Effects from process or waste management units common to non-mine sites (e.g., leaking underground storage tanks, solvent disposal from mechanical shops) or involving contaminants found at many sites (e.g., PBCs, solvents, petroleum, chemicals used in processing); are not addressed in this reference document.

The following sections describe each of these environmental impacts characteristic of mine sites requiring remediation.

3.2 Acid Drainage

The formation of acid drainage and the contaminants associated with it has been described as the largest environmental problem facing the U.S. mining industry (for additional information regarding acid drainage refer to Appendix B). Commonly referred to as acid rock drainage (ARD) or acid mine drainage (AMD), acid drainage may be generated from mine waste rock or tailings (i.e., ARD) or mine structures, such as pits and underground workings (i.e., AMD). Acid generation can occur rapidly, or it may take years or decades to appear and reach its full potential. For that reason, even a long-abandoned site can intensify in regard to its environmental impacts.

The severity of, and impacts from, AMD/ARD are primarily a function of the mineralogy of the rock material and the availability of water and oxygen. While acid may be neutralized by the receiving water, some dissolved metals may remain in solution. Dissolved metals in acid drainage may include lead, copper, silver, manganese, cadmium, iron, and zinc, among other metals. Elevated concentrations of these metals in surface water and ground water can preclude their use as drinking water or aquatic habitat.

Acid Drainage Generation. Acid is generated at mine sites when metal sulfide minerals are oxidized and sufficient water is present to mobilize the sulfur ion. Metal sulfide minerals are common constituents in the host rock associated with metal mining activity.

Prior to mining, oxidation of these minerals and the formation of sulfuric acid is a function of natural weathering processes. The oxidation of undisturbed orebodies followed by the release of acid and mobilization of metals is slow. Natural discharge from such deposits poses little threat to receiving aquatic ecosystems except in rare instances. Mining and beneficiation operations greatly increase the rate of these same chemical reactions by removing large volumes of sulfide rock material and exposing increased surface area to air and water. Materials/wastes that have the potential to generate ARD as a result of metal mining activity include mined material, such as spent ore from heap and dump leach operations, tailings, and waste rock units, as well as overburden material. AMD generation in the mines themselves occurs at the pit walls in the case of surface mining operations and in the underground workings associated with underground mines.

The potential for a mine or its associated waste to generate acid and release contaminants depends on many factors and is site-specific. These site-specific factors can be categorized as generation factors, control factors, and physical factors.

Generation Factors. Generation factors determine the ability of the material to produce acid. Water and oxygen are necessary to generate acid drainage; certain bacteria enhance acid generation. Water serves as a reactant, a medium for bacteria, and the transport medium for the oxidation products. A ready supply of atmospheric oxygen is required to drive the oxidation reaction. Oxygen is particularly important in maintaining the rapid oxidation catalyzed by bacteria at pH values below 3.5. Oxidation of sulfides is significantly reduced when the concentration of oxygen in the pore spaces of mining waste units is less than 1 or 2 percent. Different bacteria are better suited to different pH levels and physical factors (discussed below). The type of bacteria and population sizes change as growth conditions are optimized.

Chemical Control Factors. Chemical control factors determine the products of oxidation reaction. These factors include the ability of the generation rock or receiving water to either neutralize the acid (i.e., positive effect) or to change the effluent character by adding metals ions mobilized by residual acid (i.e., negative effect). Neutralization of acid by the alkalinity released when acid reacts with carbonate minerals is an important means of moderating acid production and can serve to delay the onset of acid production for long periods or even indefinitely. The most common neutralizing minerals are calcite and dolomite. Products from the oxidation reaction, such as hydrogen ions and metal ions, may also react with other non-neutralizing constituents. Possible reactions include ion exchange on clay particles, gypsum precipitation, and dissolution of other minerals. The dissolution of other minerals contributes to the contaminant load in the acid drainage. Examples of metals occurring in the dissolved form include aluminum, manganese, copper, lead, zinc, and others.

Physical Factors. Physical factors include the physical characteristics of the waste or structure, the way in which acid-generating and acid-neutralizing materials are placed, and the local hydrology. The physical nature of the material, such as particle size, permeability, and physical weathering characteristics, is important to the acid generation potential. Though difficult to weigh, each of these factors influences the potential for acid generation and is, therefore, an important consideration for long term waste management. Particle size is a fundamental concern because it affects the surface area exposed to weathering and oxidation. Surface area is inversely proportional to particle size. Very coarse grain material, as is found in waste rock dumps, exposes less surface area but may allow air and water to penetrate deeper into the unit, thereby exposing more material to oxidation and ultimately producing more acid. Air circulation in coarse material is aided by wind, changes in barometric pressure, and possibly convective gas flow caused by heat generated by the oxidation reaction. In contrast, fine-grain material (e.g., tailings) may retard air and very fine material may limit water flow; however, finer grains expose more surface area to oxidation. The relationships among particle size, surface area, and oxidation play a prominent role in acid prediction methods and in mining waste management units. As waste material weathers with time, particle size is reduced, exposing more surface area and changing physical characteristics of the waste unit. However, this will be a slower process

Highlight 3-2
Eagle Mine

Zinc and other base and precious metals were produced from ores excavated from the underground mine in central Colorado from 1878 to 1977. The resultant wastes consist of roaster piles, tailings ponds, waste rock piles and acid drainage from the mine. Percolation from the tailings ponds has contaminated ground water below and down gradient of the ponds. The ground water discharges to a nearby stream. Runoff from the roaster, waste piles and acid drainage from the mine also discharge directly to the stream. The main parameters of concern are pH, arsenic, cadmium, copper, lead, manganese, nickel, and zinc. In particular, concentrations of cadmium, copper, and zinc exceed water quality criteria in the stream. In addition, levels of dissolved solids are also above background concentrations. At least two private wells previously used for drinking water have been contaminated. The site is currently on the National Priorities List and various remedial actions have taken place.

A number of studies and publications address acid drainage. Historically, acid generation remediation efforts have centered around acid drainage from coal mines and their associated spoils. Increasingly, acid generation is being managed at hardrock mines. Active treatment (e.g., lime treatment and settling) has been successfully used and passive treatment (e.g., anoxic limestone drains) have been tried with some limited success and constant improvement.

3.3 Metal Contamination of Ground and Surface Water, and Associated Sediments

Mining operations can affect ground water quality in several ways. The most obvious occurs in mining below the water table, either in underground workings or open pits. This provides a direct conduit to aquifers. Ground water quality is also affected when waters (natural or process waters or wastewaters) infiltrate through surface materials (including overlying wastes or other material) into ground water. Contamination can also occur when there is an hydraulic connection between surface and ground water. Any of these can cause elevated pollutant levels in ground water. Further, disturbance in the ground water flow regime may affect the quantities of water available for other local uses. In addition, contaminated ground water may discharge to surface water down gradient of the mine, as contributions to base flow in a stream channel or springs.

Dissolved pollutants at a mine site are primarily metals but may include sulfates, nitrates, and radionuclides; these contaminants, once dissolved, can migrate from mining operations to local ground and surface water (contamination of surface water may also occur as contaminated soil or waste materials are eroded and washed into water bodies). These are discussed in section 3.4.). Dissolved metals may include lead, copper, silver, manganese, cadmium, iron, arsenic, and zinc. Elevated concentrations of these metals in surface water and ground water may preclude their use as drinking water. Low pH levels and high metal concentrations can have acute and chronic effects on aquatic life/biota. While AMD/ARD can enhance contaminant mobility by promoting leaching from exposed wastes and mine structures, releases can also occur under neutral pH conditions.

Dissolution of metals due to low pH is a well known characteristic of each acid drainage. Low pH is not necessary for metals to be mobilized and to contaminate waters; there is increasing concern about neutral and high pH mobilization.

Sources. Primary sources of dissolved pollutants from metal mining operations include underground and surface mine workings, overburden and waste rock piles, tailings piles and impoundments, direct discharges from conventional milling/beneficiation operations, leach piles and processing facilities, chemical storage areas (runoff and spills), and reclamation activities. Discharges of process water, mine water, storm and snowmelt runoff, and seepage are the primary transport mechanisms to surface water and ground water.

Highlight 3-3
California Gulch

The California Gulch Superfund site, located in the upper Arkansas River Valley in Lake County, Colorado, is an example of a site severely affected by metal contamination. The study area for the remedial action encompasses approximately 15 square miles and includes California Gulch, a tributary of the Arkansas River, and the City of Leadville. Mining for lead, zinc, and gold has occurred in the area since the late 1800's. The site was added to the National Priority List (NPL) in 1983. A remedial investigation (RI) conducted by EPA in 1984 indicated that the area is contaminated with metals, including cadmium, copper, lead, and zinc migrating from numerous abandoned and active mining operations. A primary source of the metals contamination in the Arkansas River is via the California Gulch. The Yak Tunnel, built to drain the local mine workings, drains into the California Gulch. Acid generated in the mine dissolves and mobilizes cadmium, copper, iron, lead, manganese, zinc, and other metals. The tunnel and its laterals and drifts collect this metal-laden acidic water and discharge it into California Gulch, the Arkansas River, and the associated shallow alluvial ground-water and sediment systems. From previous investigations and sampling data, it was concluded that, as of the early 1980's, the Yak Tunnel discharged a combined total of 210 tons per year of cadmium, lead, copper, manganese, iron, and zinc into California Gulch. Starting in 1990, one of the PRPs consented to build and operate a treatment plant for the Yak Tunnel discharge. The treatment plant operates continuously and has significantly improved water quality of the Arkansas River, into which it discharges.

Naturally occurring substances in the site area are the major source of these pollutants. Mined ore not only contains the metal being extracted but varying concentrations of a wide range of other metals (frequently, other metals may be present at much higher concentrations and can be significantly more mobile than the target mineral). Depending on the local geology, the ore (and the surrounding waste rock and overburden) can include trace levels of aluminum, arsenic, asbestos, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, selenium, and zinc.

Chemicals used in mining and beneficiation are also a potential source of water contamination. Common types of reagents include copper, zinc, chromium, cyanide, nitrate and phenolic compounds, and sulfuric acid at copper leaching operations. With the exception of leaching operations and possibly the extensive use of nitrate compounds in blasting and reclamation, the quantities of reagents used are relatively small compared to the volumes of water generated. As a result, the risks from releases of toxic pollutant from reagents not related to leaching are generally limited.

Sediment Contamination. Mining processes can result in the contamination of associated sediments in receiving streams when dissolved pollutants discharged to surface waters partition to sediments in the stream. In addition, fine grained waste materials eroded from mine sites can become sediments, as described in Section 3.4 below. Specifically, some toxic constituents (e.g., lead and mercury) associated with discharges from mining operations may be found at elevated levels in sediments, while not being detected in the water column or being detected at much lower concentrations. Sediment contamination may affect human health through the consumption of fish and other biota that bioaccumulate toxic pollutants. Elevated levels of toxic pollutants in sediments also can have direct acute and chronic impacts on macroinvertebrates and other benthic organisms. Finally, sediment contamination provides a long-term source of pollutants through potential re-dissolution in the water column. This can lead to chronic contamination of water and aquatic organisms. Currently, no national sediment standards/criteria have been established for toxic pollutants associated with mining operations. An ecological risk assessment may be an appropriate tool to evaluate sediment impacts.

3.4 Sedimentation of Surface Waters

Because of the large land area disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion is a primary concern at mine sites. Erosion may cause significant loading of sediments and any entrained chemical pollutants to nearby streams, especially during severe storm events and high snowmelt periods. Historic mining and mineral processing sites may have discharged wastes directly into surface waters. This has been particularly the case with tailings, that historically in many areas were deposited directly into surface waters or placed at the edge of surface waters where erosions would transport the tailings to the surface waters.

Erosion. Water erosion may be described as the process by which soil particles are detached, suspended, and transported from their original location. Sedimentation is the byproduct of erosion, whereby eroded particles are deposited at a different location from their origin.

The factors influencing erosion and sedimentation are interrelated and all relate to either the impact of precipitation or runoff velocity and volume. Sedimentation is considered the final stage in the erosion process; thus, the mechanisms affecting erosion also affect sedimentation. The main factors influencing erosion include rainfall/snowmelt runoff, soil infiltration rate, soil texture and structure, vegetative cover, slope length, and implementation of erosion control practices.

Sources of Loading. Major sources of erosion/sediment loadings at mining sites include open pit areas, heap and dump leach operations, waste rock and overburden piles, tailings piles, haul and access roads, ore stockpiles, exploration areas, and reclamation areas. The variability in natural site conditions (e.g., geology, vegetation, topography, climate, and proximity to and characteristics of surface waters) combined with significant differences in the quantities and characteristics of exposed materials at mines preclude any generalization of the quantities and characteristics of sediment loadings. New sources are frequently located in areas with other active operations, as well as historic abandoned mines. Other non-mining sources also may contribute to erosion impacts in the watershed. At smelter sites historic air emissions may have caused toxicity to local vegetation, increasing erosion potential in impacted areas.

Environmental Impacts. Particulate matter is detrimental to local fish populations. Decreased densities of macroinvertebrate and benthic invertebrate populations have been associated with increased suspended solids. Enhanced sedimentation within aquatic environments also has the effect of inhibiting spawning and the development of fish

Highlight 3-4
Mineral Creek and Pinto Creek

The impacts of mines on aquatic resources have been well documented. For example, a Mineral Creek fisheries and habitat survey conducted by the Arizona Game and Fish and the U.S. Fish & Wildlife Service showed that significant damage was caused by an active mining activity on the shores of Mineral Creek. In summary, the upstream control station showed an overhead cover (undercut bank, vegetation, logs, etc.) of 50% to 75%. The dominant substrate was small gravel, and in stream cover consisted of aquatic vegetation. Five species of fish were captured for a total of 309 individual fish. In contrast, the downstream station showed an overhead cover of less than 25%. The dominant substrate was small boulders, and in stream cover consisted of only interstitial spaces and very little aquatic vegetation. No species of fish were captured and very few aquatic insects were observed or captured. This Mineral Creek survey shows a significant degradation of habitat quality below the mine. Pinto Creek, which received a massive discharge of tailings and pregnant leach solution from an active copper mine, was also surveyed. The tailings had a smothering, scouring effect on the stream. Pinto Creek is gradually recovering from this devastating discharge through the import of native species from unaffected tributaries. However, the gene pool of the native fish is severely limited as only one age group of fish has repopulated Pinto Creek. A second unauthorized discharge of pollutants to the creek could eliminate that fish species.

eggs and larvae, as well as smothering benthic fauna. In addition, high turbidity may impair the passage of light, which is necessary for photosynthetic activity of aquatic plants.

Contaminated Sediments. Exposed materials from mining operations, such as mine workings, wastes, and contaminated soils, may contribute sediments with chemical pollutants, including heavy metals. Contaminated sediments in surface water may pose risks to human health and the environment as a persistent source of chemicals to human and aquatic life and those non-aquatic life that consume aquatic life. Human exposure occurs through experiencing direct contact, eating fish/shellfish that have bioaccumulated toxic chemicals, or drinking water exposed to contaminated sediments. Continued bioaccumulation of toxic pollutants in aquatic species may limit their use for human consumption. Accumulation in aquatic organisms, particularly benthic species, can also cause acute and chronic toxicity to aquatic life. Finally, organic-laden solids have the effect of reducing dissolved oxygen concentration, thus creating toxic conditions.

Physical Impacts. Beyond the potential for pollutant impacts on human and aquatic life, physical impacts are associated with the sedimentation, including the filling of deep pools resulting in the loss of habitat for fish and an increase in temperature. The sedimentation can also result in the filling of downstream reservoirs reducing the capacity for both flood control and power generation. The sedimentation can also cause the channel to widen and become shallower, which may increase the frequency of overbank flow.

3.5 Cyanide

The use of cyanide has a long history in the mining industry. For decades, it has been used as a pyrite depressant in base metal flotation, a type of beneficiation process (see Section 2.3). It also has been used for more than a century in gold recovery (see Section 2.4). In the 1950's, technology advances that allowed large-scale beneficiation of gold ores using cyanide (first demonstrated in Cripple Creek, Colorado) set the stage for the enormous increase in cyanide usage when gold prices skyrocketed in the late 1970's and 1980's. Continued improvements in cyanidation technology have allowed increasingly lower grade gold ores to be mined economically using leach operations. The use of cyanide in the leaching of gold ores has an increased potential to impact the environment because of the greater quantity that is used in leaching.

> **Highlight 3-5**
> **The Summitville Mine**
>
> The Summitville Mine is an open-pit, heap-leach gold mine using cyanide beneficiation. The mine operated until 1992 when it was shut down by the company in part due to continued releases of cyanide to the environment. The largest release, caused by pump failures resulted in a cyanide laden contaminant plume that killed fish for a distance of 17 miles in the Alamosa River.

The acute toxicity of cyanide (inhalation or ingestion of cyanide interferes with an organism's oxygen metabolism and is lethal) coupled with impacts from a number of major incidents have focused attention on the use of cyanide in the mining industry. Through the 1980's, as cyanidation operations and cyanide usage proliferated, incidents were reported in which waterfowl died when using tailings ponds or other cyanide-containing solution ponds. In addition, a number of major spills occurred, including one in South

> **Highlight 3-6**
> **Romanian Cyanide Spill**
>
> On January 31, 2000, a tailings dam failed at the Aurul gold mine near the town of Bai Mare in Romania. The failure released approximately 3.5 million cubic feet of water contaminated with cyanide and heavy metals into the the Szamos and Tizsa Rivers in Romania, Hungary, and Yugoslavia, approximately 800kms of river, before flowing into the Danube, impacting approximately 1200 km of river. The total fish kill was estimated at over 1000 metric tons of fish.

Carolina in 1990, when a dam failure resulted in the release of more than 10 million gallons of cyanide solution, causing fish kills for nearly 50 miles downstream of the operation. Regulatory authorities have responded by developing increasingly stringent regulations or non-mandatory guidelines which address the design of facilities that use cyanide (e.g., liners), operational concerns (e.g., monitoring, treatment), or closure/reclamation requirements.

Environmental Impacts. Cyanide can cause three major types of potential environmental impacts.

Free-standing Cyanide Solution. Cyanide-containing ponds and ditches can present an acute hazard to wildlife and birds. Tailings ponds may present similar hazards, although cyanide concentrations are typically much lower. Rarely in the case of abandoned mines should acute cyanide toxicity be of concern.

Release (i.e., spills) of Cyanide Solution. Spills can result in cyanide reaching surface water or ground water and causing short-term (e.g., fish kills) or long-term (e.g., contamination of drinking water) impacts. Again, because cyanide solution is not typically present at abandoned mine sites in quantities large enough to release as a spill, this type of impact is unlikely at abandoned mine sites.

Cyanide Leachate from Process or Waste units. Cyanide in active heaps and ponds and in mining wastes (e.g., heaps and dumps of spent ore, tailings impoundments) may be released and present hazards to surface water or ground water. In all but a few major cases, cyanide spills have been contained onsite, and soils have provided significant attenuation in most cases. Cyanide may also increase the potential for metals to go into solution and, therefore, be transported to other locations.

In general, cyanide is not considered a significant environmental impact concern over the long term for inactive or abandoned mines. If detoxification and reclamation are effectively performed, most residual cyanide in closed heaps and impoundments will be strongly complexed with iron. Although the stability of such complexes over long periods is not well understood, cyanide is generally considered to be much less of a long-term problem than acid generation, metals mobility, and other types of environmental impacts.

Types of Cyanide. Some basic knowledge of the different forms of cyanide is necessary to understand regulatory standards and remediation activities. Cyanide concentrations are generally measured as one of the following four forms:

Free Cyanide. Free cyanide refers to the cyanide that is present in solution as CN or HCN and includes cyanide-bonded sodium, potassium, calcium, or magnesium (free cyanide is very difficult to measure except at high concentrations and its results are often unreliable, difficult to duplicate, or inaccurate).

Weak Acid Dissociable (WAD) Cyanide. WAD cyanide is the fraction of cyanide that will volatilize to HCN in a weak acid solution at a pH of 4.5. WAD cyanide includes free cyanide, simple cyanide, and weak cyanide complexes of zinc, cadmium, silver, copper, and nickel.

Total Cyanide. Total cyanide refers to all of the cyanide present in any form, including iron, cobalt, and gold complexes.

Cyanide Amenable to Chlorination (CATC). CATC cyanide refers to the cyanide that is destroyed by chlorination. CATC is commonly used at water treatment plants.

Free cyanide is extremely toxic to most organisms, and this form has been most frequently regulated (i.e., EPA established a maximum contaminant level [MCL] under the Safe Drinking Water Act and recommended an ambient water quality criterion for protection of freshwater aquatic life under the Clean Water Act). Mining-related standards and guidelines developed more recently by states often specify WAD cyanide, largely because of the difficulty in measuring free cyanide at the low concentrations of regulatory concern. Longer term environmental concerns with cyanide, those not related to acute hazards from spills, revolve around the dissociation into toxic free cyanide of complexed cyanides in waste units and the environment. Unsaturated soils provide significant attenuation capacity for cyanide. Within a short time and distance, for example, free cyanide can volatilize to HCN if solutions are buffered by the soil to a pH roughly below 8. Adsorption, precipitation, oxidation to cyanate, and biodegradation can also attenuate free cyanide in soils under appropriate conditions. WAD cyanide behavior is similar to that of free, although WAD cyanide also can react with other metals in soils to form insoluble salts.

3.6 Air Emission and Downwind Deposition

Particulate material (PM) and gaseous emissions are emitted during mining, beneficiation, and mineral processing (refer to Chapter 2 for details about mining processes and associated waste). Gaseous emissions are generated by process operations, primarily those using heat to treat or convert ores or concentrates (e.g., roasting or smelting). Generally, particulate releases are flue dusts (e.g. from sinter, roaster, smelter, or refinery stacks) or fugitive dust (e.g. from crushers, tailings ponds, road use).

Highlight 3-7
The Bunker Hill Area

The Bunker Hill Mining and Metallurgical Complex Superfund site is an example of a mining site affected by airborne pollutants. The complex includes the Bunker Hill Mine (lead and zinc), a milling and concentration operation, a lead smelter, a silver refinery, an electrolytic zinc plant, a phosphoric acid and phosphate fertilizer plant, sulfuric acid plants, and a cadmium plant. EPA has since demolished and capped the smelter complex. The major environmental problems at the Site were caused by smelter operations and mining and milling. The smelter discharged heavy metal particulates and gases, particularly sulphur dioxide, to the atmosphere. Prior to the l970's, recovery of heavy metal particulates, such as zinc and lead, was not required from smelter stacks. Instead, tons of metal particulates were emitted directly from the stack into the atmosphere. The lead and zinc plant stacks historically used baghouses and electrostatic precipators to capture particulates for recovery of valuable metals. Because of a fire and subsequent problems with the baghouses, the plant continued to emit these particulates during the early-to-mid 1970's. Significant ecological damage has occurred in the areas surrounding the site. Soils near the smelting complex have been severely impacted by years of sulfur dioxide impact and metals deposition. The hillsides around the smelter complex were denuded of vegetation due, in part, to the smelter and mining activity. In response, 3,200 acres of hillside have been replanted since 1990.

The remediation of impacts caused by gaseous and particulate emissions from process units typically focuses on contaminated soils associated with downwind deposition. At abandoned mine sites, the processes that were the source of the emissions typically have either ceased operation or installed air pollution controls, therefore continued deposition is unlikely. Fugitive dust may still, however, be emitted from unstabilized waste management units and contaminated sites or from transportation and remediation activities.

Gaseous Emissions. Pyrometallurgical processes often generate gaseous emissions that are controlled to some extent under current regulations. In the past, these gaseous releases were typically not well controlled, and the emissions were blown downwind in the release plume. Some gaseous emissions, such as sulfur dioxide, affect the downwind environments through acid precipitation or dry deposition. Metals such as zinc, arsenic, mercury and cadmium are metals that will vaporize when heated in a pyrometallurgical process unit. In retort processing, these metals are captured as gas, then condensed, and the metal processed for use. In the absence of capture and condensation, the gaseous metals are released and condensed downwind from the release plume. Zinc released historically from smelters has had significant impacts on downwind biota as it is phytotoxic at high concentrations. Arsenic also has significant impacts downwind, primarily on faunal receptors.

Particulate Emissions. In the past, emissions from process operations, such as smelting and roasting, were not well controlled and, together with tailings deposition, caused some of the most widespread contamination. Metal smelting, in the absence of adequate air pollution controls, emitted particulates high in lead and other metal contaminants from smoke stacks that would then settle out of the air stream. Although deposition at any distance may have been at a relatively low concentration (particularly as stacks became higher), the long period of deposition (i.e., from decades in some cases to over a century in others) and the biostability of metals have created soil contamination problems of significant proportions. With the advent of air pollution regulations and subsequent air pollution controls (APC), smelter flue residues were deposited onsite in waste piles or landfills. These wastes often have high metal concentrations, high enough that, when technically feasible, the dusts may be returned to the smelter to recover the metal value.

Fugitive Dust. Fugitive dust is produced from mining operations (e.g., blasting), transportation (e.g., loading equipment, haul vehicles, conveyors), comminution (e.g., crushing and grinding), and waste management operations (i.e., waste rock dumping). Wind also entrains dust *from* dumps and spoil piles, roads, tailings, and other disturbed areas. Dust problems from tailings, in particular, may not appear until after closure/abandonment, when the waste material dries out. Only then may high levels of metals (arsenic, for example) trigger concerns. Tailings and waste rock at metal mines usually contain trace concentrations of heavy metals that may be released as fugitive dust to contaminate areas downwind as coarse particles settle out of suspension in the air. Stabilization and reclamation efforts are aimed in part at reducing fugitive dust emissions; remediation often must address the downwind soil contamination.

3.7 Physical Impacts from Mine and Waste Management Units

Mine structures and waste management units pose a unique set of problems for a site manager in planning and conducting remediations at mine sites. Structural problems with the waste units and the mines must be considered from a perspective of both ensuring the safety of remediation workers and alleviating environmental impacts that would result from structural failure and a subsequent release of contaminants.

Slope Failure. Slopes at mine sites fall into two categories: cut slopes and manufactured or filled slopes. The methods of slope formation reflect the hazards associated with each. Cut slopes are created by the removal of overburden and/or ore which results in the creation of or alteration to the surface slope of undisturbed native materials. Changes to an existing slope may create environmental problems associated with increased erosion, rapid runoff, changes in wildlife patterns and the exposure of potentially reactive natural materials. Dumping or piling of overburden, tailings, waste rock or other materials creates manufactured or filled slopes. These materials can be toxic, acid forming, or reactive. Slope failure can result in direct release or direct exposure of these materials to the surrounding environment. Saturation of waste material can also trigger slope failure.

Structural Stability of Tailings Impoundments. The most common method of tailings disposal is placement of tailings slurry in impoundments formed behind raised embankments. Modern tailings impoundments are engineered structures that serve the dual functions of permanent disposal of the tailings and conservation of water for use in the mine and mill. Today, many tailings impoundments are lined to prevent seepage, this is rarely the case at historic mine sites. In addition, modern tailings impoundments are designed to accommodate earthquake acceleration.

The historic disposal of tailings behind earthen dams and embankments raises a number of concerns related to the stability of the units. In particular, tailings impoundments are nearly always accompanied by unavoidable and often necessary seepage of mill effluent through or beneath the dam structure. Such seepage results from the uncontrolled percolation of stored water or precipitation downward through foundation materials or through the embankment. Failure to maintain hydrostatic pressure within and behind the embankment below critical levels may result in partial or complete failure of the structure, causing releases of tailings and contained mill effluent to surrounding areas. Since most modern mines recycle waste from impoundments back to the process, the cessation of this recycling at the closure/abandonment has to be accompanied by other means to maintain safe levels of hydrostatic pressure.

Structural stability depends on the physical characteristics of the waste material (e.g., percent slimes vs. sands in impoundments), the physical configuration of the waste unit, and site conditions (e.g., timing and nature of precipitation, upstream/uphill area that will provide inflows).

Subsidence. Mining subsidence is the movement of the surface resulting from the collapse of overlying strata into mine voids. The potential for subsidence exists for all forms of underground mining. Subsidence may manifest itself in the form of sinkholes or troughs. Sinkholes are usually associated with the collapse of a portion of a mine void (such as a room in room and pillar mining); the extent of the surface disturbance is usually limited in size. Troughs are formed from the subsidence of large portions of the underground void and typically occur over areas where most of the resource has been removed.

Effects of subsidence may or may not be visible from the ground surface. Sinkholes or depressions in the landscape interrupt surface water drainage patterns; ponds and streams may be drained or channels may be redirected. Farmland can be affected to the point that equipment cannot conduct surface preparation activities; irrigation systems and drainage tiles may be disrupted. In developed areas, subsidence has the potential to affect building foundations and walls, highways, and pipelines. However, metal mines are often located in remote areas where there is a lack of development, minimizing this risk. Subsidence can contribute to increased infiltration to underground mines, potentially resulting in increased AMD generation and a need for greater water treatment capacity in instances where mine drainage must be treated. Ground water flow may be interrupted as impermeable strata break down and could result in flooding of the mine voids. Impacts to ground water include changes in water quality and flow patterns (including surface water recharge).

Structures. Structures at mining and mineral processing sites can be a physical hazard for investigative and remediation workers and contain quantities of contaminates. For example, buildings at many mining and mineral processing sites were just shut down when the facility stopped production with the hope that production would be restarted. Because of this many buildings may contain both chemicals used in the process in containers that are no longer intact or quantities of material, such as flue dust or feed product that contain high concentrations of contaminates. In addition to the materials contained in the structure, the structure may be unsafe due to time, weather, and the exposures that occurred during operations, such as the heat of a smelting operations or acid spills from an acid plant.

Mine Openings. Mine openings, both horizontal and vertical, can be a significant physical hazard at an abandoned mine site. In many cases the openings are well known and are a threat to the general population, since the adventurous want to enter them and explore. These mine openings may harbor an number of physical hazards that can injure or kill those who enter, including unstable ground that could collapse or bad air, either insufficient oxygen or containing poisonous gases, such as carbon monoxide. The other physical hazard from mine openings are those that are unknown, particularly vertical shafts. If the opening has been covered, either by an old collapsed building or vegetation, they may pose the threat of falling, sometimes hundreds of feet, to individuals or wildlife who may get to close to the obscured opening.

3.8 Sources of Additional Information

To more fully understand the broad environmental impacts found at mining and mineral processing sites that are on the NPL see Appendix C - Mining Sites on the NPL. Appendix B provides further discussion of acid rock discharge (ARD) and acid mine discharge (AMD) including an annotated bibliography.

(This Page intentionally left blank)