APPENDIX B

POTENTIAL ENVIRONMENTAL IMPACTS OF HARDROCK MINING
material. Equally or more important at some sites are the pit walls at surface mining operations and the underground workings associated with underground mines.

Acid generation is largely the result of oxidation of metallic sulfides. The major metallic sulfide of concern is iron sulfide (FeS₂), or pyrite. All metal sulfides and reduced mineral species can potentially contribute to acid generation. Metal sulfides besides pyrite that contribute to acid generation include galena (lead sulfide), sphalerite (zinc sulfide) and chalcopyrite (iron copper sulfide).

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

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

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

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

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

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

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

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

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

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

Unsaturated soils provide significant attenuation capacity for cyanide. Within a short time and distance, for example, free cyanide can volatilize to HCN if solutions are buffered by the soil to a pH below 8. Adsorption, precipitation, oxidation to cyanate, and biodegradation can also attenuate free (and dissociated complexed) cyanide in soils under appropriate conditions. WAD cyanide behavior is similar to that of free cyanide except WAD cyanide also can react with other metals in soils to form insoluble salts.

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

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

In addition, the chemistry of a spent heap or tailings impoundment may change over time. Although effluent samples at closure/reclamation may meet state requirements, the effluent characteristics may be dependent on the pH. Factors affecting chemical changes in a heap or tailings impoundment include pH, moisture, mobility, and geochemical stability of the material. The principal concerns with the closure of spent ore and tailings impoundments are long-term structural stability and potential to leach contaminants. The physical characteristics of the waste material (e.g., percent slimes vs. sands in impoundments), the physical configuration of the waste unit, and site conditions (e.g., timing and nature of precipitation, upstream/uphill area that will provide inflows) influence structural stability.

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

Overall, cyanide can cause three major types of environmental impacts: first, cyanide-containing ponds and ditches can present an acute hazard to wildlife and birds. Tailings ponds present similar hazards, but less frequently (because of lower cyanide concentrations). Second, spills can result in cyanide reaching surface water or ground water and cause short-term (e.g., fish kills) or long-term (e.g., contamination of drinking water) impacts. Finally, cyanide in active heaps, ponds and in mining wastes,