APPENDIX B

POTENTIAL ENVIRONMENTAL IMPACTS OF HARDROCK MINING

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1. Introduction: The Nature of Mining Sources

Hardrock mining, as described in Appendix A, is a large-scale industrial activity that takes place in the natural environment potentially disturbing large amounts of material and land area. Large volumes of mining waste are generated because of the high waste-to-product ratios associated with producing most ores. "Waste" is defined as the leftover material generated as a result of mining and benefication activities used to recover a target mineral. Most of the materials handled in mining are wastes, or non- marketable products, distinguishing the industry from others that generate less waste in comparison to those materials used in the final product. Consequently, operations at some of the larger mine sites handle more material and generate more waste than many entire industries.

This appendix describes potential environmental effects of hardrock mining. EPA recognizes that some of the discussion in this appendix may not accurately reflect the environmental conditions at modern hardrock mining operations that are well designed, well operated, and well regulated. The intent of the discussion is to highlight environmental problems at (predominantly historic) mining sites and to suggest that these are potential problems that could occur at existing and future sites. In addition, there is some repetition in the following sections resulting from the inter-related nature of impacts (for example, the fact that erosion and sedimentation are relevant both to water quality and aquatic ecosystem quality). Following a brief section that recaps some of the discussion from Appendix A, successive sections describe several of the major impacts of mining operations.

Overview of operations and major pollutant sources. At mining sites, the major pollutant sources of concern include waste rock/overburden disposal, tailings, heap leaches/dump leaches, and mine water. Waste rock/overburden is the soil and rock mining operations move during the process of accessing an ore or mineral body. It also includes rock removed while sinking shafts, and accessing or exploiting the ore body and rock bedded with the ore. The size of the waste rock ranges from small clay particles to boulders. Waste rock can be used as backfill in previously excavated areas or transported off-site and used at construction projects. However, most of the waste rock generated is disposed of in piles near the mine site.

Tailings are the waste solids remaining after beneficiation of ore through a variety of milling processes. After the ore is extracted from the mine, the first step in beneficiation is generally crushing and grinding. The crushed ores are then concentrated to free the valuable mineral and metal particles from the less valuable rock. Beneficiation processes include physical/chemical separation techniques such as gravity concentration, magnetic separation, electrostatic separation, flotation, solvent extraction, electrowinning, leaching, precipitation, and amalgamation. Conventional beneficiation processes generate tailings, which generally leave the mill as a slurry consisting of 40 to 70 percent liquid and 30 to 60 percent solids. Most mine tailings are disposed of in onsite impoundments, such as tailing ponds.

Leaching is another beneficiation process commonly used to recover certain metals, including gold, silver, copper, and uranium, from their ores. In dump leaching, the material to be leached is generally placed (or is already located) directly on the ground and a leaching solution is applied to the material. The type of leaching solution used depends on the characteristics of the ore and the mineral. As the liquid percolates through the ore, it leaches out metals. Leaching may recover economic quantities for years or decades. Dump leach piles can be very large, often covering hundreds of acres. Heap leaching (as distinguished from dump leaching) is used for higher trade (more valuable) ores and is generally smaller than dump leach operations. Almost invariably, there are one or more impermeable liners under the leach material to maximize recovery of the leachate. Heap leaching often takes place over months rather than years. When leaching no longer produces economically attractive quantities of valuable metals, the spent ore is left in place (or nearby) after rinsing or other detoxification.

Long-Term Nature of Mining Impacts. Closure of a mining operation occurs during temporary shutdown of operations or permanent decommissioning of the facilities. During downturns in metals markets and cash flows, temporary shutdowns can reduce the expenditures necessary to maintain environmental controls (roads and diversions erode, siltation ponds and spillways deteriorate even as they are filling and losing treatment capacity). Although reclamation is often thought of as involving only regrading and revegetation, permanent closure now includes such actions as removal/disposal of stored fuels and chemicals, structure tear down, removal of roadways and ditches, sealing of adits, capping of tailings, waste detoxification and final removal of sediment control structures and/or reestablishment of drainage ways. Long-term maintenance is required in many closure situations, such as equipment fueling and lubrication after normal maintenance facilities have been removed, water diversions, dam stability, water treatment, and treatment sludge management. Without accrued funds or other cash flows to cover these expenses, there can be substantial risk of inadequate attention to proper site closure. Reclamation cost estimates--and bonds--are still sometimes based primarily on regrading and revegetation, and thus can easily underestimate true closure expenses.

The long-term nature of mining impacts requires that predictive tools, design performance, monitoring, and financial assurance be effective for many decades. For example, negative changes in geochemistry over time can occur when a materials' environment changes (e.g., going from a reducing environment to an oxidizing one) or buffering capacity is exceeded (such as when the total neutralizing capacity of a rock mass is exceeded by acid generation). When these conditions are present, problems can develop well into, or after, a facility's operating life. Predictive tools can help mitigate potential problems by factoring control measures into facility designs and operating plans, while design/operation can be modified based on monitoring. Financial assurance helps ensure that resources will be available to address long-term mine water and site management.

Complicating the effective environmental control at mining sites is the interrelationship between the extraction, beneficiation, and processing of the ore material and the waste materials generated from each of these operations. Together, mining operations and the pollutant sources of concern can affect surface and ground water quality, create hydrologic impacts, decrease air quality, contaminate soils, and diminish ecosystem quality. The major categories of environmental problems encountered from mining are discussed briefly below. The following sections describe surface water quality, ground water quality, hydrologic impacts, physical stability, air quality, soils, and terrestrial and aquatic habitat/ecosystem quality issues.

2. SURFACE WATER QUALITY ISSUES

One of the problems that can be associated with mining operations is the release of pollutants to surface waters. Many activities and sources associated with a mine site can contribute toxic and nontoxic materials to surface waters. Open pits, tailings ponds, ore and subore stockpiles, waste rock dumps, and heap and dump leach piles are all potentially significant sources of toxic pollutants. The mobility of the pollutants from these sources is magnified by exposure to rainfall and snowfall. The eventual discharge of surface runoff, produced from rainfall and snow melt, is one mechanism by which pollutants are released into surface waters. Seepage from impoundment areas and ground water originating from open pits and mine openings is another example by which heavy metals can be mobilized and eventually released to surface waters. Releases of pollutants to surface waters may also occur indirectly via ground water that has a hydrological connection to surface water.

Impacts to surface waters include the buildup of sediments that may be contaminated with heavy metals or other toxics, short- and long-term reductions in pH levels (particularly for lakes and reservoirs), destruction or degradation of aquatic habitat, and contamination of drinking water supplies and other human health issues.

Acid Drainage. It is generally acknowledged that a major environmental problem facing the U.S. mining industry is the formation of acid drainage and the associated mobilization of contaminants. Commonly called acid mine drainage (AMD) or acid rock drainage (ARD), acid drainage primarily depends on the mineralogy of the rock material and the availability of water and oxygen. Acid drainage is generated at both abandoned and active mine sites. Although testing methods used to predict AMD have improved in recent years, there is often substantial uncertainty, and new mines can develop unpredicted AMD after only a few years of operation.

The potential for a mine or its associated waste to generate acid and release contaminants depends on many site-specific factors. AMD occurs at mine sites when metal sulfide minerals are oxidized. Metal sulfide minerals are common constituents in the host rock associated with metal mining activity. Before mining, oxidation of these minerals and the formation of sulfuric acid is a (slow) function of natural weathering processes. Natural discharge from such deposits poses little threat to aquatic ecosystems except in rare instances. Mining and beneficiation operations greatly increase the rate of these same chemical reactions by removing sulfide rock material and exposing the material to air and water. Once acid drainage has occurred, controlling the releases is a difficult and costly problem, so prediction is becoming an important tool for regulators and operators.

Materials and wastes from metal mining activities that have the potential to generate acid drainage include spent ore from heap and dump leach operations, tailings, waste rock, and overburden material. Equally or more important at some sites are the pit walls at surface mining operations and the underground workings associated with underground mines.

Acid generation is largely the result of oxidation of metallic sulfides. The major metallic sulfide of concern is iron sulfide (FeS_2), or pyrite. All metal sulfides and reduced mineral species can potentially contribute to acid generation. Metal sulfides besides pyrite that contribute to acid generation include galena (lead sulfide), sphalerite (zinc sulfide) and chalcopyrite (iron copper sulfide).

Both water and oxygen are necessary to generate acid drainage. Water serves as both a reactant and a medium for bacteria to catalyze the oxidation process. Water also transports the oxidation products. A ready supply of atmospheric oxygen is required to drive the oxidation reaction. Oxygen is particularly important to maintain the rapid bacterially catalyzed oxidation at pH values below 3.5. Oxidation is significantly reduced when the concentration of oxygen in the pore space of mining waste units is less than 1 or 2 percent. The type of bacteria and the population necessary to catalyze oxidation change as pH levels, chemical and physical characteristics of the soil and water environments change (Ferguson and Erickson, 1988).

Other factors affecting acid drainage are the physical characteristics of the material, the placement of the acid-generating and any acid-neutralizing materials (whether naturally occurring in the material or supplemental), and the climatologic and hydrologic regime in the vicinity. The physical characteristics of the material, such as particle size, permeability, and weathering characteristics, are important to the acid generation potential. Particle size is a fundamental concern since it affects the surface area exposed to weathering and oxidation: smaller particles have more surface area and therefore more reactive sites than larger particles. The relationships between particle size, surface area, and oxidation play a prominent role in acid prediction methods.

The hydrology of the area surrounding mine workings and waste units is important in the analysis of acid generation potential. Wetting and drying cycles in any of the mine workings or other waste units will affect the character of any produced acid drainage. Frequent wetting will generate a more constant volume of acid and other contaminants as water moves through and flushes oxidation products out of the system. The buildup of contaminants in the system is proportional to the length of time between wetting cycles. As the length of the dry cycle increases, oxidation products will accumulate in the system. A high magnitude wetting event will then flush the accumulated contaminants out of the system. This relationship is typical of the increase in the contaminant load observed following heavy precipitation for those areas having a wet season. In underground mines, however, the acid generating material occurs below the water table and the slow diffusion of oxygen in water can retard acid production.

During acid generation, the pH values of the associated waters typically decrease to values near 2.5. These conditions result in the dissolution of the minerals associated with the metallic sulfides and release of toxic metal cations (e.g., lead, copper, silver, manganese, cadmium, iron, and zinc). In addition, the concentration of dissolved anions (e.g., sulfate) also increases.

Acid generation and drainage affect both surface and ground water. The sources of surface water contamination are leachate from mine openings, seepage and discharges from waste rock or tailings or spent ore, ground water seepage, and surface water runoff from waste rock and tailings piles. It should also be noted that mined materials--waste rock or tailings--used for construction or other purposes (e.g., road beds, rock drains, fill material) or off a mine site can also develop acid drainage.

The receptors of contaminated surface water include aquatic birds, fish and other aquatic organisms, and humans. Direct ingestion of contaminated surface water or direct contact through outdoor activities such as swimming can affect humans. Fish, birds, and other aquatic organisms are potentially affected by bottom foraging and direct exposure to surface water.

No easy or inexpensive solutions to acid drainage exist. Two primary approaches to addressing acid generation are 1) avoiding mining deposits with high acid generating potential and 2) isolating or otherwise special-handling wastes with acid generation potential. In practice, avoiding mining in areas with the potential to generate acids may be difficult due to the widespread distribution of sulfide minerals. Isolation of materials with the potential to generate acids is now being tried as a means of reducing the perpetual effects to surface water and ground water from mining wastes. Control of materials with a potential for acid generation can be implemented by preventing or minimizing oxygen from contacting the material, preventing water from contacting the material, and/or ensuring that an adequate amount of natural or introduced material is available which can neutralize any acid produced. Techniques used to isolate acid generating materials include subaqueous disposal, covers, waste blending, hydrologic controls, bacterial control, and treatment.

Acid generation prediction tests are increasingly relied upon to assess the long-term potential of a material, or waste, to generate acid. Mineralogy and other factors affecting the potential for AMD formation are highly variable from site to site, and this can result in difficult, costly, and questionable predictions. In general, the methods used to predict the acid generation potential are classified as either static or kinetic. These tests are not intended to predict the rate of acid generation, only the potential to produce acid. Static tests can be conducted quickly and are inexpensive compared with kinetic tests. Kinetic tests are intended to mimic the processes found in the waste unit environment, usually at an accelerated rate. These tests require more time and are much more expensive than static tests.

Cyanide Heap Leaching. For over a century, the mining industry has used cyanide as a pyrite depressant in base metal flotation and in gold extraction. Continued improvements in cyanidation technology have allowed the economic mining of increasingly lower-grade gold ores. Together with continued high gold prices, these improvements have resulted in increasing amounts of cyanide being used in mining. The mining industry now uses much of the sodium cyanide produced in the United States, with more than 100 million pounds used by gold/silver leaching operations in 1990.

Aqueous cyanide (CN^-) has a negative valence and reacts readily to form more stable compounds. Aqueous cyanide complexes readily with metals in the ore, ranging from readily soluble complexes such as sodium and calcium cyanide, to the complexes measured by weak acid dissociable (WAD) cyanide analytical methods, to strong complexes such as iron-cyanide. At a pH below 9, weaker cyanide compounds can dissociate and form HCN, a volatile poison gas that rapidly evaporates at atmospheric pressure. The stronger complexes are generally very stable in natural aqueous conditions.

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 below 8. Adsorption, precipitation, oxidation to cyanate, and biodegradation can also attenuate free (and dissociated complexed) cyanide in soils under appropriate conditions. WAD cyanide behavior is similar to that of free cyanide except WAD cyanide also can react with other metals in soils to form insoluble salts.

Many other constituents besides cyanide may be present in the waste material, creating potential problems following closure and reclamation. Nitrate (from cyanide degradation) and heavy metals (from trace heavy metals in the ore) migrations are examples of other significant problems that can be faced at the closure of cyanide operations.

Water balance is a major concern at some sites. In arid regions, with limited water resources, the amount of water necessary to rinse heaps to a required standard could be a significant concern. Conversely, in wet climates like South Carolina, excess water from heavy precipitation and/or snow melt can place a strain on system operations and may make draining or revegetating a heap or impoundment very difficult.

In addition, the chemistry of a spent heap or tailings impoundment may change over time. Although effluent samples at closure/reclamation may meet state requirements, the effluent characteristics may be dependent on the pH. Factors affecting chemical changes in a heap or tailings impoundment include pH, moisture, mobility, and geochemical stability of the material. The principal concerns with the closure of spent ore and tailings impoundments are long-term structural stability and potential to leach contaminants. 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) influence structural stability.

The acute toxicity of cyanide, and many major incidents, have focused attention on the use of cyanide in the mining industry. When exposure occurs (e.g., via inhalation or ingestion), cyanide interferes with many organisms' oxygen metabolism and can be lethal in a short time.

Overall, cyanide can cause three major types of environmental impacts: first, cyanide-containing ponds and ditches can present an acute hazard to wildlife and birds. Tailings ponds present similar hazards, but less frequently (because of lower cyanide concentrations). Second, spills can result in cyanide reaching surface water or ground water and cause short-term (e.g., fish kills) or long-term (e.g., contamination of drinking water) impacts. Finally, cyanide in active heaps, ponds and in mining wastes, primarily spent ore heaps, dumps and tailings impoundments, may be released and present hazards to surface water or ground water. Geochemical changes can also affect the mobility of heavy metals.

Through the 1980s, as cyanidation operations and cyanide usage proliferated, many incidents occurred where waterfowl died after using tailings ponds or other cyanide-containing solution ponds (e.g., pregnant or barren ponds). Operators in Nevada, California, and Arizona reported to regulatory authorities more than 9,000 wildlife deaths, mostly waterfowl, that had occurred on federal lands in those states from 1984 through 1989. In addition, many major spills have occurred, the most significant occurring in South 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.

The heightened awareness of the threat to wildlife presented by cyanide-containing ponds and wastes led federal land managers and states to develop and implement increasingly stringent regulations or, more often, non-mandatory guidelines. These regulations and/or guidelines address the design of facilities that use cyanide (e.g., requiring/recommending liners and site preparation for heap leach piles or tailings impoundments), operational concerns (e.g., monitoring of solutions in processes and in ponds, and sometimes treatment requirements for cyanide-containing wastes), and closure/reclamation requirements (e.g., rinsing to a set cyanide concentration in rinsate before reclamation can begin). Operators are generally required to take steps either to reduce/eliminate access to cyanide solutions or to reduce cyanide concentrations in exposed materials to below lethal levels. Regulatory requirements and guidelines as to the allowable concentration of cyanide in exposed process solutions are widely variable (when numeric limitations are established, they generally range around 50 mg/l), as are the means by which operators comply. Operators reduce access in several ways, including covering solution ponds with netting or covers, using cannons and other hazing devices (e.g., decoy owls) to scare off waterfowl and other wildlife, and/or installing fencing to preclude access by large wildlife.

Closure and reclamation measures are becoming increasingly well established for cyanide heap leaching operations but are not entirely proven because of their recent use. Closure entails those activities conducted after a cyanide unit ceases operating in order to prepare the site for reclamation. Closure essentially consists of those activities required to remove a hazard or undesirable component, whether it is chemical or physical, to the extent required by states or federal land managers. It can entail detoxification/neutralization of wastes, treatment and/or evaporation of rinse liquids and pond water, dismantling associated equipment and piping, removal or treatment of waste, reconstruction, grading or stabilizing, and/or chemical testing. Reclamation consists of those activities undertaken to return the site to a condition suitable for the future uses specified by the state or federal land manager. Reclamation may involve regrading; backfilling ponds; removal of wastes; site drainage control such as diversions, channels, riprap, and collection basins; perforating liners to allow drainage through heaps; capping to reduce infiltration and/or to provide a substrate for revegetation; and revegetation to establish ground cover and protect against erosion.

Metals and Dissolved Pollutants. Dissolved pollutants (primarily metals, sulfates, and nitrates) can migrate from mining operations to local ground and surface water. While AMD can enhance contaminant mobility by promoting leaching from exposed wastes and mine structures, releases can also occur under neutral pH conditions. 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, runoff, and seepage are the primary transport mechanisms to surface water and ground water.

One potential source of dissolved pollutants is chemical usage in mining and beneficiation. Common types of reagents include copper, zinc, chromium, cyanide, nitrate and phenolic compounds, and, at copper leaching operations, sulfuric acid. Except for leaching operations and possibly the extensive use of nitrate compounds in blasting and reclamation, the quantities of reagents used are very small compared with the volumes of water generated. As a result, the risks from releases of toxic pollutants from non-leaching-related reagents are generally limited.

Naturally occurring substances in the ore create a major source of pollutants. Mined ore not only contains the mineral being extracted but varying concentrations of a wide range of other minerals, including radioactive minerals. Frequently other minerals may be present at much higher concentrations and can be much 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, as well as naturally occurring radioactive materials.

The occurrence of specific pollutants, their release potential, and the associated risks are highly dependent on facility-specific conditions, including: design and operation of extraction and beneficiation operations, waste and materials management practices, extent of treatment/mitigation measures, the environmental setting (including climate, geology, hydrogeology, waste and ore mineralogy and geochemistry, etc.) and nature of and proximity to human and environmental receptors.

EPA's 1986 *Quality Criteria for Water* (EPA 440/5-86-001) provides information on the acute and chronic impacts of dissolved pollutants in surface water (including suggested water quality standards). Each state has promulgated water quality criteria for surface waters based on the designated uses of the waters and has established guidelines on how to apply the standards. Regulators and operators have to be aware that, unlike many other types of industrial operations and discharges, toxic constituent loadings from mining operations can be extremely variable, from day to day, over months, and/or years. Furthermore, the receiving water may be particularly sensitive to loadings of toxic pollutants during specific periods (e.g., under certain flow conditions).

Dissolved pollutants discharged to surface waters can partition to sediments. Specifically, some toxic constituents (e.g., lead and mercury) associated with discharges from mining operations are often found at elevated levels in sediments, while undetected in the water column. Sediment contamination may affect human health through consumption of fish that bioaccumulate toxic pollutants. Furthermore, elevated levels of toxic pollutants in sediments can have direct acute and chronic impacts on macroinvertebrates and other aquatic life. Finally, sediment contamination provides a long-term source of pollutants through potential redissolution in the water column.

Erosion and Sedimentation. Because of the large area of land disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion can be a major concern at hardrock mining sites. Consequently, erosion control must be considered from the beginning of operations through completion of reclamation. Erosion may cause significant loadings of sediments (and any entrained chemical pollutants) to nearby waterbodies, especially during severe storm events and high snow melt periods.

Sediment-laden surface runoff typically originates as sheet flow and collects in rills, natural channels or gullies, or artificial conveyances. The ultimate deposition of the sediment may occur in surface waters or it may be deposited within the flood plains of a stream valley. Historically, erosion and sedimentation processes have caused the buildup of thick layers of mineral fines and sediment within regional flood plains and the alteration of aquatic habitat and the loss of storage capacity within surface waters. The main factors influencing erosion includes the volume and velocity of runoff from precipitation events, the rate of precipitation infiltration downward through the soil, the amount of vegetative cover, the slope length or the distance from the point of origin of overland flow to the point where deposition begins, and operational erosion control structures.

Major sources of erosion/sediment loadings at mining sites can include open pit areas, heap and dump leaches, waste rock and overburden piles, tailings piles and dams, haul roads and access roads, ore stockpiles, vehicle and equipment maintenance areas, exploration areas, and reclamation areas. A further concern is that exposed materials from mining operations (mine workings, wastes, contaminated soils, etc.) may contribute sediments with chemical pollutants, principally heavy metals. 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.

The types of impacts associated with erosion and sedimentation are numerous, typically producing both short-term and long-term impacts. In surface waters, elevated concentrations of particulate matter in the water column can produce both chronic and acute toxic effects in fish. The buildup of sediment in stream beds also destroys benthic macroinvertebrate habitat by smothering and filling pore spaces between cobbles while simultaneously reducing suitable fish spawning areas. Over the long-term, bio-geochemical reactions in deposited contaminated sediments may result in resuspension of dissolved forms (possibly bioaccumulative) of heavy metals into the water column. Contaminated sediments in surface waters may be a persistent source of toxics thus a chronic threat to aquatic organisms and/or human health. Exposure may occur through direct contact, consumption of fish/shellfish, or drinking water exposed to contaminated sediments. 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.

Sediments deposited in layers in flood plains or terrestrial ecosystems can produce many impacts associated with surface waters, ground water, and terrestrial ecosystems. Minerals associated with deposited sediments may depress the pH of surface runoff thereby mobilizing heavy metals that can infiltrate into the surrounding subsoil or can be carried away to nearby surface waters. The associated impacts could include substantial pH depression or metals loadings to surface waters and/or persistent contamination of ground water sources. Contaminated sediments may also lower the pH of soils to the extent that vegetation and suitable habitat are lost.

Beyond the potential for pollutant impacts on human and aquatic life, there are potential physical impacts associated with the increased runoff velocities and volumes from new land disturbance activities. Increased velocities and volumes can lead to downstream flooding, scouring of stream channels, and structural damage to bridge footings and culvert entries.

In areas where air emissions have deposited acidic particles and the native vegetation has been destroyed, runoff has the potential to increase the rate of erosion and lead to removal of soil from the affected area. This is particularly true where the landscape is characterized by steep and rocky slopes. Once the soils have been removed, it is difficult for the slope to be revegetated either naturally or with human assistance.

Particulate matter, entrained in water currents, can be toxic to fish. Decreased densities of macroinvertebrate and benthic invertebrate populations have been associated with increased suspended solids. Enhanced sedimentation within aquatic environments also inhibits spawning and the development of fish eggs and larvae, and smothering of benthic fauna. In addition, high turbidity may impair the passage of light, which is necessary for photosynthetic activity of aquatic plants.

Two options exist for reducing erosion and the off-site transport of sediment: end-of-pipe treatment and implementing best management practices to prevent or to eliminate pollution. The selection of the most effective means to control erosion is based on site-specific considerations such as: facility size, climate, geographic location, geology/hydrology and the environmental setting of each facility, and volume and type of discharge generated. Each facility will be unique in that the source, type, and volume of contaminated discharges will differ. The fate and transport of pollutants in these discharges will also vary. Mining facilities are often in remote locations and may operate only seasonally or intermittently, yet need year-round controls because pollutant sources remain exposed to precipitation when reclamation is not completed. At least six categories of best management practice options are available to limit erosion and the off-site transport of sediment, including discharge diversions; drainage/storm water conveyance systems; runoff dispersion; sediment control and collection; vegetation and soil stabilization; and capping of contaminated sources.

3. GROUND WATER QUALITY

Ground water impacts due to mining are not as widespread as surface water impacts because of the much slower velocity of ground water movement, the more limited extent of many affected aquifers, and the lack of available oxygen to continue the oxidation process. Nevertheless, the fact that ground water contamination is extremely difficult to remedy once it occurs makes it a serious concern.

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. Finally, the ground water may recharge surface water downgradient of the mine, through contributions to base flow in a stream channel or springs.

The ability of pollutants to dissolve and migrate from materials or workings to ground water varies significantly depending on the constituent of concern, the nature of the material/waste, the design of the management, soil characteristics, and local hydrogeology (including depth, flows, and geochemistry of the underlying aquifers). Risks to human health and the environment from contaminated ground water usage vary with the types of and distance to local users. In addition, impacts on ground water can also indirectly affect surface water quality (through recharge and/or seepage).

Zinc and other base and precious metals were produced from ores excavated from an 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 (Superfund) and various remedial actions have been proposed.

4. HYDROLOGIC IMPACTS

Mining operations themselves are a critical part of environmental control because they interact with the site hydrology. Mine design not only impacts day-to-day operations, but also closure and post-closure conditions. Mine design, and location, can affect the following site conditions, which in turn can result affect environmental performance.

- Regional surface and ground water movement.
- Ground water inflow into the mine, with subsequent contact with mining related pollutants.
- Surface water inflow and precipitation related recharge.
- Increases in surface and ground water interaction with the mine workings because of subsidence.
- Loss of surface features such as lakes through subsidence.
- Pathways for post closure flow resulting from adits, shafts, and overall mine design.
- Operational and post closure geochemistry and resulting toxics mobility.
- Overall site water and mass balance.

Specifically, mine water, ground water withdrawal, and land subsidence can potentially create environmental problems that cannot be easily corrected.

Mine Water. Mine water is produced when the water table is higher than the underground mine workings or the depth of an open pit surface mine. When this occurs, the water must be pumped out of the mine. Alternatively, water may be pumped from wells surrounding the mine to create a cone of depression in the ground water table, thereby reducing infiltration. When the mine is operational, mine water must be continually removed from the mine to facilitate the removal of the ore. However, once mining operations end, the removal and management of mine water often end, resulting in possible accumulation in rock fractures, shafts, tunnels, and open pits and uncontrolled releases to the environment.

Ground Water Drawdown. Ground water drawdown and associated impacts to surface waters and nearby wetlands can be a serious concern in some areas, particularly in the Carlin Trend of northeastern Nevada. Several Carlin Trend gold mines are dewatering open pits; one mine is permitted to pump more than 60,000 gallons/minute. Cumulatively, the pumping could curtail flows in the Humboldt River and its tributaries and degrade or eliminate associated wetland areas. For example, Newmont Gold's South Operations project could result in impacts to 1,342 acres of riparian (river bank) habitat, 857 of which are jurisdictional waters of the United States. An additional 10 acres of seeps and springs at 25 different sites could also be affected. Ground water pumping at two of the largest 15 or so mines that are or will be dewatering in the area, the Newmont Gold's South Operations site and the nearby Barrick Gold Corporation's Betze Pit, could cumulatively affect a total of 2,700 acres of wetlands and riparian areas.

Impacts from ground water drawdown may include reduction or elimination of surface water flows; degradation of surface water quality and beneficial uses; degradation of habitat (not only riparian zones, springs, and other wetland habitats, but also upland habitats such as greasewood as ground water levels decline below the deep root zone); reduced or eliminated production in domestic supply wells; and erosion, sedimentation, and other water quality/quantity problems associated with discharge of the pumped ground water back into surface waters downstream from the dewatered area. The impacts could last for many decades. While dewatering is occurring, discharge of the pumped water, after appropriate treatment, can often be used to mitigate adverse effects on surface waters. However, when dewatering ceases, the cones of depression may take many decades to recharge and may continue to reduce surface flows in the Humboldt River and its tributaries. Mitigation measures that rely on the use of pumped water to create wetlands may only last as long as dewatering occurs.

Besides off-site habitat replacement, mitigation may include small-scale ground water pumping projects in the affected area to provide individual wetlands or stream segments with a continuous water supply. However, this must be carefully designed not to affect ground water and surface water adversely in the immediate area of pumping.

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

The threat and extent of subsidence is related to the method of mining employed. Typically, traditional room and pillar methods leave enough material in place to avoid subsidence effects. However, high-volume extraction techniques, such as pillar retreat, can increase the likelihood that subsidence will occur. At some mines, waste rock and/or stabilized tailings are backfilled in the mine to minimize subsidence.

Effects of subsidence may not be confined to or even 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. Ground water flow may be interrupted or disrupted as impermeable strata break down, and this could result in flooding of the mine voids. Impacts to ground water include changes in water quality and flow patterns, including surface water recharge.

5. PHYSICAL STABILITY

Physical stability of mine units is an important long term environmental concern because of the amounts of materials involved and the consequences of slope failure. Mining operations can result in the formation of slopes composed of earth, rock, tailings, other mine wastes, or combinations of materials. Other than sheer physical impacts, catastrophic slope failure can affect the environment or human health when toxic materials are released from the failure especially if it occurs in an area where such a release results in a direct pathway to receptors. Ensuring physical stability requires adequate pre-mining design of waste management units and may require long-term maintenance.

Mine slopes fall into two categories: natural or cut slopes and manufactured or filled slopes. The methods of slope formation reflect the hazards associated with each. Natural or cut slopes are created by the removal of overburden 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.

Slope failure results from exceeding the internal mass strength of the materials composing the slope. This occurs when the slope angle is increased to a point where the internal mass strength can no longer withstand the excess load resulting from over steepening or overloading of the slope. When the driving forces associated with over steepening exceed the internal resisting forces, the slope fails and the materials move to a more stable position.

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. The disposal of tailings behind earthen dams and embankments raises many concerns related to the stability and environmental performance of the units. In particular, tailings impoundments are frequently accompanied by unavoidable and often necessary seepage of mill effluent through or beneath the dam structure. Such seepage results from the percolation of stored water downward through foundation materials or through the embankment and the controlled release of water to maintain embankment stability. Impoundment seepage raises the probability of surface water and ground water contamination and, coupled with the potential for acid rock drainage, may require long-term water treatment well after the active life of the facility. Seepage from tailings impoundments can be reduced by construction of lined facilities, which is becoming more common in modern design and construction. Moreover, 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.

Tailings impoundments and the embankments that confine them are designed using information on tailings characteristics, available construction materials, site specific factors (such as topography, geology, hydrology and seismicity) and costs. Dynamic interplay among these factors influences the location (or siting) and actual design of the impoundment.

A primary concern in the design of tailings impoundments is the control of pore water pressure within and beneath the embankment. Excessive pore pressure within the embankment may lead to exceeding the sheer strength of the fill material, resulting in local or general slope failure. Additionally, high pore pressures within or beneath the embankment face may result in uncontrolled seepage at the dam face leading to piping failure. Similarly, seepage through weak permeable layers of the foundation may result in piping or exceeding soil shear strength, causing foundation subsidence and compromising the stability of the overlying embankment.

Embankment drainage systems also create a post-closure environmental concern. Contaminated effluent, possibly including acid rock drainage, may be released from the impoundment after the active life of the project because the impoundment is not designed to be impermeable. If the active pump-back system for the toe pond is no longer in operation, such effluent may be released to area surface water. Accordingly, treatment-in-perpetuity or some alternative passive treatment or containment method may be necessary to prevent surface water releases.

Another trade off between stability and environmental performance is the incorporation of liners. In areas of shallow alluvial ground water, liners may be necessary to prevent intrusion of water into the impoundment. However, such liners will simultaneously increase the retention of impounded water behind the dam and reduce dam stability, all else being equal. On the other hand, the absence of a liner may increase the downward migration of impoundment constituents to shallow ground water.

Surface water controls may be very important in post-closure stability considerations. Surface water runoff diversions are generally employed to limit the intrusion of excessive amounts of water into the impoundment, which reduces dam stability and prevents drying of tailings. Failure of surface water controls after impoundment closure could result in an increase in pore water pressure within the impoundment, threatening the stability of the embankment. Usually, active measures to control surface water runon and runoff during the operative life of the project may require alternative methods or long-term management after closure.

Many systems have been developed for monitoring movement of slopes. Inclinometers and slope indicators can be built into new slopes as part of construction or installed in existing slopes. Frequent monitoring of inclinometers and slope indicators can track the movement or lack of movement within a slope mass. The key becomes assessing the proper locations for monitoring systems and in interpreting the results of the monitoring systems. This monitoring program should be coupled with ground water monitoring to assess seepage or changes of seepage within the slope mass.

6. AIR QUALITY

The primary air pollutant of concern at mining sites is particulate matter. EPA has established National Ambient Air Quality Standards for particulate matter with a diameter of less than 10 microns, and State Implementation Plans must ensure sufficient control of particulate emissions from all sources to allow attainment of the ambient air standard and to meet opacity requirements.

A variety of mining operations emit particulates, usually as fugitive dust (as opposed to emissions from stacks), and relatively simple controls are often sufficient:

- Ore crushing and conveyors can be substantial sources of fugitive dust, and control generally involves water sprays or mists in the immediate area of the crusher and along conveyor routes.
- Loading bins for ore, limestone, and other materials also generate dust. Again, water sprays are typically used for control.
- Blasting generates dust that can be, and is sometimes, controlled with water sprays.
- Equipment and vehicle travel on access and haul roads are major sources of fine and coarse dust. Most mines use water trucks to dampen the surface periodically.
- Waste rock dumping can generate dust, but this generally consists of coarse particles that settle out rapidly with no other controls.
- Venting of shafts can emit dusts.
- Wind also entrains dust from dumps and spoil piles, roads, tailings (either dry as disposed or the dry portions of impoundments), and other disturbed areas. Spray from water trucks are often used when the mine is operating. During temporary closures, particularly after the active life, stabilization and reclamation are aimed in part at reducing fugitive dust emissions. Tailings in particular can be a potent source of fine particulates; temporary or permanent closure great increases the potential for surface tailings to dry out and become sources of dust. Rock and/or topsoil covers, possibly with vegetative covers, can be effective controls.

Tailings and waste rock at metal mines usually contain trace concentrations of heavy metals. Fugitive dust would also contain such metals, and areas immediately downwind could accumulate heavy metals concentrations greater than the background levels as coarse particles settle out of suspension in the air. Occasionally, wind has caused cyanide sprays on heap leach piles to blow short distances and caused very localized damage. Consequently, more operators are turning to drip application of cyanide solutions, a solution with multiple advantages in arid environments since this also minimizes evaporative losses.

The inherent risk from toxic dust depends upon the proximity of environmental receptors, the susceptibility of the receptor, the type and form of ore being mined. High levels of arsenic, lead, and radionuclides in windblown dust would be expected to pose the greatest risk.

Some of the larger copper and gold tailings ponds in the arid west can cover areas over several square miles. The sand-sized tailings particles are especially susceptible to prevailing wind transport due to the lack of moisture and the flat topography. Most tailings ponds are not covered during operation, although some pond water will be near the current tailings disposal pipe, spigot, or cyclone. Most abandoned and inactive tailings ponds do not have any cover.

Particulate from smelter flue stacks may pose significant human health and environmental risks (in general, smelter emissions are no longer a significant concern in the United States). While smelter flue dust collected before stack emission is recycled at most active smelters, windblown flue dust at inactive and abandoned smelters has caused significant environmental damage. For example, air emissions from the Palmerton Zinc smelter in Palmerton, Pennsylvania, contained large quantities of zinc, lead, cadmium, and sulfur dioxides. The emissions led to the defoliation of approximately 2,000 acres on nearby Blue Mountain, and deposited heavy metals throughout the valley. The rate of erosion escalated on Blue Mountain and the mountain side became denuded of all soils, making revegetation impossible.

7. SOILS

Mining operations routinely modify the surrounding landscape by exposing previously undisturbed earthen materials. Erosion of exposed soils, extracted mineral ores, tailings, and fine material in waste rock piles can result in substantial sediment loadings to surface waters and drainageways. In addition, spills and leaks of hazardous materials and the deposition of contaminated windblown dust can lead to soil contamination.

Soil Contamination. Human health and environmental risks from soils generally fall into two categories: (1) contaminated soil resulting from windblown dust, and (2) soils contaminated from chemical spills and residues. Fugitive dust can pose significant environmental problems at some mines. The inherent toxicity of the dust depends upon the proximity of environmental receptors and type of ore being mined. High levels of arsenic, lead, and radionuclides in windblown dust usually pose the greatest risk. The Bunker Hill Superfund site is an example of soil contamination from fugitive dust, stack emissions, and deposition of discarded mine tailings. Soils contaminated from chemical spills and residues at mine sites may pose a direct contact risk when these materials are misused as fill materials, ornamental landscaping, or soil supplements.

As noted above, cyanide may escape from heap sprays at gold facilities. If the cyanide lands on unsaturated soils, free cyanide can volatilize to HCN (this is not usually a problem, however). Adsorption, precipitation, oxidation to cyanate, and biodegradation also attenuate free (and dissociated complexed) cyanide in soils under appropriate conditions. Minor spills of cyanide are common at gold facilities. Spills or leaks of cyanide occur, for example, when portions of a heap leach pile slumps into a drainage ditch or solution pond and cause an overflow of cyanide-containing solution. They can also occur when a pipe carrying pregnant or barren solution, or tailings slurry, fails or is punctured/severed by mining equipment or vehicles. In all but a few major cases, cyanide spills have been contained on-site, and soils usually provide significant attenuation. Facilities routinely store hypochlorite or other oxidants for use in detoxifying such spills.

8. TERRESTRIAL AND AQUATIC HABITAT/ECOSYSTEM QUALITY

By its very nature, mining causes land disturbances. These disturbances can affect aquatic resources, wildlife, vegetation, and wetlands, and can lead to habitat destruction. Surface mining activities directly destroy habitat as a result of removal of overburden to expose ore bodies, deposition of waste and other materials on the ground surface,, and the construction of roads, buildings, and other facilities.

Aquatic Life. Mining operations can have two major types of impacts on aquatic resources, including aquatic life. The first type of impact results from the contribution of eroded soil and material to streams and water bodies and from the release of pollutants from ore, waste rock, or other sources. The second results from the direct disruption of ephemeral, intermittent, or perennial streams; wetlands; or other water bodies. Temporary disruptions occur from road construction and similar activities. Permanent impacts are caused by actual mining of the area or by placement of refuse, tailings, or waste rock directly in the drainageway. More often than not, this is in the upper headwaters of intermittent or ephemeral streams. In addition, lowering of area surface water and ground water caused by mine dewatering can affect sensitive environments and associated aquatic life.

Aquatic life is generally defined as fish and benthic macroinvertebrates; however, phytoplankton and other life forms may also be considered, depending on the type of aquatic habitat and the nature of impacts being assessed.

The impacts of mining operations on aquatic resources can be either beneficial or adverse. Potential impacts also vary significantly with the affected species. For example, increases in stream flow may preclude habitation of certain species of macroinvertebrates and/or fish but may also provide new habitat for other species of aquatic life.

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 instream 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 instream 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.

Wildlife. Mining operations can have substantial impacts on terrestrial wildlife, ranging from temporary noise disturbances to destruction of food resources and breeding habitat. Unless closure and reclamation return the land essentially to its pre-mining state, certain impacts to some individuals or species will be permanent.

Biological diversity is often viewed as a way to measure the health of an ecosystem. Noise during the construction phase or during operations, for example, may displace local wildlife populations from otherwise undisturbed areas surrounding the site. Some individuals or species may rapidly acclimate to such disturbances and return while others may return during less disruptive operational activities. Still other individuals may be displaced for the life of the project. Other wildlife impacts include habitat loss, degradation, or alteration. Wildlife may be displaced into poorer quality habitat and therefore may experience a decrease in productivity or other adverse impact. Habitat loss may be temporary (e.g., construction-related impacts), long-term (e.g., over the life of a mine), or essentially permanent (e.g., the replacement of forested areas with waste rock piles).

Vegetation. Vegetation consists of natural and managed plant communities. Native uplands consist of forests, shrublands and grasslands; managed uplands include agricultural lands, primarily croplands and pastures.

Native plant communities perform several functions in the landscape. Vegetation supports wildlife, with the diversity of vegetation strongly related to the diversity of wildlife within the area. Vegetation stabilizes the soil surface, holding soil in place and trapping sediment that may otherwise become mobilized; it also functions to modify microclimatic conditions, retaining soil moisture and lowering surface temperatures. A diverse landscape also provides some degree of aesthetic value.

All vegetation within the active mining area is removed before and during mine development and operation. Vegetation immediately adjacent may be affected by the roads, water diversions or other development. Vegetation further removed from activities may be affected by sediment carried by overland flow and by fugitive dust.

9. REFERENCES

U.S. Environmental Protection Agency, Office of Federal Activities. 1994. *EIA Guidelines for Mining*. Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994a. *Copper - Extraction and Beneficiation of Ores and Minerals, Volume 4*, EPA/530-R-94-031, NTIS/PB94-200 979, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994b. *Design and Technical Evaluation of Tailings Dams*, EPA/530-R-94-038, NTIS/PB94-201 845, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994c. *Gold - Extraction and Beneficiation of Ores and Minerals, Volume 2*, EPA/530-R-94-013, NTIS/PB94-170 305, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994d. *Gold Placer - Extraction and Beneficiation of Ores and Minerals, Volume 6*, EPA/530-R-94-035, NTIS/PB94-201 811, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994e. *Innovative Methods of Managing Environmental Releases at Mine Sites*, EPA/530-R-94-012, NTIS/PB94-170 255, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994f. *Iron - Extraction and Beneficiation of Ores and Minerals, Volume 3*, EPA/530-R-94-030, NTIS/PB94-195 203, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994g. *Lead-Zinc - Extraction and Beneficiation of Ores and Minerals, Volume 1*, EPA/530-R-94-011, NTIS/PB94-170 248, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994h. *Other Mining Sectors: Phosphate and Molybdenite - Extraction and Beneficiation of Ores and Minerals, Volume 7*, EPA/530-R-94-034, NTIS/PB94-201 001, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994i. *Treatment of Cyanide Heap Leaches and Tailings*, EPA/530-R-94-037, NTIS/PB94-201 837, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994j. *Uranium - Extraction and Beneficiation of Ores and Minerals, Volume 5*, EPA/530-R-94-032, NTIS/PB94-200 987, Washington, D.C.

U.S. Environmental Protection Agency, Office of Solid Waste. 1994k. *Acid Mine Drainage Prediction*, EPA/530-R-94-036, NTIS/PB94-201 829, Washington, D.C.