MINING SUPPORT PACKAGE

METALLIC ORES AND MINERALS

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1. INTRODUCTION AND SUMMARY

This document is an overview of the environmental impacts of metal mining and processing. It is general in nature and is provided as an introduction to some of the methods available to prevent, control, and mitigate these impacts. Metals are a valuable natural resource for many countries and a necessity for the economies of all nations that depend on metal products. However, unless proper controls are taken in mining and processing metals, serious environmental damage can result. The environmental effects of mining and/or mineral processing include: alteration of the landscape with pits and waste rock; subsidence of the land over underground mine workings; pollution of surface water with acid drainage and metals from waste rock and tailings and chemicals from mineral beneficiation; damage to sensitive ecosystems that support fish and wildlife; and human health risks from contaminated water sources. To prevent these impacts, government policy-makers are taking more steps to strongly encourage pollution prevention options and to adopt regulatory and enforcement strategies for minimizing the harmful environmental impacts of mining and mineral processing.

1.1 Purpose and Overview of the Mining Support Package

This document gives a brief description of the metals mining process, examines some of the options for preventing environmental damage from mining, and outlines various strategies for regulating mining practices to insure that environmental impacts are controlled. Examples of environmental management approaches are presented so that government planners can make informed decisions on the approaches best suited to their needs.

Since this document is intended as an overview document, those wishing to explore the subject more thoroughly should consult the references listed in the *Sources of Additional Information* section for additional reading material.

1.2 Metals Mining/Processing and the Environment

In many countries, mining is performed on a large scale, using heavy equipment and explosives, advanced beneficiation technologies, and a sizable work force. These operations may be owned or managed by the public sector, the private sector, or shared jointly between the two. The mining industry often extracts and processes a variety of metals, minerals, and gems within a single country and generates profits, tax revenues, jobs, and foreign exchange earnings for mine owners, employees, and host country governments. While the economic benefits to private companies, governments, and employees may be substantial, by its very nature the extraction of a non-renewable resource from the earth has environmental effects. Table 1 summarizes some of the potential effects of industrial mining on the environment that are discussed in more detail in the support package.

Table 1: Steps in Mining and Beneficiation and Their Environmental Impact

Mining
Process Water Pollution Air Pollution Solid Waste Land, Habitat, Wildlife
Site Preparation Increased turbidity from erosion due to removal of vegetation Exhaust from construction vehicles, dust Clearing Debris Deforestation and habitat loss from road and site construction
Blasting/ Excavation Acid Mine Drainage (AMD)

Increased turbidity from erosion of soils

Petroleum wastes from trucks

Surface Contamination from runoff

Ground water contamination from acid waste water discharges Dust blown to surrounding area

Exhaust from heavy machinery Overburden if not reused

Waste rock Loss of habitat

Increase in soil erosion

Loss of plant population from dust and water pollution

Reduction in groundwater resulting from pumping for use in processing

Loss of fish population from water pollution

Nearby structural damages from vibration and settling

Competition for land use
Crushing/
Concentration Acid Waste Water Discharges Dust created during transportation Additional waste rock

Tailings Loss of habitat
Leaching Acid Rock Drainage

Surface and ground water pollution from ruptures in pipes or ponds holding leach solution Heavy metals in dust run off into surface water and leaches into ground water Sludges from neutralization of contaminated water Loss of plant population from water pollution

Loss of fish and water fowl population from water pollution

Loss of terrestrial habitat through soil contamination and destruction of cover/food sources

In addition, small-scale mining, common in many countries for the extraction of gold and other minerals, can cause similar kinds of environmental damage and also may strain the ability of surrounding residential centers to provide adequate services to a rapidly increasing population. Many governments are challenged with balancing the economic benefits of mining with the environmental costs of this activity.

1.3 Towards Sustainable Development: Pollution Prevention and Control

Since the mining industry is important to the economies of many countries, and the mining process is often unavoidably destructive, governments often choose to tolerate some level of environmental damage resulting from mining activities. Many, but not all, of the environmental impacts of mining can be minimized through careful planning, monitoring, and enforcement of clear, well-defined regulations. The use of pollution prevention technologies and environmental controls also can substantially reduce the volume of contaminants released and the concentration of the contaminants discharged into the surrounding environment. In some cases, these pollution prevention approaches may also be economically beneficial to mine operators because they may decrease the process chemicals needed, and therefore the cost of producing a given amount of mineral. The list below summarizes some of the environmental control technologies and regulatory approaches discussed in this document.

Summary of Pollution Prevention, Control, and Management Options

Water Pollution Prevention and Control

Diversion Systems - Reducing the amount of contaminated water produced by channeling runoff away from exposed mine pits and waste dumps.

Drainage Ditches - Channeling contaminated water into containment ponds for treatment or recycling.

Containment Ponds - Constructing ponds to hold contaminated water for treatment which prevent contamination of ground or surface water e.g. synthetic or clay liners.

Recycling Systems - Reusing contaminated water, after appropriate filtering or treatment, in the extraction process for dust elimination or drilling.

Subsurface drainage systems and barriers - Collecting or deflecting groundwater prior to contact with exposed mine pits, preventing groundwater contamination.

Liners - Underlinings for leach units or tailings ponds to prevent or minimize leakage of contaminated water to ground or surface waters.

Runoff Controls - Providing means for stabilizing, filtering, and/or settling out soil materials which can be picked up during storm runoff for the purpose of controlling erosion of disturbed areas and limiting stream sedimentation.

Wastewater Treatment - Including the use of lime to reduce acidity and settle out metals and other solid contaminants.

Wetlands - An experimental and unproven technology, constructed wetlands rely on natural processes of wetlands to remove water contaminants before discharge.

Air Pollution Prevention and Control

Dust Elimination Technologies - Water sprinklers used to reduce dust created during excavation and transport.

Dust Suppressant Agents - Compounds such as magnesium chloride can be used to reduce dust in solid piles and tailings subject to significant wind erosion. These compounds can harm plant and aquatic life, however, and should only be used where it can be shown that they will not pose an environmental threat.

Closure and Reclamation Approaches

Mine Closure and "Capping" - Covering exposed mine pits, tailings, and waste rock dumps with natural or natural/synthetic material to reduce contamination of groundwater and creation of dust once mines are no longer active.

Revegetation and Regrading - Using plant cover and landscape alteration to reduce erosion, dust, and runoff contamination, reintroduce native species to the former mine site, and allow alternative uses of the land.

Sample Planning, Monitoring, Enforcement, and Compliance Approaches

Regulations - Enacting laws and rules governing technology use, acceptable contaminant levels, reporting and monitoring procedures, penalties, fines, reclamation bonds, etc.

Environmental Impact Assessments - Preparing detailed reports that estimate environmental impacts of proposed sites and present plans for complying with regulations and managing potential future environmental problems.

Mine site plan, review, approval and permitting - Reviewing alternative approaches to mine design and extraction/beneficiation prior to issuance of mine permits, and exploring strategies that might minimize environmental impacts. This approach may also include plans for mine closure, land reclamation and appropriate environmental management systems.

Self-monitoring, Self-reporting - Using company-managed environmental monitoring and reporting systems to supplement government-run enforcement efforts. This approach may improve cooperation between government and industry, reduce costs, and still provide adequate environmental protection.

The approaches selected by governments to manage the environmental impact of mining depend on a variety of criteria, including the size and breadth of the mining industry, nature of the mine environment, the funds available for enforcement and inspection, the availability and local costs of new technological solutions, and the current relationship between government and mine operators in each country. Since no single approach is appropriate to all countries or regions within countries, this support document can only offer some approaches for consideration. Nevertheless, it is hoped that this information will allow policy-makers to more fully appreciate the problem while taking advantage of the full range of potential solutions.

2. PROFILE OF THE MINERAL INDUSTRY AND OVERVIEW OF THE MINING AND MINERAL PROCESSING INDUSTRY

Mining takes place in a wide range of countries, in all regions of the world, in different topographic and climatic conditions, and at all levels of economic prosperity. Many of the same basic principles are applied whether one is extracting copper from the mountains of Zaire, or bauxite from Australia. Since mineral deposits have fixed locations there is little choice as to where the industry may seek to develop. Although governments may choose to control who may mine a country's national resources, many of the same large multinational corporations manage mining operations in countries around the globe. Often these companies operate through joint ventures with government owned firms, or may compete against public or private companies run by host country nationals.

Since many companies operate mining operations on a global scale, and the minerals extracted are often subject to prices determined on world markets, there is less variation in technologies used in countries of different economic and technological development than in other more localized industries. Although the wage scales of local workers in different countries and the costs of procuring specialized equipment do have some bearing on technologies used in the mining industry, the basic processes are still quite similar whether a mine is located in Peru, Russia, or the United States. Even mining conducted on a small-scale by individual "prospectors" still requires the basic operations of excavating non-valuable cover, extracting the target mineral, and processing the raw ore to concentrate the valuable elements. This section primarily deals with industrial-scale mining techniques, and the particular problems of small-scale mining will be presented later in the support package.

Primary steps that mine operators will perform include extraction, milling, and/or leaching. Extraction is the process of mining or removal of ore from deposits in the ground. Once the ore is removed, additional milling processes are required to isolate the valuable mineral from the remaining wastes. Depending on the grade of the ore at metal mines, ore may be initially crushed, then either processed further by beneficiation or concentrated through heap leaching. Beneficiation employs one or more methods to separate material into two or more constituents, at least one of which is the desired product. These methods are used to prepare ores for further intensive processing and use the differences between the physical properties of the various minerals in the ore to concentrate the target mineral. Beneficiation processes rely on differences such as size and density. Following beneficiation, the valuable mineral can be further concentrated through a variety of metallurgical processes. Heap leaching of ore is performed by stacking the ore and applying chemical solutions directly through a sprinkler. The solutions then percolate through the ore, dissolving the metals. The metal-laden solution is then collected at the base of the pile and pumped to a processing plant where the metal is recovered from the liquid.

2.1 Extraction Methods

There are two basic ways in which minerals are mined--surface and underground. The choice of extractive technique depends on the type of mineral being mined, the shape, size, and location of the ore body, and cost considerations. Solution mining is a specialized process used on certain types of metal deposits and will be discussed briefly in the section on leaching below. Surface and underground mining are more common and are used to extract a wide variety of minerals.

Surface or open pit mining is used for large, near-surface deposits which have a low commodity value per unit of volume. Rock is drilled, blasted, loaded into trucks and hauled to a facility where it is crushed and ground to a uniform size. Surface mining requires the removal and disposal of a layer of soil and rock containing no minerals, commonly called the *overburden*. A second layer of rock, known as *waste rock*, containing low concentrations of ore is also removed and, in some cases, disposed of. Once the high-quality deposit is exposed, excavation continues, with further disposal of surrounding low-grade waste rock, until the valuable body of ore has been removed. The high-quality ore is broken into pieces that can be easily transported and moved to a crushing plant for further processing.

Underground mining methods are used when mineralized rock occurs deep beneath the Earth's surface. To reach the ore body, remove ore and waste, and provide ventilation, miners must excavate either a vertical shaft, a horizontal adit, or an inclined passageway. Within the ore deposit, horizontal passages called *drifts* and *crosscuts* are developed on several levels to access mining areas called *stopes*. Blasted rock is hauled away from the stopes by trains, loaders, or trucks that may bring it directly to the surface or transport it to a shaft where it is hoisted to the surface and sent to a crushing facility.

In both underground and surface operations, extraction of ore and wastes requires the use of heavy machinery and explosives. A variety of bulldozers and shovels as well as hand-held drills and jackhammers are used to remove soil and soft waste rock. Explosives such as mixtures of ammonium nitrate and fuel oil are used to blast away harder rock deposits. In addition, small transportation equipment is used to transport ore to the surface of underground mines, and large loaders and trucks are used to carry ore away from the mine site for further processing.

2.2 Beneficiation

Mined ore, with a few exceptions, must be beneficiated before further processing. *Beneficiation*, commonly referred to as milling, is the processing of ores to regulate the size of a desired product, remove unwanted constituents, and/or improve the quality, purity, or assay grade of a desired product. Processing methods range from simple washing screening and drying, to highly complex methods used to process copper, lead, zinc, silver, and gold ores.

2.2.1 Amalgamation

Gold and other metals, when brought into contact with metallic mercury, will *amalgamate* -- meaning that the liquid mercury will alloy with the surface gold to form a mercury-coated particle which has surface properties similar to those of pure mercury. The amalgamated particles will coalesce or cling together much as drops of pure mercury will collect into a single puddle. When mercury has amalgamated as much gold as possible, the result is a gray plastic mass. When this mass is heated, the mercury distills off, leaving behind metallic gold.

2.2.2 Flotation

Metals can also be concentrated through *flotation*. Flotation is a method of mineral separation in which a number of reagents selectively float or sink finely crushed minerals in an enclosed flotation cell. These techniques use physical and chemical properties of the target minerals along with process chemicals to separate relatively pure minerals from remaining wastes. The wastes, including the liquids used in the process, are then discarded. The solid mine wastes from flotation are known as the mine *tailings*.

2.2.3 Leaching

In some instances, low grade ore is not simply discarded after extraction. Instead, low concentrations of ore are extracted through a variety of beneficiation processes known as *leaching*. All leaching methods involve pouring a solution (commonly acid or cyanide) over rock to dissolve metals into a solution for later extraction.

There are four main types of leaching: dump, heap, vat, and *in situ*. In each type, the basic components of the process are deposits of low grade ore, a leaching solution, and a holding/recovery area used to extract the desired metal from the solution. The leaching process used depends on the concentration of metals in the ore and the economics of the mining operation. For instance, dump leaching is often used on copper ore with 0.05 percent or more copper content, while heap leaching is used for higher grade ores with copper concentrations between 0.5 and 1 percent.

In situ leaching, also called solution mining, is an alternative to the underground and surface techniques described above. Solution mining involves pumping a reagent, such as a sulfuric acid solution, directly into the ore body. The reagent dissolves the metals in the ore and the solution is collected by various means and then pumped to the surface for later extraction through electrical/chemical techniques.

Dump leaching is the most widely used and often the most environmentally-damaging leaching process. It involves the creation of large dump piles of low-grade crushed and uncrushed ore that cannot be profitably processed through other methods. These leach dumps often rise to heights of up to 60 meters and contain several million metric tons of rock. Precipitation, and additional acidic leach solution is used to dissolve the desired minerals into solution. The leaching solution is sprayed, injected, and/or washed over the dump pile, and the solution is collected in a pond.

Heap leaching is a modified form of dump leaching usually conducted on a smaller scale and with higher-grade ore. The ore, usually crushed, is placed on a specially-prepared pad made of synthetic material, asphalt, or compacted clay. Reagents typically composed of strong acids, bases, or cyanide are used as the leaching solution.

Vat leaching requires the highest grade ore of any leaching process and involves placing crushed ore into an enclosed vat of reagents.

In all leaching processes, the desired metals must be recovered from the leaching solution. The leaching solution containing dissolved metals is pumped from a holding pond to an extraction plant. Metals are recovered from the solution using chemical or electrical processes. Once the metal has been removed from the leach solution, the solution is typically used again in the leaching process.

3. PRINCIPAL MINING-RELATED ENVIRONMENTAL PROBLEMS, AND ASSOCIATED POLLUTION PREVENTION AND CONTROL OPTIONS

The typical mining methods described above create the potential for a variety of environmental problems at many stages in the process. Heavy machinery, explosives, and underground or otherwise hazardous working conditions common to the excavation process present dangers to employees and surrounding residents. Reagents used in leaching or created through natural chemical reactions with exposed mine rock can lead to contamination of streams, rivers, or underground water sources as a result of ruptures in holding ponds or uncontrolled runoff. Dust, often containing heavy metals and silica in various forms, created through excavation and transportation of ore, pollutes the air, land, and water surrounding the mine site. The primary sources of environmental problems associated with each stage of the industrial mining process have been summarized in Table 1. These environmental problems and some common methods to minimize their impacts are discussed in the following sections.

In addition to environmental problems caused by the mining process, serious air and water pollution problems can also be created in later stages of mineral/metal processing operations. Smelting (melting or fusing of the ore to separate metal constituents) and coking (producing carbon for smelting or refining by carbonizing coal in high temperature ovens) can both result in the emission of harmful contaminants into the air. Although these refinement steps are beyond the scope of this document, which focusses on the initial extraction and beneficiation processes, it should be recognized that smelting operations may be located close to mining operations so as to reduce transportation costs. An understanding of the environmental problems caused by these processes and the pollution prevention and control options available to minimize their impact will be important as well.

3.1 Mining-Related Water Pollution and Options for Prevention and Control

In many respects, water pollution represents the most common and most serious environmental problem caused by mining. Metal-bearing rock that interacts with rainwater or with process chemicals such as cyanide and mercury can lead to water pollution impacts at all stages of the mining/beneficiation/disposal process. Principal sources of water contamination include:

Runoff from excavated mine pits and changes in surrounding terrain;

Milling and leaching operations, especially when cyanide, mercury, or other process chemicals are used in beneficiation;

Runoff from waste and tailings dumps; and

Leakage of process or runoff waters from pipes or holding ponds;

Mine pits create large exposed surfaces of mineral and metal-bearing rock that can contaminate rainfall which may eventually flow into surrounding streams or percolate into groundwater. The excavation of mine pits results in problems of erosion, leading to an increase of sedimentation in streams that may adversely impact wildlife and change water courses. Changes in terrain may increase runoff and as a result reduce groundwater levels in the region surrounding the mine site. The use of chemicals such as cyanide and mercury in beneficiation also results in polluted wastewaters that need to be treated and/or controlled upon discharge. These chemicals represent pollution hazards in and of themselves and also cause metals pollution through interaction with minerals in milling and leaching operations, in waste dumps, and along discharge pathways. Waste and tailings dumps, a solid waste problem, also contaminate runoff as well as surrounding streams and sources of groundwater through interaction of water, remaining metals, and residual process chemicals.

The effects of mine-related water pollution can include toxic metals and hazardous chemical constituents in water supplies that may make water unfit to drink, reduction or elimination of native fish, plant, and bird species that live near contaminated streams, or reduction in groundwater available for agriculture and livestock. The thorough understanding of local hydrologic factors coupled with the use of proper technologies to control the levels of water pollution are especially important.

Many of the water pollution prevention and control options are relatively inexpensive and require no special equipment, sophisticated technology, or special training to install and maintain. Water pollution controls do work best, however, when they are planned and implemented early in the life of a mine. This section briefly discusses the primary water control problems and defines options that can be used in a complete system to minimize the water pollution threat.

3.1.1 Acid Mine Drainage and Acid Rock Drainage

Acid Mine Drainage and Acid Rock Drainage are two persistent and potentially severe pollution problems associated with the mining industry. They are caused by naturally-occurring chemical interactions of water, air, bacteria, and exposed mine rock. The resulting contamination of surrounding water sources with acids and dissolved metals can kill plants and fish and, in serious cases, poison humans who drink contaminated water or eat fish and plants from polluted rivers and streams. This section examines how Acid Mine Drainage and Acid Rock Drainage occur, describes their environmental impacts, and explores potential measures for prevention, monitoring, and control.

How Acid Mine Drainage and Acid Rock Drainage Occur

Acid Mine Drainage and Acid Rock Drainage occur when sulphide-containing minerals such as *pyrite* and *pyrrhotite*, common to many mine sites, are exposed to air and water. These minerals, which may either be present as a result of excavation or naturally-occurring, may react with water and oxygen to create ferrous ions and sulfuric acid. With bacteria acting as a catalyst, the ferrous ions react further with oxygen, producing hydrated iron oxide, known as "yellowboy". This combination of yellowboy and sulfuric acid contaminates surrounding soil, groundwater, and surface water, producing water with a low pH level and a high sulphate, iron, and heavy metals content. When this process occurs within a mine it is called Acid Mine Drainage. When it occurs in waste rock and tailings piles it is known as Acid Rock Drainage. Since the processes have similar impacts, they will be discussed together as acid drainage.

The Environmental Impact of Acid Drainage

When acid drainage occurs, acidic and metals-laden water may be carried out of the mine site into groundwater or nearby streams and rivers. Acid drainage lowers the pH of the surrounding water, making it corrosive and unable to support many forms of aquatic life. Vegetation growing along streams is also affected as plant species that can survive in acidic water replace native species.

The flow of acidic mine water can also carry toxic, metal-bearing sediment into streams. These toxic sediments may kill waterborne plant and animal species. In the most extreme cases, acid drainage may kill all living organisms in nearby streams. If humans are exposed to water or fish contaminated with heavy metal, serious health effects may occur.

Acid drainage can continue to be a problem long after a mine closes. Abandoned mines and refuse piles can produce acid damage for over 50 years. The U.S. Forest Service estimates that 5,000 - 10,000 miles of streams in the U.S. are currently affected by acid drainage from active and inactive mines and waste rock piles (see United States Department of Agriculture, Acid Drainage From Mines on the National Forests: A Management Challenge. Program Aid 1505, March 1993.) Because of the difficulty and cost of acid damage cleanup, environmental agencies often focus their efforts on prevention.

Pollution Prevention: Avoiding Acid Drainage

There are no widely-applicable technologies to stop a fully-developed acid drainage situation. Once acid drainage occurs, there are several widely-applicable technologies to address it. These technologies require perpetual maintenance, however. This makes it particularly important to prevent acid drainage before it starts. Prevention of acid drainage requires control of the basic elements of the problem: oxygen, water, bacteria, and sulphide minerals. Within a mine, oxygen levels cannot be controlled, so Acid Mine Drainage prevention measures focus on control of the other three parameters, particularly on water flows.

In addition, a number of computer-based predictive models have been developed that allow mine operators and regulators to identify potential acid drainage problems early in their development. Through the use of continuous sampling and analysis, many of the control approaches described below can be implemented and modified appropriately with changing conditions at the mine site.

Controlling Water Flow

The primary strategy for minimizing acid drainage focuses on water control. A comprehensive water control strategy works both to limit contact between water and exposed mine rock and to control the flow of water that has been contaminated by mineral-bearing rock. Systems for water control at mine sites require consideration of rainfall runoff as well as process water used or produced when mine dewatering is required in excavation, concentration, and leaching. Although the type of water controls used vary widely according to topography, rock type, and climatic conditions, efforts typically are aimed at directing water flows to a few containment ponds for easy treatment or evaporation. The five principal technologies used to control water flow at mine sites are: diversion systems, containment ponds, ground-water pumping systems, subsurface drainage systems, and subsurface barriers.

Control of Surface Water

Surface water is controlled by diversion systems, primarily made up of drainage ditches. Some drainage ditches channel water away from mining sites before runoff reaches exposed minerals while others in the diversion system direct contaminated water into holding ponds for evaporation or treatment. Ditches are often constructed from soils and clays found in the area surrounding a mine site. At some sites, ditches are constructed from concrete or mixtures of natural and synthetic materials. Although these synthetic materials are more expensive, they often do a more complete job of controlling runoff and process water. Drainage ditches are typically constructed to handle a volume of water produced in heavy rains that may occur only a few times a decade. In this way, overflow of contaminated water is minimal in all except the most severe rainstorms.

Containment ponds and collection dams are used to hold contaminated water for evaporation and treatment. Containment ponds are constructed of materials that prevent seepage and leakage of contained water. Ponds may be simple constructions of clay or impermeable rock built in natural drainage basins, or they may be complex, expensive structures built of cement or synthetic material with liners and elaborate leakage monitoring systems. Generally, ponds used to hold leaching solutions are more sophisticated than holding ponds for mine runoff because of the valuable nature of the metal-rich solutions in leaching holding ponds.

Control of Groundwater

Water control systems at mine sites must also prevent the contamination of groundwater sources. Groundwater pumping systems are used to control or reduce underground seepage of contaminated water from collection ponds and waste piles. Wells are drilled where underground water movement is detected, and pumps are then used to move the water out of the ground to holding ponds and/or to a treatment plant. Subsurface drainage systems are also used to control seepage in mining areas. These systems use a drain channel and wells to collect contaminated water that has seeped underground and move it to a treatment plant. Subsurface drainage systems are often more cost-effective than pumping systems, but are practical only in situations where the contaminated water has sunk to a depth typically less than 25 meters.

Subsurface barriers are used to divert groundwater away from mining operations. The most common forms are slurry walls and grouting. Slurry walls are made of low-permeability materials (concrete-bentonite mixtures) that are installed in the ground around mining operations. Grouting involves the injection of a liquid solution (commonly cement) into rock crevices and joints to reduce water flow. Both grouting and slurry walls are only effective up to depths of around 20 meters.

Siting Waste Piles Away From Ground and Surface Water

In addition to controlling water flow, acid drainage minimization also requires that waste and tailings dumps be properly designed and sited. When selecting a site for waste dumps, mine operators should consider the topography of the site and the proximity to groundwater, streams, and rivers. Dumps can be sloped to minimize uncontrolled runoff and to control the velocity of water that flows into containment ponds. If rivers are nearby, the dump, containment ponds, and surrounding diversion systems can be designed to channel water away from these protected areas for control and treatment.

Monitoring of Acid Drainage

Monitoring provides information about the physical condition of the mine site and the surrounding water quality. If properly performed, monitoring can furnish timely and accurate information allowing regulators and mine operators to take necessary actions to avoid damaging acid drainage situations.

Monitoring the Mining Site

Preventing acid rock drainage requires careful monitoring of waste rock dumps, ore stockpiles and leaching sites. The stability of waste rock mounds is one important consideration. Unstable piles can cause rocks to shift and roll away from the monitored confines of the mine site. The large-scale movement of waste piles may change runoff channels and damage diversion systems, increasing uncontrolled flows of contaminated water to ground and surface water. A regular program of waste and tailings dump observation can detect unstable conditions that can be corrected by regrading dumps with heavy machinery or repairing dump barriers and ditches.

Water Quality Monitoring

A range of chemical, physical, and biological parameters can be used to evaluate water quality, including: pH, metal content, aquatic toxicity testing using indicator species, and temperature. Appropriate parameters are selected according to the characteristics of each mining site. It is also important to select sampling sites that are near streams and lakes that receive runoff from waste piles. Monitoring is often performed on a regular basis so that changes in contaminant levels can be detected quickly. If monitoring detects abnormal levels of contamination, these sources can be traced and additional control measures imposed.

Treating Acid Drainage

The Conventional Approach

The conventional approach to treating contaminated water produced through acid drainage involves an expensive, multi-step process that pumps polluted water to a treatment facility, neutralizes the contaminants in the water, and turns these neutralized wastes into sludge for disposal. The process is divided into the following steps:

Equalization,
Neutralization,
Aeration,
Sedimentation, and
Sludge disposal.

The process is depicted in Figure 1. The first step in the process, equalization, involves pumping polluted water into a holding basin. The holding basin may be the containment pond at the base of the waste or tailings dump, or may be an additional basin constructed for this purpose. A steady “equalized” flow of water is then pumped out of the holding basin to a treatment plant for neutralization. Lime is commonly added to the water in the treatment plant to neutralize the acid. The next step, aeration, involves moving the treated water to another basin where it is exposed to air. This allows ferrous ions in the water to bind with the lime, creating a solid. The solid then settles to the bottom of the pond as sediment. This sediment contains most of the contaminants that had previously been mixed with the water. The accumulated sludge at the bottom of the basin can then be removed for disposal.

Sludge disposal is the most expensive and difficult part of acid drainage treatment. The easiest method for final disposal is to pump the sludge into abandoned mines. The long-term environmental impact of this method is undetermined. While the mine is still active, the sludge may be placed in a basin next to the sediment pond. The sludge is left in this second pond (also called a sludge lagoon) until evaporation takes place and the sludge dries. The sludge can then be transferred to an appropriate safe location for long term storage/or disposal.
space for figure 1

An Unconventional Approach--the Use of Wetlands

The long-term impact of highly acidic water containing metals upon wetland areas and surrounding wildlife is well known and of concern. Wetlands serve as important wildlife habitat and ecosystems as well as natural flood control in and of themselves. Man-made wetlands have been used experimentally in some circumstances to treat acid drainage containing metals, however, their use for this purpose remains controversial. In these cases, wetlands, areas sometimes or always inundated with water, can serve as a passive system to filter polluted water. They have been of interest in the control of acid drainage because they do not require the addition of chemicals or the use of large-scale pumping of contaminated water. They rely on natural processes to neutralize the contaminants in the polluted water, theoretically offering a less costly method of treatment than conventional approaches. Naturally occurring microbes may be able to cause oxidation and precipitation of ferrous ions in acidic water. Sludge then settles to the bottom.

Despite some theories that this method might prove cost-effective, current research results are inconclusive and raise questions particularly about residuals metals contamination and other biological effects.

3.1.2 Water Contamination From Beneficiation

Leach sites have the potential to introduce highly concentrated levels of acids and heavy metals into surrounding water sources. The leaching process mimics acid drainage although it is conducted under much more aggressive conditions, using high concentrations of acid, base, or cyanide to extract metals from ore. Since leaching produces large volumes of contaminated water, it is crucial that leach dumps and associated holding/extraction areas be designed to limit contamination. It is also critical that high standards of quality assurance and quality control be applied throughout the construction process. Most of the environmental problems associated with leaching are caused by leakage, spillage, or seepage of the leaching solution at various stages of the process. Potential problems include:

Seepage of solutions through soils and liners beneath leach piles;

Leakage from solution-holding ponds and transfer channels;

Spills from ruptured pipes and recovery equipment;

Pond overflow caused by excessive runoff; and

Ruptures of dams or liners in solution holding ponds.

Pollution Prevention: Minimizing Discharges from Leach Areas

To prevent groundwater and surface water contamination caused by the leaching process, governments can help mining companies set up properly-designed leaching sites by providing technical assistance and/or guidelines. Governments may also wish to supplement these guidelines with enforceable regulations to help bring companies into compliance. These guidelines and regulations could encourage or require mining companies to do the following:

Locate waste piles away from groundwater and surface water;

Design leaching sites as self-contained systems that pump the leaching solution back into the leaching pile;

Line solution holding ponds with gunite (sprayed cement), clay, or synthetics, and ditches with concrete using multiple liners with leak detection when appropriate;

Apply high standards of quality assurance and quality control throughout the construction process;

Monitor the leach area closely in order to detect releases early; and

Establish systems and procedures for spill control, clean-up and notifications, should a release occur.

While some of these environmental controls involve additional costs to mine owners, others can actually reduce mining costs. For example, improved holding pond liners that reduce seepage of metal-bearing solution can increase the volume of minerals extracted. Improved systems for recycling leaching solution can also decrease costs while minimizing the volume of contaminants produced. On the other hand, locating leaching sites away from groundwater and surface water may increase transportation costs.

3.1.3 Hydrologic Impact and Erosion of Sediment

In addition to water contamination resulting from acids and dissolved metals, mining operations have other effects on water sources in the vicinity of mine sites. Changes to the natural topography of the land surrounding the mine site can reduce the amount of precipitation that seeps into aquifers and can increase runoff to streams and rivers, causing erosion problems. This section addresses the effects of mining on groundwater levels as well as the impacts of surface mining on the erosion of sediments.

Hydrologic Impact

Surface mining can increase or decrease the amount of runoff to streams around the mining area. Increased surface runoff can reduce seepage to underground water sources, causing groundwater levels to fall. Frequently too, mines must be continuously dewatered to allow required access to flooded ore bodies. This change in hydrology can lead to a temporary or permanent loss of water in wells for several miles around the site. A reduction in groundwater levels is a particularly sensitive problem in semiarid areas because of the importance of groundwater as a source of drinking water for livestock and as an irrigation source for agriculture.

It is necessary to determine the impact of mining on groundwater levels prior to beginning mining operations. Hydrologic modeling in conjunction with mine site monitoring can forecast hydrologic impacts. In addition, steps must be taken once operations begin to minimize the harmful hydrologic impact of mines. There are, however, few specific remedies for restoring groundwater to its original level. Wells can be drilled deeper to reach the reduced groundwater levels or additional water can be transported to affected communities. In areas where groundwater is crucial, the mining industry and regulators can work together to consider how mine operators will address the potential future impacts of planned mining projects on groundwater levels before mining operations begin.

Erosion of Sediment

Sediment is considered one of the world's principal pollutants. Sediment can contain heavy metals and other toxic substances. Even when sediment is not toxic, it can cause severe environmental damage by clogging reservoirs, increasing flood crests, and destroying crops. It can also destroy habitat for fish and other aquatic life. Erosion and sedimentation are usually gentle natural processes that occur over long periods of time, but surface mining can accelerate this process by stripping away protective soil cover and changing the natural topology of the land. A heavy rainstorm can move tons of soil at an exposed, poorly designed surface mine in a brief period of time.

When designing a mine, it is important to consider the mine's potential impact on erosion. Three key factors are land type, soil and rock types, and proximity of water sources to the mine. Mine planners can consider ways to minimize damage to physical features critical to the control of erosion and sedimentation. There are several steps that can be taken to minimize erosion and sediment damage. Barriers made from natural or man-made materials, such as hay bales and rip rap (rock facing), can be erected to control sediment runoff. These barriers can be part of a general system to pool runoff into an impoundment area or can be built specifically for at-risk sections of the mine site. Planting and cultivation of dense vegetative covers of grass and weeds, shrubs, vines, or trees is often a very effective and inexpensive method of preventing erosion on steep slopes and along drainage pathways.

In some instances, care in site selection and development can help minimize effects on erosion and sedimentation with no added cost. The mine can be designed to minimize disruptions to natural runoff paths. Often, mine operators try to limit development and building construction near streams and rivers in order to maintain floodplains that naturally control water flow. Ongoing monitoring and maintenance of natural and artificial erosion prevention structures is necessary to ensure that sedimentation is adequately controlled.

3.1.4 References for More Information on Water Pollution Prevention and Control

Mining-related water pollution is discussed extensively in many of the references detailed at the end of this document. Especially useful is the EPA's Office of Solid Waste's series *Extraction and Beneficiation of Ores and Minerals*. This series of reports includes information on the gold, copper, lead, zinc, iron, uranium, and gold placer sectors. In addition, M. Sengupta's *Environmental Impacts of Mining* (available from Lewis Publishers) discusses the use of wetlands for the treatment of mine drainage. For specific information on the environmental hazards of leaching, the National Technical Information Service document *Copper Dump Leaching and Management Practices that Minimize the Potential for Environmental Releases* comprehensively covers the water pollution controls for leaching operations in Copper mining. The full references for these documents can be found in the *Sources of Additional Information* section.

3.2 Air and Noise Pollution and Options for Prevention and Control

Although the most serious air pollution problems associated with the minerals industry occur during smelting, substantial air pollution can also occur at mining sites during excavation and transportation. In addition, the explosives used in mining operations represent an environmental hazard that may impair the hearing of employees and surrounding residents, and may damage natural formations and man-made structures in the vicinity of mining sites.

3.2.1 Dust

An important air pollution impact produced during mining is dust. Dust is created at all stages of the mining process, including excavation, processing, and transportation. Dust clouds may be carried far from the mine site depending on wind and other climatic conditions. As such, the harmful effects of mine dust may impair the health of residents who live near mining sites as well as that of mine employees.

Dust control methods at mine sites are aimed at reducing amounts and concentrations of dust produced and minimizing human exposure to the dust remaining. The most important element of dust control at underground mines is properly designed dust capture and removal integrated into the ventilation system. Ventilation design is a highly specialized field and ventilation engineers are often consulted during planning and evaluation of new sites. Water sprays are also widely used in processes such as the transportation of material and the crushing of ore. These sprays can greatly reduce the level of dust at the site. Surface stabilization of solid piles or tailing areas which can easily become airborne in windy dry conditions can be controlled by applying dust suppressant agents such as lignin sulfonates, magnesium chloride and other compounds if circumstances and use will not adversely affect nearby plants and aquatic life from runoff into streams.

3.2.2 Fumes and Exhaust

Despite the best attempts to control dust, there are areas in any mining operation where workers may be exposed to elevated dust concentrations. For these areas, it is important that a respirator program is in effect, including a provision for periodic fit testing. Modern mining techniques require the use of a variety of hazardous chemicals such as acids, mercury, and cyanide for ore processing. In addition, heavy machinery and explosives used throughout the excavation process produce harmful exhausts and gases. This section briefly describes the potential effects of these hazards on employees and provides recommendations for their control.

A serious hazard at underground mining operations results from exhaust gases released by diesel engines and fumes produced during blasting. These exhausts produce carbon monoxide and nitrogen oxide gas that can collect in underground cavities. Workers exposed to high concentrations of these gases risk serious illness and death. The design of proper ventilation systems at underground mining areas is therefore critical. Ventilation system plans are often reviewed by qualified experts before mine operations begin.

It is also important to carefully and continuously monitor levels of carbon monoxide and nitrogen oxide gas in active underground mines. Gas levels can be monitored with direct-reading devices containing built-in alarms. If gas concentrations approach dangerous levels, the alarms can signal workers to evacuate the area. Process controls and alarms on key variables such as pH and temperature are also commonly used to prevent releases of hazardous chemicals.

3.2.3 Noise

Explosives and heavy machinery are used regularly at mining sites, resulting in potentially harmful amounts of noise pollution. Miners subject to high noise levels for extended periods of time may become permanently deaf. The European Community has set limits for daily exposure at 85 decibels with no peak sounds above 140 decibels. Noise levels can be monitored and steps taken to reduce volumes where appropriate. Ear plugs or other noise-dampening devices may be appropriate for employees in some cases.

3.2.4 Blasting

The use of explosives for excavation is common in surface mining. Control of vibrational damage to natural formations is therefore an important environmental consideration. Damage to natural formations has been observed up to 500 meters away from blasting sites. Many mines limit the number of explosions, using millisecond delays between blasts to minimize concussion and noise, especially near population centers, natural scenic formations, wells, and stream channels.

Several states in the United States have established guidelines for preventing or minimizing vibrational damage. Listed below is a table established by the U.S. state of West Virginia for safe blasting distances.

Distance to Nearest Residence Building or Other Structure (meters)	**Max. Explosive Charge (kg)**
30	**2**
150	**45**
300	**180**
460	**410**
610	**730**
760	**1140**
910	**1630**
1060	**2220**
1220	**2900**
1370	**3670**
1520	**4530**

3.2.5 References for More Information on Air and Noise Pollution and Prevention Options

EPA's Office of Solid Waste's series on mining and the United Nations Environment Programme (UNEP) publication are both good sources for information on air pollution from mining dust. In addition, more detailed information about worker health effects from dust and noise exposure as well as other hazardous working conditions can be obtained by contacting the United States Occupational Safety and Health Administration (OSHA) in Washington D.C., the World Health Organization (WHO) in Geneva, or the International Labor Organization (ILO).

3.3 Environmental Impacts of Non-Modern and Small-Scale Mining Methods

Many of the environmental problems discussed above are common to medium and large scale mining operations using modern techniques. In many countries, however, small mining ventures using non-modern methods employ large numbers of people and have large cumulative effects on human health and the environment. In addition, mines in some countries employ traditional labor-intensive methods on a large scale. This section describes non-modern and small-scale mining, especially gold-mining, and its associated environmental problems. In addition, measures that governments can take to lessen the environmental impact of these mining operations are presented.

"Non-modern mining" refers to mining ventures that use hand tools and primitive extraction methods instead of heavy machinery and complex chemical purification technologies. These operations can be very large and well organized, as in the copper extraction industry in Peru. "Small-scale Mining" refers to these non-modern methods performed by collections of individual miners. In contrast to industrial mining, which is typically performed by large companies, small-scale mining is generally undertaken by individual prospectors with limited resources. Small-scale mining for gold takes place in many developing countries, including the Philippines, Brazil, Venezuela, and many countries in West and Central Africa. Historically, such small-scale gold mining has occurred in the context of a "gold rush" that brings large numbers of people to a previously rural area.

Non-modern mining has three principal environmental impacts. First, rural areas where mining occurs often lack roads, sewage and water systems, and health services to handle the population increase caused by a "gold rush" or by a rapid increase in employment opportunities at a company mine. This lack of services can lead to both public health and environmental problems. For example, the lack of proper wastewater facilities can lead to the pollution of surrounding ground and surface water, poisoning water supplies and endangering local flora and fauna. Second, the primitive equipment, methods, and conditions of non-modern mining can be hazardous to miners' health. Miners can poison themselves through improper use of toxic chemicals, such as mercury and cyanide, or develop chronic lung difficulties from dust in the mining environment. Third, when mining activity ceases, prospectors do not have the resources to restore excavated land to its prior state. For example, in Brazil, small-scale gold mining has caused deforestation of the rainforest.

Many developing nations regard small-scale mining as an opportunity for economic advancement of their citizens, and see these small ventures as a more equitable way of sharing a country's natural resources. In addition, companies that adopt non-modern methods can employ significant numbers of workers. Some nations are therefore reluctant to impose strict controls on small-scale and non-modern mining activity. In addition, small-scale miners are typically a migrant population, and are more difficult to regulate than large companies. Governments that want to reduce the environmental impacts of small-scale and non-modern mining, without eliminating the practice entirely, could consider the following actions:

Provide technical assistance to small-scale miners to encourage environmentally-sound mining practices;

Build appropriate infrastructure in rural areas to handle the influx of miners; and

Enact laws that restrict non-modern mining practices that damage the environment.

3.3.1 References for More Information on Non-Modern and Small-Scale Mining

The United Nations Environment Program document, *Environmental Aspects of Selected Non-Ferrous Metals Ore Mining*, discusses small-scale gold mining issues.

3.4 Mine Closure

When a mine closes, measures are often taken to minimize the future environmental impact of the abandoned mine site, as well as to ensure the safety of surrounding residents. Often efforts are made to make the mined land resemble pre-mining topography, approximate original soil material, and to reestablish the same or similar vegetative cover. Reclamation activity is often aimed at establishing a permanently-stable landscape that is environmentally compatible with the surrounding ecosystem.

Mine closure typically involves securing waste and tailings dumps, covering or “capping” mine pits and leach areas, and reclaiming and revegetating the land disturbed during mine operations. Often these closure activities are less expensive and more effective if they are planned for early in the life of a mine site. Many governments therefore require that plans for mine closure be included in an Environmental Impact Assessment developed before operations begin. Governments and regulatory agencies also normally require that mining operators post bonds or provide other financial assurances to cover all closure activities in case of default.

Mining operations where acid drainage is a problem or where leaching is used are of particular concern. Often acid drainage at these abandoned sites continues for many years after operations cease, causing serious water contamination. Cover systems for mine pits and leach areas are often used to minimize these lingering effects. Cover systems generally include some type of mine or leach area cap overlaid with a material capable of supporting vegetation. Sometimes the installation of a cover system is preceded by the detoxicification of leached ore piles to insure that residual toxic chemicals are properly neutralized. Capping entails the placement of a layer of material composed of natural soils and rock, clays, and/or synthetic liners over the leach pile or mine pit. Multilayered caps consisting of a layer supporting plant growth, a layer of loose soil that allows drainage, and a low-permeability layer that prevents exposure of mine rock are the most common. Capped soils may also be treated with lime or other chemicals to reduce the toxicity of the underlying waste pile. In addition, runoff from sites can still be monitored, and contaminated water can be treated, using the techniques described in the acid drainage section above.

After the mine pit and leach area are capped, the mine area can be reclaimed through restoration of the pre-mining topography and revegetation of the land. In many instances, leach and waste dumps have modified the land to such an extent that efforts at total reconstruction of pre-mining land shapes is impossible or prohibitively expensive. Nevertheless, trucks, shovels, and draglines used for waste hauling during active operations can be employed to construct roughly similar landscapes once operations are complete. Since dumping activity occurs throughout the active life of the mine, desired post-closure topography must be planned into the design of waste dumps and leach areas. Closure activity can then focus on refining these landscapes by trimming dump piles and preparing the ground for revegetation.

Revegetation minimizes erosion at closed mining sites, reduces wind-blown dust, absorbs contaminants harmful to humans, and helps reestablish natural ecosystems in the surrounding area. The ability of post-mining land to support plant life is determined by the properties of the soil in the area where plants lay down their roots, the seed mix, and the local climatology. Particularly important is the location of the mine since arid locations and those at high altitudes with short growing seasons represent extreme challenges to revegetation. Efforts are made to grade for minimum slope requirements and replace soil that approximates the pre-mining chemical and physical properties of the original soil. Often the most cost-efficient way to resoil is to save the soil from the area originally excavated. In instances where this is not possible, however, soil can be taken from the surrounding area or brought to the mining site expressly for revegetation.

4. PLANNING, MONITORING, ENFORCEMENT AND COMPLIANCE APPROACHES

Although there are a variety of approaches to managing mining-related environmental problems, a comprehensive program is often the most successful and cost effective. A successful program generally establishes environmental objectives through clearly defined requirements, sets voluntary goals on liabilities, balances planning, permitting, monitoring, enforcement, and builds compliance through education and cooperation between industry, government, and the surrounding community. The following are characteristics of effective mining environmental management programs in some countries:

Environmental management is given a high priority during the planning, licensing, and development of mining operations.

Environmental accountability within industry and government rests with high levels of management and policy-makers.

Employees at all levels have an individual responsibility for environmental management. Mine management ensures that adequate resources, staff, and training are available to implement environmental plans.

Industry and government involve the local community and other directly interested parties in the environmental aspects of all phases of mining activities.

Environmentally sound mining technologies and practices are adopted in all phases of mining activities. Best management practices are adopted to minimize environmental degradation.

It is important to emphasize that many of the environmental control technologies and recommendations discussed in the previous section require careful planning early in the mining process. They also need to be re-examined throughout the life of the mine as conditions change and initial assumptions need to be modified. Ventilation systems that minimize hazards to workers, diversion ditches and containment ponds that limit contamination of streams and rivers, and well-designed properly installed leach areas that reduce the potential for major contaminant releases all must be planned before operations begin if serious problems are to be avoided. In addition, ongoing monitoring is required to detect changes in the environment that pinpoint inadequacies of current controls or identify the need for maintenance. Finally, adequate attention to preparing a mine site for closure is necessary if acid drainage is to be minimized once a mine site is no longer active.

Environmental impacts are minimized when environmental considerations are an integral component of mining operations, from the planning stages through closure. This section considers a general approach for integrating environmental concerns into every stage of the mining process.

4.1 Using Environmental Impact Assessments During Planning

To bring environmental concerns into the initial stages of mining projects, governments and industry often use Environmental Impact Assessments (EIAs) when projects are first proposed. An EIA examines the potential environmental impacts of a project, and outlines ways in which these impacts can be avoided or mitigated through better project design. The EIA is a cyclical planning process involving government, industry, and involved citizens, that requires examination, review, and reformulation of project design until an approach acceptable to industry and regulators can be developed. EIAs typically address several key areas, including:

identification -- what will be the direct and indirect impacts of the project on the environment? what regulations apply?

prediction -- what will be the extent of the changes?

evaluation -- will the changes be significant? and

mitigation -- what can be done to avoid or reduce the impact?

EIAs address the entire lifespan of a mining operation, including measures for revegetation and closure. They are designed to address all of the major environmental issues associated with mining operations so that expected environmental impacts, planned control measures, and methods of monitoring are clear to governments and mining operators.

A suggested outline for an environmental assessment is included in the appendices at the end of this document. EPA's Office of Solid Waste, in cooperation with the Office of Federal Activities, prepared an EIA technical document and checklist to assist those reviewing EIA on mining projects. Excerpts are included in Appendix 3 which highlight the general environmental questions that should be raised and addressed to fully understand the environmental effects of any proposed mining project.

4.2 Monitoring Active Mines

Monitoring allows government regulators and mining operators to observe a mine's impact on the surrounding environment and to take steps to minimize that impact. Monitoring in and around a mine site is necessary to characterize baseline conditions and to identify changes in conditions during active mining and after mining has taken place. The information is used to identify unanticipated environmental effects, as well as to locate routine repair and maintenance needs. Monitoring provides input to decisions on appropriate mitigation and reclamation strategies. In addition, monitoring can indicate the loss of raw and refined material, and identify general operational inefficiencies that affect mine profitability.

Environmental conditions that are typically monitored include physical processes such as water flow, and chemical characteristics such as water quality. Health and safety measures, such as air quality of underground operations, medical monitoring, dust concentrations and stability of stored hazardous chemical are also subject to regular monitoring. Changes in fish and plant populations are also observed to measure the impact of contaminants on the surrounding environment. The frequency and complexity of monitoring activity must strike a balance between the expense of monitoring operations and the cost savings associated with early detection of environmental damage.

4.3 Establishing Technical and Performance Standards and Permitting for Mining

In most countries, mining, like other industrial activity, is subject to laws, regulations, and standards in many areas of operation. Environmental requirements such as waste disposal and control of water contamination are sometimes incorporated into these laws. Although mining laws are rarely specific and extensive enough to be considered a complete environmental control program, they often draw upon laws in related areas (e.g. general environmental legislation, and/or legislation on health, safety, and chemicals) to provide a legal framework for environmental protection. Some environmental issues that mining laws can incorporate into specific regulations or individual permits/licenses include:

Mine worker exposure limits and monitoring requirements;

Establishment of wastewater retention and treatment techniques, and safe management of contaminated runoff;

Soil erosion control and revegetation procedures during operation and after closure;

Numerical limits for discharges;

A requirement to prepare plans for solid waste and soil disposal prior to approval of operations including financial assurances such as bonding for all closure requirements.

Mandatory reclamation, bonding, and/or restoration of sites and disturbed areas, and removal of all unused structures and machinery; and

In addition, related legislation may cover aspects of environmental regulation of direct concern to the mining industry, including:

Laws governing land use and the impact of development on endangered species, tropical forests, and flora and fauna;

Laws governing the impact of development on indigenous cultures;

Water quality laws that limit discharges into streams or rivers;

Proper transport, storage, handling, and disposal of chemicals.

“Clean Air” laws that govern emissions of toxins in gases or dust; and

Controls for soil contamination by wastes and chemicals.

These environmental regulations can be packaged in a number of ways, depending in part on the existence of an environmental legal framework apart from laws governing mining. New laws can be drafted to build on, and be consistent with the existing legal structure. The appendix at the end of this document shows excerpts from environmental mining laws and regulations in the United States and Bolivia. These are intended to serve as examples and are not presented as the only or best responses to the environmental problems associated with mining activities in other countries or regions.

4.4 Compliance Monitoring and Enforcement Programs

This Document is intended to accompany the Principles of Environmental Enforcement Text, U.S. EPA, which describes the basic elements and approaches for establishing effective compliance strategies and enforcement programs. As a supplement to international efforts to advance effective environmental compliance and enforcement programs, the readers are referred as well to the UNEP IE training manual on Institution Building for Industrial Compliance and Proceedings of the series of International Conferences on Environmental Compliance and Enforcement for further discussion.

4.5 Mining Associations and General Sources of Information

Additional information on mining and the environment can be found through:

The American Mining Congress, 1920 N St., Suite 300, Washington D.C. 20036
Tel:(202)-861-2800
California Mining Association, 1 Capitol Mall, Suite 220, Sacramento, CA 95814

Tel (916) 447-1977, Fax: (916) 447-0348
Colorado Mining Association, 1600 Broadway, Suite 1340, Denver, CO 80202
Tel: (303) 894-0536, Fax: (303) 894-8416
Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401
Tel: (303) 273-3000, Fax: (303) 273-3278
The International Council on Metals and the Environment, 360 Albert St., Ottawa, Ontario, Canada, K1R7X7
Tel: (613)-235-4263
Environment-Neutral Drainage Program, 555 Booth Street, Ottowa, Ontario, K1AOG1
Tel: (613) 995-4681
Northwest Miner's Association, 10 North Post Street, Suite 414 Spokane, WA 99201,
Tel: (509) 624-1158, Fax: (509) 623-1241

5. APPENDICES

5.1 APPENDIX 1: Sample Environmental Regulations

5.1.1 Sample Outline of An Environmental Assessment Report

Environmental assessment reports are usually concise, limited to significant environmental issues, and aimed at project designers, and project decision-makers. The level of detail corresponds to the degree of potential impacts. The report often includes the following sections:

1. *Executive summary*: A summary of significant findings and recommended actions.

2. *Environmental regulations:* The policy, legal, and administrative framework related to the project. This is especially important in the case of co-financed projects when the requirement of many organizations must be accommodated.

3. *Project description:* A detailed description of the project, including its technical, geographic, ecological, economic, and social context. Include any off-site investments required as part of the project, for example, pipelines, roads, power plants, water supply, housing, storage facilities.

4. *Baseline data:* The study area's dimensions and a description of relevant physical, biological, and socio-economic conditions, including any changes anticipated before the project commences.

5. *Analysis of alternatives:* Alternatives to the proposed project, including the "no action" option. This section examines the potential environmental impacts, capital and recurrent costs, institutional capacities, training, and monitoring requirements for all design, site, technology, and operational alternatives.

6. *Environmental impacts:* The positive and negative impacts likely to result from the proposed project, and comparison with alternatives. This section reviews the extent and quality of available data, identifies key gaps in data, estimates uncertainties associated with predictions, and specifies topics that do not require further attention.

7. *Mitigation plan:* Feasible, cost-effective mitigation measures that may reduce adverse impacts on the environment to acceptable levels. The plan can consider compensatory measures if mitigation cannot be implemented effectively.

8. *Monitoring plan:* This section recommends a monitoring plan, including implementation by a designated monitoring agency or individual, cost estimates and other pertinent information such as training.

9. *Appendices:*

Personnel and organizations involved in the environmental assessment.

Persons and organizations contacted, including addresses and telephone numbers.

References to all written materials used in study preparation. This is especially important given the large amount of unpublished documentation often used.

Record of interagency/forum meetings. This includes lists of both those invited and those that actually attended, as well as a summary of the discussions.

5.1.2 Excerpts from the Bolivian Mining Code

Article 70

The tapping of mineral resources shall take account of integrated raw material management, the processing of waste material, the safe disposal of tailings, waste and clearance materials, efficient energy use and rational deposit management.

Article 71

Mining operations shall, both during and on completion, make provision for recovery of the areas mined so as to reduce and control erosion, stabilize the land and protect water resources, streams and hot springs.

Article 72

The Ministry of Mining and Metallurgy shall, in coordination with the National Secretariat for the Environment, establish appropriate technical standards in order to set permissible limits for the various actions and effects relating to mining activities.

Article 92

Any individual or group shall have a right to participate in environmental management, in accordance with the provisions of this Law, and shall have a duty to play an active role in the community in the defense and/or conservation of the environment and, if necessary, to utilize the rights conferred on them by this Law.

Article 105

Any environmental crime is committed by anyone that violates paragraphs (2) and (7) of Article 216 of the Criminal Code and specifically when someone:

(a) poisons, contaminates or adulterates water intended for public consumption, for use in industrial agriculture or fisheries, to levels above the permissible limits to be established in respective regulations;

(b) violates livestock health standards or spreads epizootic diseases or crop pests.

Such crimes shall be subject to one to ten years imprisonment.

Article 107

Anyone that dumps or discharges untreated wastewater, chemical or biochemical liquids, objects and any kind of wastes into/on to watersheds, shores/beaches, aquifers, river basins, rivers, lakes, lagoons or ponds, that are capable of polluting or degrading the water and exceed the limits to be established in the respective regulations, shall be subject to one to four years' imprisonment and a fine of 100 percent of the damage caused.

Article 112

Anyone that stores, dumps or markets industrial wastes in liquid, solid or gaseous form that endanger human life and/or cannot be assimilated by the environment, or that do not comply with health and environmental protection standards, shall be subject to up to two years' imprisonment.

5.1.3 Excerpts from United States EPA Regulations

§ 440.102 Effluent limitations representing the degree of effluent reduction attainable by the application of the best practicable control technology (BPT).

Except as provided in Subpart L of this part and 40 CFR 125.30 through 125.32, any existing point source subject to this subpart must achieve the following effluent limitations representing the degree of effluent reduction attainable by the application of the best practicable control technology currently available (BPT):

(a) The concentration of pollutants discharged in mine drainage from mines operated to obtain copper bearing ores, lead bearing ores, zinc bearing ores, gold bearing ores, or silver bearing ores, or any combination of these ores in open-pit or underground operations other than placer deposits shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cu	30	15
Zn	15	75
Pb	6	3
Hg	002	001
Ph	(*)	(*)

**Within the range 6.0 to 9.0*

(b) The concentration of pollutants discharged from mills which employ the froth flotation process alone or in conjunction with other processes, for the beneficiation of copper ores, lead ores, zinc ores, gold ores, or silver ores, or any combination of these ores shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cu	30	15
Zn	10	5
Pb	6	3
Hg	002	001
Cd	10	05
Ph	(*)	(*)

**Within the range 6.0 to 9.0*

(c) (1) Except as provided in paragraph (c) of this section, there shall be no discharge of process wastewater to navigable water from mines and mills which employ dump, heap, in situ leach or vat leach processes for the extraction of copper from ores or ore waste materials. The Agency recognizes that the elimination of the discharge of pollutants to navigable waters may result in an increase in discharges of some pollutants to other media. The Agency has considered these impacts and has addressed them in preamble published on December 3, 1982.

(2) In the event that the annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility exceeds the annual evaporation a volume of water equivalent to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(d) (1) Except as provided in paragraph (d) of this section, there shall be no discharge of process wastewater to navigable waters from mills which extract gold or silver by use of the cyanidation process. The Agency recognizes that the elimination of the discharge of pollutants to other media. The Agency has considered these impacts and has addressed them in the preamble published on December 3,1982.

(2) In the event that the annual precipitation falling on the treatment facility exceeds the annual evaporation, a volume of water equivalent to the difference between annual precipitation falling on the treatment facility and the drainage area contributing surface runoff to the treatment facility and annual evaporation may be discharged subject to the limitations set forth in paragraph (a) of this section.

(e) The concentration of pollutants discharged in mine drainage from mines producing 5,000 metric tons (5,512 short tons) or more of molybdenum bearing ores per year shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cd	10	05
Cu	3	15
Zn	10	5
Pb	6	3
As	10	5
Ph	(*)	(*)

**Within the range 6.0 to 9.0*

(f) The concentration of pollutants discharged in mine drainage from mines producing less than 5,000 metric tons (5,512 short tons) or discharged from mills processing less than 5,000 metric tons (5,512 short tons) of molybdenum ores per year by methods other than ore leaching shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	50	30
Ph	(*)	(*)

**Within the range 6.0 to 9.0*

(g) The concentration of pollutants discharged from mills processing 5,000 metric tons (5,512 short tons) or more molybdenum ores per year by purely physical methods including ore crushing, washing, jigging, heavy media separation shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	50	30
Cd	10	05
Cu	30	15
Zn	10	5
As	10	5
pH	(*)	(*)

**Within the range 6.0 to 9.0*

(h) The concentration of pollutants discharged from mills processing 5,000 metric tons (5,512 short tons) or more molybdenum ores per year by froth flotation methods shall not exceed:

Effluent characteristic	Effluent limitations	
	Maximum for any 1 day	Average of daily values for 30 consecutive days
	Milligrams per liter	
TSS	30	20
Cd	10	05
Cu	30	15
Zn	1.0	5
As	1.0	5
pH	(*)	(*)

**Within the range 6.0 to 9.0*

5.2 APPENDIX 2: Sample Cost Estimates

Listed below are cost estimates for several key environmental control mechanisms. These are drawn from examples in the U.S. from Copper Dump Leaching and Management Practices That Minimize The Potential For Environmental Releases, published by the U.S. Department of Commerce, National Technical Information Services. The report was published in 1988.

These figures give a rough approximation of the costs for environmental safeguards. Obviously costs will vary widely according to local conditions.

Table 1: 1986 Liner Installation Costs

Liner Type	Installed Cost, $\$/\text{m}^3$
Soil-bentonite	1.90
Soil Cement	

(15 cm thick and sealer) 3.30
Asphalt-concrete
(10 cm thick, hot mix) 7.30-10.2
Chlorinated polyethylene (CPE) 7.4-12.7
High-density polyethylene (HDPE) (60 mil) 8.6

Table 2: 1986 Costs for Establishing Surface Water Controls
Operation OutputUnit Cost, $
General Excavation
Front-end Loader
Bulldozer
35-40 m^3/h
40-120 m^3/h
0.8-1.4/m^3
1.2-1.1/m^3
Ditch excavation
0.9 m deep
1.2 m deep
75-100 m/day
50-70 m/day
4.78-7.00/m
6.8-10.20/m
Building embankments;
spreading, shaping, compacting

Material delivered by scraper:

Material delivered by backdump:

0.55-1.1/m^3

1.10-1.70/m^3
Ditch Stabilization
Riprap
Gunite (with 5-cm mesh, 2.5 cm thick)
Hauling, spreading gravel
47 m^3/day

790 m^3/day
21.7-25.8/m^3

7.00-8.00/m^3

Table 3: Typical Costs for Capping and Revegetation

Material Available on Site	Clay	Sand	Soil
Excavation	1.86	1.00	1.17
Loading	1.58	0.84	0.98
Hauling	13.39	3.39	3.39
Spreading and Compacting	12.52	0.55	2.52
Material purchased off site			
Purchase	10.90	7.88	13.70
Transportation	7.35	7.35	7.35
Spreading	2.52		

5.3 APPENDIX 3: Checklist for Environmental Impact Assessments of Proposed Mining Projects

The following is an excerpt from the U.S. EPA Publication: TECHNICAL DOCUMENT - Background for NEPA Reviewers: Non-Coal Mining Operations, December 1994, U.S. Environmental Protection Agency, Office of Solid Waste, Special Waste Branch, December 1994. It summarizes the general environmental questions that should be raised and addressed to fully understand the environmental effects of any proposed mining project.

SUMMARY OF QUESTIONS THAT SHOULD BE ASKED WHEN REVIEWING NEPA DOCUMENTATION

The following are questions that may be appropriate to ask about mining operations when reviewing NEPA documentation:

General Questions Applicable to Most Mining Operations

- Has the local geology been defined, including all stratigraphic layers to be encountered in mining?

- Has baseline data been collected to establish the surface water flow rates (including seasonal variability) and water quality (including sediments) prior to disturbance? Has the physical condition of streams within the project area been determined? Has aquatic life been adequately characterized? What are the designated and actual uses of surface water in the project area and downstream?

- What is the overall water balance for the facility? Have all potential discharges to groundwater and surface water been anticipated and described (and controls provided, as appropriate)? Does the applicant intend to obtain all necessary NPDES permits? Can the facility ensure compliance with applicable water quality standards?

- Has the hydrogeology of the site been mapped/clearly delineated? Has baseline groundwater quality been determined? What are the designated and actual uses of groundwater? What are the locations of all wells in the area and what are their uses?

- Has the erosion potential been quantified? Have the appropriate runoff models been used? Are the assumptions defined and justified? Have the potential impacts on surface water been determined? Wherever possible, has model data been validated by comparison to actual field data? What runon and runoff control measures, including BMPs, will be used? Will they be maintained during active operations and afterward?

- Have baseline studies been conducted to characterize aquatic and terrestrial life/habitats prior to mining/disturbance? Are there any threatened, endangered, or rare species and/or critical habitats in the area? Have the requirements of the Endangered Species Act been followed? What measures will be taken to protect wildlife/habitat, including siting?

- Will any disturbance impact wetlands? If yes, what mitigation measures will be taken? If jurisdictional wetlands are impacted, have CWA §404(b) requirements been followed?

- Are the cumulative impacts over the life of the mine (including possible expansions) described?

- Is public access to the site controlled? Is wildlife access to the site controlled? Is the control described?

- Have the pre- and post-mining land uses been compared?

- What wastes will be generated? In what volumes? What are the expected compositions of waste materials? What management practices will be used? Do waste/materials management units have liners? Will adequate surface preparation be performed prior to liner installation? Do units have drainage collection systems? Leak detection systems?

- Have leachability tests been performed on wastes (for metals, sulfates, and other potential pollutants)? Have radionuclide levels been determined, (where appropriate)? If there is sulfide mineralization, has ARD/AMD testing been conducted? Is there a plan to continue waste characterization/acid generation testing during operations?

- Where wastes can generate ARD, what measures will be used to minimize acid generation and/or provide treatment prior to discharge? Are mitigation measures for ARD/AMD based on proven technologies (e.g., conventional treatment), state-of-the-art technologies, or passive treatment practices (e.g., wetlands)? If unproven methods are to be used, how will performance be monitored and have contingencies been provided for?

- Is there a multi-media monitoring program (including surface and groundwater, sediments, and air)? Are proposed parameters representative of likely discharges? Where and how often will monitoring occur? Do monitoring frequencies account for seasonal/operational variability? If impacts are detected, what actions will be taken? How and to whom will data be reported?

- Is there a spill prevention and response plan? Does it address all areas where spills are likely to occur? Is secondary containment provided for storage areas and pipelines?

- Is there a reclamation/closure plan? Will concurrent reclamation be performed? Have proposed revegetation procedures been successfully used in the area previously? Has long-term mine water management been addressed? After closure, will drainage systems/discharges continue to be monitored/maintained/addressed?

- Has the baseline air quality been determined? How will air emissions be minimized? Have stack and fugitive emissions been characterized/predicted/modelled? What technologies will be used to control such emissions? How will any air pollution control wastes be managed? Does the project plan ensure compliance with Federal and State CAA requirements? Has the baseline meteorology for the area been adequately characterized and data made available?

Mine Workings

- Is groundwater pumped to control water inflow into the mine workings/pit? At what rate is the water pumped? Have the extent of aquifer drawdown and the subsequent impacts been described?

- Are all aquifers and surface waters that might be impacted identified and included in a monitoring plan? Are groundwater discharge areas (wetlands, ponds, lakes, streams, seeps, etc.) included in a monitoring plan? Does the monitoring plan account for seasonal variances? If an impact is suspected, what responses are proposed?

- What are the consequences when mining and water withdrawal cease and the pit/mine workings are subsequently flooded? What action will be taken once mining stops and pumping is no longer employed to dewater the workings?

- Have the characteristics of the mine water been determined, including AMD? Will collection and treatment be provided, as appropriate?

Waste Rock/Overburden

- How much overburden, waste rock, and ore will be excavated and stored or disposed of? Are planned management units described fully?

- Have leaching characteristics of waste rock/overburden been determined (including ARD)? How often during mining will leaching characteristics be evaluated? What measures are proposed to ensure protection of groundwater and surface water from constituents leaching from waste rock dumps or overburden piles?

- Has the stability of waste management units/impoundments been determined? Did the analysis consider any seismic risk? Will adequate drainage of berms be provided? How will stability be measured during and after active operations?

- Is closure and reclamation of these waste rock/overburden described in detail? Is recontouring of the piles to stable slopes required? Will concurrent reclamation be conducted, if appropriate?

Tailings Impoundments

- What are the constituents in the tailings? What type of sampling was conducted and was it representative? Have leaching characteristics of tailings been determined? If so, what methods were employed? How often will sampling and characterization be conducted during operation? Have reagents used during beneficiation been addressed in the constituent analysis? What measures are proposed to ensure protection of groundwater from constituents leaching from tailings impoundments?

- What other wastes does the operator dispose of in the tailings pond or tailings area? How are these materials managed as wastes?

- Does the project plan provide for maximum possible water reclaim/re-use? Have all potential source reduction/recycling opportunities been identified and reviewed?

- Has adequate precipitation and snow melt data been compiled? Have all collection/containment and treatment systems been properly designed to manage up to a specific storm event and snow melt contributions (i.e., are they appropriate for the predicted water balance)?

- What analysis was conducted to determine stability of any structures (i.e., dams or berms) associated with the tailings pile or pond? Did the analysis consider snow melt contributions? Did the analysis consider seismic risk? Does the document contain detailed drawings so that structural stability can be determined? Have runon, runoff and unit capacity been evaluated? Have these evaluations considered storm water and annual snow melt?

- Does the plan provide for maximum recycling/reuse of pond water? Is there a surface water discharge? What are the expected flow rates and discharge characteristics? Has adequate treatment been provided, if necessary?

- Is the closure and reclamation of the tailings ponds described in detail? What steps constitute closure? Is recontouring of the pond required? Is a cap proposed?

Copper Dump Leach Operations and SX/EW Plants

- What is the planned design of the dumps? How much material will be leached? How will solution be applied? Has the stability of been determined? How will stability be measured during and after active operations?

- What are the characteristics of dump materials, including ARD potential? What type of sampling/testing was conducted and was it representative? What analytical method was used to determine the constituents and what were the results? Are there any other wastes generated (e.g., bleed streams)? What are their characteristics and how will they be managed?

- Is the leaching process a closed loop system (e.g., is all solution collected)? What will the water balance be after leaching ceases? Have the capacities of the solution transport ditches and collection ponds been evaluated considering process solutions <u>and</u> runoff/snow melt contributions? Are solution ditches and ponds lined/double-lined? Is there a leak detection/collection system?

- How will reagents be transported/stored? Is there secondary containment/leak detection? Is there a spill prevention and response plan?

- How will the dump affect ground and surface water quality during leaching operations and after closure? Will monitoring be performed? Where, when, and for which parameters?

- Will the dump be operated on a seasonal basis? Are temporary closure procedures proposed? Will the dump be monitored on a regular basis during the inactive season?

- What is the proposed closure/reclamation plan? Will concurrent reclamation be conducted, if appropriate?

Cyanide Leaching Operations

- Are the heap leach pad and process ponds lined appropriately? Is a leak detection system in place and operational? Is an adequate monitoring plan proposed? What triggers (chemical constituents) are to be employed within the monitoring plan to signify the possibility of a leak? What are the proposed contingency plans in the event a leak is detected?

- Has the stability of heaps/spent ore management units/impoundments been determined? Did the analysis consider any seismic risk? How will stability be measured during and after active operations?

- Has adequate precipitation and snow melt data been compiled? Have all collection/containment and treatment systems been properly designed to manage up to a specific storm event and snow melt contributions (i.e., are they appropriate for the predicted water balance)?

- Are the closure of heaps described in detail? What is the closure treatment method? What "standard" will be used to measure successful closure? Do spent heaps present risks after closure, including ARD potential?

- Will the heap be operated on a seasonal basis? Are temporary closure procedures proposed? Will the heap be monitored on a regular basis during the inactive season?

- Will concurrent reclamation be conducted, if appropriate?

- How will reagents be transported/stored? What measures will be taken to prevent spills? Is there a spill prevention and control plan being developed?

- What measures will be used to limit human and wildlife access to the leaching operation?

In Situ **Mining**

- What are the proposed lixiviants? Is there demonstration as to the integrity of the target aquifer? Are injection and recovery rates sufficient to maintain a cone of depression within the target aquifer? Are monitoring plans developed to detect constituents of the lixiviant or an appropriate byproduct? What are the contingency plans in the event of an excursion? What methods are proposed for aquifer restoration?

- Have waste streams been identified? What are the expected compositions of waste materials? How are the end products of each waste stream managed? Have radionuclide levels been determined, (where appropriate)?

- Are solution ditches and ponds lined? Is there leak detection? Is there a plan to address spills and leaks?

Milling Operations

- What types of beneficiation will be used at the mill? What are the waste streams associated with these operations? What are the constituents of each waste stream? What type of sampling was conducted to provide the description and was it representative? Were the waste streams tested using the Toxicity Characteristic Leaching Procedure (TCLP) or other test method? What were the results?

- How will air emissions be minimized? What technologies will be implemented for fugitive dust emission control? What performance standards were described for these technologies? How will air pollution control dust be managed? If air pollution control dust will be reused, in what process will it be reused?

- How will waste streams be managed? Will on-site ponds be used? Will water be recycled back to the process?

- Is closure and reclamation of the mill and surrounding area described in detail? Will the mill be disassembled after the operation is closed? Is the closure and reclamation proposed for the site described in detail?

- How will reagents be transported/stored? Is there secondary containment? Is there a plan to prevent/address spills or leaks of reagents, products, and wastes?

Smelting/Refining Operations

- What are the waste streams associated with the smelter or refining operation? What are the constituents of each waste stream? What type of sampling was conducted? Was it representative? Were the waste streams tested using the TCLP or other test method? What were the results?

- How will waste water streams be treated and/or managed? Will on-site ponds be used? If so, will they be lined? Will the water be recycled back to the process?

- How will slag from the smelting furnace be managed? Will any be recycled back to the concentrator?

- How will emissions be minimized? What technologies will be implemented for fugitive dust and gas emission control? What performance standards were described for each of these technologies? How will air pollution control dust be managed? If air pollution control dust will be reused, in what process will it be reused? How and where will air pollution control sludge be managed?

- Where and how are wastes such as bleed electrolytes, acid rinsing, tank bottoms, vessel cleanouts, used oil, etc. being disposed of? Is the facility permitted?

- For metallurgical sulfuric acid plants, how will acid blowdown be handled? What are the characteristics of the acid plant blowdown (constituent concentrations, etc.)?

Phosphoric Acid Production/Phosphogypstacks

- What is the specific manufacturing process used at the site? What is the water balance for the facility? What are the current and planned dimensions for the phosphogypstack and cooling ponds?

- What is the pH and chemical composition (phosphorous, sulfur, fluoride, radionuclides, metals, etc.) of the phosphogypsum and process wastewaters/cooling pond waters? If a leaching test was performed on the phosphogypsum, how was it performed? Because leachate is expected to have an extremely low pH (<1), a standard Toxicity Characteristic Leaching Procedure (TCLP) will likely underestimate leaching potential.

- What other wastes/wastewaters does the operator dispose of in the stacks and/or cooling ponds?

- What is the capacity of the drainage system? Does it take local climatic factors into consideration? Is overflow anticipated? If yes, how will it be managed?

- Was an analysis conducted to determine the structural stability of the phosphogypstacks? Has the analysis been certified by a professional engineer (PE)? If applicable, did the analysis consider snow loading? Does the documentation include drawings to verify the structural stability?

- What measures will be used to limit public and wildlife access to the phosphogypstacks?

- Is there a closure plan for the phosphogypstacks? How long will be required for the stack to fully drain? Will environmental monitoring continue after closure as long as the potential for impacts remain?

5.4 APPENDIX 4: The Berlin Accords

As the Berlin Round Table drew to a close, a series of discussions were held to obtain a consensus of the views amongst participants at the meeting. This appendix comprises the full document submitted.

Worldwide long-term economic development can best be achieved through the pursuit of sustainable development policies comprising a balance of economic, socio-cultural and environmental protection measures. While taking into account global environmental concerns, each country should apply this concept to meet the needs of its environment and economic circumstances.

Sustainable mining activities require good environmental stewardship in all activities, from exploration and processing to decommissioning and reclamation. It acknowledges the importance of integrating environmental and economic considerations in the decision-making process and the fact that mineral deposits are unique in their occurrence. It recognizes the importance of mining to the social, economic, and material needs of society, in particular for developing countries, and the minerals, notably metals, offer great potential for the use of future generations through increased recycling programmes.

Sustainable mining under appropriate environmental guidelines is based on interaction between industry, governments, non-governmental organizations and the public, directed towards optimizing economic development while minimizing environmental degradation. The need for such guidelines is recognized by industry, governments, and international agencies. It is also recognized that the political will of governments, together with the commitment of industry management and that of the community, are the essential conditions needed to enforce environmental legislation and, more importantly, to ensure compliance with all applicable laws for the protection of the environment, employees, and the public.

5.4.1 Addressed to the Mineral Sector

Governments, mining companies, and the minerals industries should as a minimum:

1. Recognize environmental management as a high priority, notably during the licensing process and through the development and implementation of environmental management systems. These should include early and comprehensive environmental impact assessments, pollution control and other preventative and mitigative measures, monitoring and auditing activities and emergency response procedures.
2. Establish environmental accountability in industry and government at the highest management and policy-making levels.
3. Encourage employees at all levels to recognize their responsibility for environmental management and ensure that adequate resources, staff, and requisite training are available to implement environmental plans.
4. Ensure the participation and dialogue with the affected community and other interested parties on the environmental aspects of all phases of mining activities.
5. Adopt best practices to minimize environmental degradation, notably in the absence of specific environmental regulations.
6. Adopt environmentally sound technologies in all phases of mining activities and increase the emphasis on the transfer of appropriate technologies which mitigate environmental impacts, including those from small-scale mining operations.
7. Seek to provide additional funds and innovative financial arrangements to improve environmental performance of existing mining operations.
8. Adopt risk analysis and risk management in the development of regulation and in the design, operation, and decommissioning of mining activities, including the handling and disposal of hazardous mining and other wastes.
9. Reinforce the infrastructure, information systems service, training, and skills in environmental management in relation to mining activities.
10. Avoid the use of such environmental regulations that act as unnecessary barriers to trade and investment.
11. Recognize the linkages between ecology, socio-cultural conditions and human health and safety, both within the workplace and the natural environment.
12. Evaluate and adopt, wherever appropriate, economic and administrative instruments such as tax incentive policies to encourage the reduction of pollutant emissions and the introduction of innovative technology.
13. Explore the feasibility of reciprocal agreements to reduce transboundary pollution.
14. Encourage long-term mining investment by having clear environmental standards with stable and predictable environmental criteria and procedures.

5.4.2 Addressed to Development Assistance Agencies

Multilateral and bilateral assistance agencies have an essential role to play in furthering environmental management, particularly in developing nations, and in assisting these nations in programmes to protect their environment, both nationally and as part of the global environmental system. Accordingly, they should:

1. Accord high priority to the mitigation of environmental degradation associated with mining in developing countries to achieve high environmental performance.
2. Initiate, as an integral part of any exploration and mining project, environmental institution building programmes. Special support should be giving to countries actively working to improve their environmental capabilities.
3. Require that all mining projects supported shall contain a training component that will include specific training on environmental awareness and its application to the mining.
4. Support increased research regarding the development of new processes, with fewer environmental impacts, including recycling.
5. Support the development of activities that would mitigate adverse effects on the socio-cultural fabric and the ecosystem. To achieve this objective, international agencies should give priority to education and training which increase awareness of these issues and allow the affected community to participate in decision-making.
6. In supporting mining projects, agencies should also take into account the following:
    rehabilitation of displaced population;
    environmental history of the country;
    large-scale impact on socio-economic patterns;
    the overall economic balance of the project vis-a-vis its total environmental impact;
    the impact on other natural resources and ecologically sensitive areas (e.g. protected forest lands, mangroves, wildlife parks, and neighboring waterbodies.)
7. Promote conferences and policy research on environmental management practices and technologies, and ensure the dissemination of this information.
8. Support and promote regional co-operative programmes to achieve sustainable development of mineral resources.
9. Adopt environmentally safe methods of mining and processing for existing projects. 10. Increase and co-ordinate their assistance to developing nations in the field of environmental policies management.

5.5 APPENDIX 5: Annotated Bibliography

5.5.1 Accessing Information on Mining

A number of organizations have compiled information in recent years on the environmental impacts of mining. These sources can be contacted by phone, or in come cases via the internet, for more detailed information on specific topics. Major sources of information include:

> *The U.S. Environmental Protection Agency, which provides information on mining through the National Technical Information System (NTIS) or through the internet (see the box below). The NTIS can be contacted by calling (703) 487-4600 and requesting a document by its NTIS number (e.g., PB88-162631). Some of the documents available through*

the NTIS are identified in section 5.5.4.

The U.S. Bureau of Mines, a leading research agency on advanced mining methods and environmental technology for mine remediation, can be contacted in Washington D.C. at (202) 501-9770.

The United Nations Environment Program (UNEP) has conducted a number of conferences and prepared various documents on the environmental impacts of mining. They can be contacted at: The United Nations Environment Program (UNEP), Industry and Environment Program Activity Center, 39-43, Quai Andre Citroen, 75739 Peris Cedex 15 - France. Telephone: 33 (1) 40 58 88 50.

Additional information on mining and the environment can be found through:

The American Mining Congress, 1920 N St., Suite 300, Washington D.C. 20036
Tel:(202)-861-2800

California Mining Association, 1 Capitol Mall, Suite 220, Sacramento, CA 95814
Tel (916) 447-1977, Fax: (916) 447-0348

Colorado Mining Association, 1600 Broadway, Suite 1340, Denver, CO 80202
Tel: (303) 894-0536, Fax: (303) 894-8416

Colorado School of Mines, 1500 Illinois Street, Golden, CO 80401
Tel: (303) 273-3000, Fax: (303) 273-3278

The International Council on Metals and the Environment, 360 Albert St., Ottawa, Ontario, Canada, K1R7X7
Tel: (613)-235-4263

Mine Environment-Neutral Drainage Program, 555 Booth Street, Ottowa, Ontario, K1AOG1
Tel: (613) 995-4681

Northwest Miner's Association, 10 North Post Street, Suite 414
Spokane, WA 99201
Tel: (509) 624-1158, Fax: (509) 623-1241

In addition, most international embassies will have access to their country's mining codes.

There are a number of good, practical sources that we have used extensively for the preparation of this support package and that can provide policy-makers with additional information as needed. These are discussed in more detail below.

5.5.2 The Mining Process

The following sources cover general and specific techniques for the extraction and processing of minerals. In addition, the reference from the U.S. EPA Office of Solid Waste on copper mining covers pollution prevention techniques and environmental controls. It includes a number of detailed case studies on environmental problems at copper mines in the United States.

U.S. Environmental Protection Agency, *Technical Resource Document: Copper, Office of Solid Waste,* EPA, 1994.

This report describes all of the major components of the copper mining process including types of mines, leaching operations, and waste products.

Contact: U.S. Environmental Protection Agency, Office of Solid Waste, 401 M Street S.W., Washington D.C. 20460

U.S. Environmental Protection Agency, *Extraction and Beneficiation of Ores and Minerals: Volume 4 Copper,* Office of Solid Waste, EPA.

This report provides an informative, non-technical description of copper mining methods and their environmental effects. It also contains a description of current U.S. regulations and the organization of mining regulatory administration in the United States. The document also contains several site case studies detailing environmental inspections at U.S. mining operations.

Robert W. Bartlett Solution Mining: *Leaching and Fluid Recovery of Materials,* Philadelphia, Pennsylvania: Gordon and Breach Science Publishers.

This book describes various leaching methods as well as procedures that can be taken to limit the environmental damage caused by the leaching process. It is written at a fairly advanced level and requires an understanding of chemistry for full comprehension of the details.

Contact: Gordon and Breach Scientific Publishers, P.O Box 786 Copper Station, New York , New York, 10276
Tel: (718) 273-4700

A.B. Cummins and I.A. Givens, *SME Mining Engineering Handbook,* Society of Mining Engineers of the American Institute of Mining, New York, NY: Metallurgy, and Petroleum Engineers, Inc., 1973.

Contact: Society of Mining Engineers of the American Institute of Mining, Metallurgy, and Petroleum Engineers. P.O. Box 625002 Littleton,Co. 801-62-5002.
Tel: (303)-973-9550

A standard text in the industry, this manual presents detailed information on mine planning and operations.

5.5.3 Pollution Prevention and Environmental Control Technologies

These references touch on most pollution prevention and environment controls applicable to many types of mining. More detailed references to specific environmental problems can be found in the sections that follow.

M. Sengupta, *Environmental Impacts of Mining: Monitoring, Restoration, and Control,* Boca Raton, Florida: Lewis Publishers, 1993.

This book provides a superb overview of the environmental impact of mining. It presents specific information on control and prevention options for a number of environmental problems, including acid mine drainage, hydrologic impact, acid rock drainage, erosion, and sediment control.

Contact : CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida 33431. Tel: (407) 994-0555

United Nations Environment Program, *Environmental Aspects of Selected Non-Ferrous Metals Ore Mining, A Technical Guide,* Paris, France: UNEP, 1991.

This report provides information on the mining process, major environmental problems, and some control and prevention options for environmental problems. The report is written for the non-technical reader and contains numerous notes detailing other sources of information. The section, Procedures for Environmental Control, is particularly good for establishing an overall environmental strategy for mining.

Contact: United Nations Environment Programme, Industry and Environment Programme Activity Centre, 39-43 Quai Andre Citroen, 75739 Paris Cedex 15-France. Tel: 33 (1) 40 58 88 50. Fax 33 (1) 40 58 88 74

U.S. Department of the Interior, Bureau of Mines, *Selected Publications and Papers of the Bureau of Mines, 1993-1994: Environmental Technology*, August, 1994.

This report contains abstracts for Bureau of Mines publications regarding environmental technology and mines.

U.S. Environmental Protection Agency, *Extraction and Beneficiation of Ores and Minerals: Volume 4 Copper,* Office of Solid Waste, EPA.

See description under 'THE MINING PROCESS'

U.S. Environmental Protection Agency, Office of Solid Waste/Office of Federal Activities, *Background for NEPA Reviewers -- Non Coal Mining Operations*, EPA, December, 1994.

This report provides a general description of mining operations at non-coal mining sites, potential environmental impacts associated with these operations, and possible prevention/mitigation measures that may be taken. The report is intended for use by EPA staff in conducting National Environmental Policy Act (NEPA) reviews of mining site decisions. Appendix 3 contains an excerpt from this document highlighting the general environmental questions that should be addressed to fully understand the environmental effects of any proposed mining project.

U.S. Environmental Protection Agency, Office of Solid Waste, *Report to Congress on Solid Wastes from Mineral Processing: Volume II, Methods and Analyses*, EPA, July, 1990.

This report reviews the source and volume of mining wastes produced annually, present disposal and utilization practices, potential risks to human health and the environment from these wastes, alternatives to current disposal methods, and cost and other considerations associated with the alternatives. The report was produced as a result of EPA's exclusion of mining wastes from regulation under the Resource Conservation and Recovery Act (RCRA) until more information could be gathered about the issue.

5.5.4 Acid Mine Drainage and Leaching

U.S. Department of Agriculture, *Acid Drainage From Mines on the National Forests,* Forest Service, March, 1993.

This article details acid mine drainage in U.S. national forests and research efforts to control its impact.

Contact: U.S. Forest Service, 14 and Independence Ave, S.W. Minerals and Geology Staff, Fourth Floor Central Wing, Washington D.C. 20250
Tel: (202)-205-1224

U.S. Department of Interior, Bureau of Mines, 810 7th Street N.W., Dept of Environmental Technology, Mail Stop 6205, Washington D.C. 20241 Tel:(202) 501-9271

PEI Associates INC, *Copper Dump Leaching and Management Practices that Minimize the Potential for Environmental Releases,* Cincinnati, Ohio: U.S. Department of Commerce, National Technical Information Service PB88-155114, January, 1988.

This report presents a description of the extent of copper dump leaching in the U.S., the potential for environmental impact, and management practices that can be used to minimize environmental releases. This report is highly technical and provides detailed information on copper leaching systems.

Contact: Hazardous Waste Engineering Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45246.
Tel: (513)-569-7562

5.5.5 Information on Mining and Mineral Processing from EPA's Office of Solid Waste, Mining Waste Section

Documents Prepared by EPA Office of Solid Waste

Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale, EPA, December 31, 1985. NTIS # PB88-162631

Report to Congress: Wastes from Mineral Processing, EPA, July 1990.
NTIS # PB90-258492

Strawman II, Recommendations for a Regulatory Program for Mining Waste and Materials Under Subtitle D of the Resource Conservation and Recovery Act, EPA, May 21, 1990. NTIS #PB91-178418

Summary of Data Presented in the Background Document for Effluent Limitations Guidelines and Standards - Ore Mining and Dressing Point Source Category.
NTIS # PB94-113388

Summary of Data Presented in the Background Document for Effluent Limitations Guidelines and Standards - Mineral Mining and Processing Point Source Category.
NTIS # PB94-113396

Summary and Technical Review of Supporting Literature for the 1985 Report to Congress on Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale. NTIS # PB94-113404

Mining Sites on the National Priorities List - NPL Site Summary Reports (listed in alphabetical order by the name of the NPL site).

Volume I - Aluminum Company of America to Cleveland Mill.
NTIS # PB92-124767

Volume II - Commencement Bay Nearshore/Tideflats to Kerr McGee. NTIS # PB92-124775

Volume III - Kerr-McGee Chemical Corporation to Ormet Corporation.
NTIS # 92-124783

Volume IV - Oronogo-Duenweg Mining Belt to Tar Creek.
NTIS # PB92-124791

Volume V - Teledyne Wah Chang to Wayne Interim Storage Facility.
NTIS # PB92-124809

Entire set of volumes I-V. NTIS # PB92-124759

Technical Resource Documents on Extraction and Beneficiation of Ores and Minerals.

Volume 1 - Lead-Zinc NTIS # PB94-170248
Volume 2 - Gold NTIS # PB94-170305
Volume 3 - Iron NTIS # PB94-195203
Volume 4 - Copper NTIS # PB94-200979
Volume 5 - Uranium NTIS # PB94-200987
Volume 6 - Gold Placer NTIS # PB94-201811
Volume 7 - Other Mining Sectors NTIS # PB94-201001
Volume 8 - Brine, Solution and Underground Melting NTIS # PB94-200995

Innovative Methods of Managing Environmental Releases at Mine Sites.
NTIS # PB94-170255

Acid Mine Drainage Prediction in Mining NTIS # PB94-201829

Detoxification of Cyanide in Heap Leach Piles and Tailings NTIS # PB94-201837

Design and Operation of Tailings Dams NTIS # PB94-201845

Treatment of Cyanide Heap Leaches & Tailings NTIS # PB94-201837

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Inactive and Abandoned Noncoal Mines:
Volume I - A Scoping Study. NTIS # PB92-190115
Volume II - State Reports. NTIS # PB92-190123
Volume III - Appendix: State Reports. NTIS # PB92-190131

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Volume I - Summary Report (Projected Regulatory, Programmatic and Fiscal Impacts of EPA's Strawman II on State Mine Waste Management Programs). NTIS # PB92-190156

Volume II - State Reports of Western Governors' Association Mine Waste Task Force States (Projected Regulatory, Programmatic and Fiscal Impacts of EPA's Strawman II on State Mine Waste Management Programs). NTIS # PB92-190164

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5.5.6 International Sources of Information

Gary McGee, Mining and Environmental Law, Ottawa, Ontario: Energy Mines and Resources Canada.

Overview of Mineral Resources Branch of Department of Energy, Mines and Resources Canada; includes 1989-1990 Budget, Mandate, and Environmental Programs.

Contact: Mineral Technology Branch, Department of Energy, Mines and Resources Canada; 555 Booth Street, Ottawa, Ontario K1A0G1 Tel: (613)-995-4119

Bolivian Embassy in Washington D.C., *Investment Law, Hydrocarbons Law, and Bolivian Mining Code,* Congress of Bolivia: April 11,1991.

Bolivian mining regulation.

Contact: Consejo Nacional Canero- CONALCA
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