APPENDIX E

WASTEWATER MANAGEMENT

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1.0   GOALS AND PURPOSE OF THE APPENDIX

The goal of this appendix is to provide an overview of mining wastewater management and identify information related to wastewater management that should be included in EISs and NPDES permit applications for mines. The more specific goals for this appendix include:

- describing typical wastewater streams at mine sites, including process wastewaters, mine drainage, and storm water
- describing approaches that can be used to manage waste streams;
- presenting EPA's expectations for the level of detail required in a mine proposal, and
- EPA's expectations for the level of analysis needed to support NEPA disclosure, permitting, and sound decision-making.

Appendix E is intended to be used in conjunction with other appendices in this source book to which the reader is referred for more detailed information. Relevant appendices include Appendix A, *Hydrology,* Appendix B, *Receiving Waters,* Appendix C, *Characterization of Ore, Waste Rock and Tailings,* Appendix D, *Effluent Quality*, Appendix F, *Solid Waste Management,* and Appendix H, *Erosion and Sedimentation.*

Managing wastewater at a mine site encompasses physical handling and treatment methods, water and mass balance development, and recycling. Mine planners must evaluate the natural waters and wastewaters at a site (Viessman and Hammer, 1993). Natural waters are those waters that are not affected by the mining process. In contrast, wastewaters are waters that have been affected by the mining process and must be managed because they have the potential to release and/or transport contaminants. The types of wastewaters associated with mining activities are described in the following section.

2.0   MINING WASTEWATERS

Understanding the generation of wastewaters associated with a mine site is an important first step in developing a wastewater management scheme, especially in regards to maximizing the opportunity for source control (Section 4.0).   As discussed in the main text of the Source Book, wastewaters associated with mining facilities are typically classified as mine drainage, process water, or storm water. Table E-1 provides a description of the types of mining-related waste waters that are associated with these classifications and some regulations that are applicable to each. Section 2.0 of the Source Book provides more detail on the regulations applicable to these terms and how they relate to NPDES permitting.

Table E-1. Summary of Mining Wastewaters		
Type of Wastewater	*Description*	*Applicable Regulations -1*
Mine Drainage	Any water drained, pumped, or siphoned from an active mining area, such as mine adit discharge and open pit mine waters.	Subject to effluent limitation guidelines at 40 CFR 440, which limit discharges of pH, suspended solids and metals. Provides for storm exemptions.
Process Water	Mill effluent, tailings impoundment/pile discharge or seepage, leach pile runoff/seepage, leach ponds.	Subject to effluent limitation guidelines at 40 CFR 440, includes combination of effluent limits/no discharge requirements for many facilities. Provides for storm exemptions.
Storm Water Associated with Industrial Activity	Storm water discharges directly related to manufacturing, processing, or raw materials processing; includes storm water runoff that contacts waste rock, overburden, or tailings dams/dikes not combined with mine drainage or process water.	Storm water permit regulations, including individual, baseline general permit and multi-sector permit; see FR Volume 63, No. 152, August 7, 1998, pp. 42533-42548 for most recent listing of covered discharges.
1- Wastewaters proposed for discharge to waters of the U.S. are subject to the NPDES regulations (40 CFR 122), including compliance with water quality standards.		

It is important to characterize each type of wastewater to determine: (1) regulatory constraints (for example, many process waters are subject to "no discharge" restrictions which must be factored into plans for wastewater management), and (2) potential management options (for example, in order to maximize the reuse of wastewaters, to determine if treatment is necessary, etc.)   It is particularly important to characterize the potential for production of acid rock drainage (ARD). The oxidation of naturally occurring pyrite and other sulfide minerals in mines, waste rock dumps, and tailings impounds can produce acid water that contain elevated levels of metals, sulfate, and total dissolved solids. The mechanism of ARD production is described in Appendix F - *Solid Waste Management.* ARD testing is discussed in more detail in Appendix C -*Characterization of Ore Waste Rock and Tailings*. Wastewaters should be characterized in terms of both flow and chemistry.

Wastewater proposed for discharge from the site (effluent) might also require whole effluent toxicity testing . Characterization of effluent quality is discussed in detail in Appendix D - *Effluent Quality*. Management of mining wastewaters is discussed in the following sections.

3.0   OVERVIEW OF MINING WASTEWATER MANAGEMENT

As well as characterizing the chemistry of the wastewater, successful wastewater management requires a thorough understanding of water flow and the site water and mass balance. Decisions on water management practices and facility designs must be made based on the water balance. Historically, mines have found it difficult to predict facility water balances. For example, there have been several cases in Region 10 where no discharge of process water was predicted by the mine operator based on initial water balances that were later found to be inadequate (and a discharge was required). Therefore, EPA recommends a conservative approach to predicting flows taking into account all site development, operational, closure, and post-closure/reclaimed conditions and considering seasonal climatic fluctuations. See Appendix A - *Hydrology* for more information related to the development of a water balance.

Mine operators typically have a range of different options for wastewater management. These options are described in the following sections. Section 4.0 briefly discusses options for source control and re-use. Section 5.0 provides a detailed discussion of active wastewater treatment technologies and Section 6.0 describes passive treatment options. Section 7.0 presents approaches to performing treatability studies. Section 8.0 discusses wastewater disposal options. Section 9.0 discusses storm water management.

4.0   POLLUTION PREVENTION

The volumes of mine wastewaters requiring treatment and disposal should be minimized by pollution prevention practices. Pollution prevention includes source control, recycling, and reuse. Source control involves minimizing the volume of potentially contaminated water generated at a site. For example, contamination of surface runoff may be prevented by routing surface flow around waste rock piles and tailings impoundments or capping these waste units to prevent contact with pollution sources and/or infiltration and seepage (see Appendix F, *Solid Waste Management* for discussion of pollution prevention practices for solid wastes.) Another approach to minimizing the need for wastewater disposal is to maximize the potential for water re-use/recycling.

Reducing the volume of wastewater produced by a mine clearly provides environmental benefits through decreased loadings to surface and ground water. In addition, pollution prevention can reduce overall operational costs. In wet climates, for example, the costs of wastewater treatment and residuals disposal can be reduced because less treatment is required. (Less wastewater treatment is required in wet climates due to the sheer abundance of fresh water and the dilution that is naturally available.) This results in lower capital expenditures for treatment and, potentially, lower energy costs. In arid climates where water supply costs are high, operational costs can be reduced by using recycled water.

EPA encourages operators to use pollution prevention approaches to limit wastewater generation and the need for disposal. EPA expects mine operators to demonstrate that they have

considered and implemented all potential pollution prevention options for wastewater in developing their plans of operations.

5.0   ACTIVE TREATMENT OF MINING WASTEWATERS

Treatment of mining wastewaters may be necessary in order to reuse the water in processing and/or to comply with NPDES permit effluent limitations. This section discusses some treatment technologies that may be used for these purposes. Section 5.1 discusses treatment for removal of metals, Section 5.2 discusses cyanide treatment, Section 5.3 discusses solid-liquid separation, and Section 5.4 discusses sludge removal. The technologies discussed may be used separately or in combination to meet treatment goals. Section 7 discusses treatability testing and other considerations related to selecting a treatment technology or set of technologies.

5.1   Metals Removal

This section describes technologies that may be used to remove metals from mining wastewaters. The discussion is focused on the more commonly used physical and chemical technologies. Biological techniques are also discussed, although they currently have more limited application. Since metals cannot be destroyed, the treatment processes involve separating the metals from the wastewater.

The selection of a treatment technology depends upon the characteristics of the wastewater and treatment goals. Understanding the pH and oxidation state of various wastewater streams is critical because these parameters largely determine the solubility and, hence, mobility of metal species. Mine drainage typically is rich in metals; Smith et al. (1994) illustrated a general negative correlation between metals concentrations and pH that extends over 5 orders of magnitude. Under oxidized, low pH conditions, metals usually occur as highly soluble sulfate salts. Treatment technologies for mining wastewater often employ pH adjustment to convert these soluble salts to less soluble hydroxide or sulfide salts, which then can be removed by physical means (i.e., settling, precipitation/clarification or filtration). In characterizing wastewater and selecting treatment technologies, it is always important to understand both the soluble and total concentrations of metals present; pH conditions typically determine this balance.

5.1.1   Chemical Precipitation

Chemical precipitation in wastewater treatment involves the addition of chemicals to alter the physical state of dissolved and suspended solids and to facilitate their removal by sedimentation. Chemical precipitation typically is a two-step process in which soluble metals are first converted to an insoluble form (i.e., dissolved heavy metal ions may be chemically precipitated as insoluble hydroxides or sulfides), then agglomerated into large, heavy particles and removed by physical means such as sedimentation/clarification, filtration, or centrifugation.

This technique provides a well-developed and effective treatment process for removing a wide range of heavy metals from wastewater.

Successful precipitation of metals depends primarily on two factors:

- The addition of sufficient anions to drive the chemical reaction toward precipitation of the solute
- Physical removal of the resulting solid phase from the wastewater.

The three most common methods of chemical precipitation (hydroxide precipitation, sulfide precipitation, and coprecipitation) are discussed in the following subsections. Other precipitation processes have been developed (e.g., insoluble starch xanthate process) but are not in widespread use. All these processes require subsequent solids-liquid separation (Section 5.3) and sludge removal (Section 5.4).

5.1.1.1 Hydroxide Precipitation

Hydroxide precipitation is the conventional method of removing heavy metals from wastewater. Normally, this process involves the addition of caustic soda or lime to adjust the solution pH to the point of minimum solubility. The total residual metal concentration is a complex function of pH, with the lowest residual metal concentration occurring at some optimum pH value (Figure E-1). The residual concentration will increase when the pH is either lowered or raised from this optimum value.

Hydroxide precipitation is simple, effective, and widely practiced, but has limitations due to the high solubilities and amphoteric properties of certain metal hydroxides (Kim, 1981). (Amphoteric metals act as both acids and bases and will redissolve in excessively acid or alkaline solutions.) In addition, the minimum solubilities for different metals occur at different pH values and the precipitation of individual hydroxides occurs only in a narrow pH range (Figure E-1). For these reasons, the maximum removal efficiency of mixed metals cannot be achieved at a single precipitation pH (Bhattacharyya et al., 1981). Therefore, depending upon treatment goals, multiple stages of precipitation at different pH levels may be required. Treatment by hydroxide precipitation alone may not be adequate to achieve some treatment goals (e.g., NPDES permit effluent discharge limits based on aquatic life water quality criteria may be very low for some metals). Therefore, additional treatment via some of the other technologies discussed in the next sections or use of more effective, but less widely practiced, treatment technologies may be necessary.

Theoretical metal concentrations based on hydroxide precipitation can be predicted; however, numerical estimations of metal removal by precipitation as metal hydroxides should always be treated carefully because over-simplifying theoretical solubility data can lead to errors of several orders of magnitude (AWWA, 1990). For this reason, and other reasons discussed in Section 7.0, treatability testing is critical to predict wastewater-specific metals removal efficiency.

5.1.1.2 Sulfide Precipitation

Sulfide precipitation is an alternative precipitation method that offers advantages due mainly to the high reactivity of sulfides with heavy metal ions and the very low solubilities of metal sulfides over a broad pH range. Metals can be removed by sulfide precipitation to extremely low concentrations at a single pH (Figure E-1). Consequently, sulfide precipitation may be a viable treatment alternative when hydroxide precipitation is not possible, or effective in removing metal ions to the low concentrations that may be required to meet water quality-based effluent limits . The extent to which metal sulfides precipitate is a function of pH, type of metal, sulfide dosage, and the presence of other interfering ions (Bhattacharyya et al., 1981).

Figure E-1. Solubility of metal hydroxides and sulfides

The current methods of sulfide precipitation - the soluble sulfide method and the insoluble sulfide method - differ in the technique of delivering sulfide ions. The soluble sulfide method involves adding Na_2S or $NaHS$ solutions to the wastewater. The insoluble sulfide method uses a sparingly soluble metal sulfide, such as FeS used by the proprietary Sulfex method (Scott, 1979). Some sulfide precipitation occurs naturally in conventional hydroxide precipitation systems because low levels of sulfides are often found in the untreated wastewater.

The current sulfide precipitation methods have several drawbacks. The addition of NaS usually produces colloidal or very fine particles, which settle poorly and should be treated with coagulants and flocculants before final clarification. The use of FeS requires an excessive amount of reagent and produces a large amount of sludge because of the addition of iron (Kim, 1981). To minimize these problems, calcium sulfide can be used as the sulfide source. The addition of CaS (as a slurry) produces precipitates that settle easily; the increase in the sludge volume is minimal because calcium is mostly dissolved in the wastewater after reaction (Kim, 1981).

One example of the use of sulfide precipitation is the Red Dog Mine, operated by Cominco, in Alaska. The Red Dog Mine implemented sulfide precipitation to meet effluent limits for cadmium that could not be consistently achieved with their existing hydroxide precipitation system. The currently approved plan of operations for the proposed Kensington Project includes use of sulfide precipitation for mine drainage treatment.

5.1.1.3 Coprecipitation

"Coprecipitation" generally describes a single-stage process that combines two precipitants in a reaction vessel that serves to increase metal precipitation efficiency greater than the use of either single precipitant. Chemical precipitants that have been used for mining wastewaters include sulfides, hydroxide, and ferric iron. The advantages of coprecipitation, in comparison with the lime and the sulfide precipitation processes, are that coprecipitation consumes less of the expensive sulfide reagent, while also effectively removing metals that have low sulfide solubilities. Thus, coprecipitation may allow for compliance with stringent discharge limits at a cost less than that of sulfide precipitation alone. A conventional hydroxide precipitation system can be modified easily to facilitate hydroxide-sulfide coprecipitation (Kim, 1981). The greatest disadvantage to coprecipitation is probably the need to maintain quantities of more than one chemical precipitant onsite. At East Helena, Montana, ASARCO uses the term "co-precipitation" to describe a different type of water treatment at its' smelter site. ASARCO adds iron sulfate along with hydroxide in a high density sludge (HDS) process to coprecipitate iron and arsenic and meet the arsenic water quality criteria.

5.1.2 Ion Exchange

The ion exchange process is essentially similar to the adsorption system in which the wastewater is passed through a resin (solid porous particles with reactive surface "sites"). The metal ions in the wastewater that have a stronger affinity for the reactive (adsorption) sites than

the attached group, are exchanged with the attached group that results in removal of the metal ions from the wastewater. The metal-loaded resins must periodically be regenerated by the introduction of a solution of concentrated ions, such as sodium chloride, which displaces the removed metals from the exchange sites. The regeneration stream, rich in displaced metals, must then be treated or disposed.

The efficiency and performance of an ion exchange system generally depend on pH, temperature, and pollutant concentrations. The highest removal efficiencies are most often observed for polyvalent ions (EPA, 1979). Ion exchange systems usually require some degree of pretreatment or preconditioning (e.g., coagulation and filtration) of wastewater to reduce suspended solid concentrations, which tend to clog ion exchange resins.

Application of ion exchange technology has historically been limited, by economics and resin exchange capacity, to the treatment of water containing 500 mg/L or less of total dissolved solids (TDS) (EPA, 1979). The ion exchange process has relatively high operating and maintenance costs. At higher TDS levels, calcium and magnesium removal predominates, resulting in the need for frequent regeneration, and large volumes of regenerant to dispose. The technology has been most commonly applied to water purification and selective removal of heavy metals (i.e., only soluble, ionized metals) and metal-cyanide complexes from industrial wastewater. For example, ion exchange is used by electroplaters discharging to publicly owned treatment facilities to reduce high concentrations of arsenic, barium, cadmium, chromium, copper, cyanide, lead, iron, manganese, mercury, selenium, silver, and zinc. EPA knows of no active mines in Region 10 where ion exchange is currently being used to treat wastewater.

5.1.3 Reverse Osmosis

Osmosis is defined as the spontaneous passage of a solvent from a dilute solution to a more concentrated one through a semi-permeable membrane (Ramalho, 1983). The process utilizes semi-permeable membrane materials and pressure to selectively slow or stop the passage of ions (including metals). In reverse osmosis, pressure is applied to the wastewater, forcing the permeate (i.e., clean water) to diffuse through the membrane. Reverse osmosis divides the wastewater into two components: the permeate, which is suitable for reuse/recycle or discharge , and a concentrated residue (i.e., brine stream) containing nearly all of the original pollutants. The reverse osmosis unit produces a brine stream equal to about 10 to 50 percent of the treated in-flow volume that must be treated and disposed. In part, the volume of the brine stream will depend on the initial TDS of the feed stream (brine volume increases with TDS concentrations).

Reverse osmosis is a sensitive process that cannot withstand varying input conditions. For example, the presence of scale-forming ions (e.g., calcium, manganese, iron) may cause fouling of the membranes. As a result, pretreatment (e.g., filtration and carbon adsorption) is generally necessary. Generally the pH, temperature, and suspended solids levels of the wastewater must be modified prior to reverse osmosis treatment in the interest of efficiency and membrane life (EPA, 1979).

Reverse osmosis is highly effective in removing metals to very low levels and it is one of the few processes that will also reduce TDS in the waste stream. TDS concentrations of 100 mg/l can usually be achieved with single-pass systems. Two or more units operated in series can achieve even lower TDS concentrations (10 to 25 mg/L). Historically, metals removal by reverse osmosis has been limited by high capital costs, intensive maintenance requirements, and high energy costs. EPA is not aware of any active mines in Region 10 which currently use reverse osmosis to treat wastewater.

5.1.4   Carbon Adsorption

In carbon adsorption, wastewater is typically pumped through one or more vessels containing activated carbon. Organics and some metals are adsorbed onto the carbon. As with ion exchange, the carbon must be periodically reactivated or disposed and replaced with fresh carbon. Carbon adsorption is most commonly used to remove organic materials in tertiary wastewater treatment. It has been observed that some incidental metals removal also occurs in such systems. Most probably, this removal is the result of organic material adsorbed on the carbon degrading under anaerobic conditions and producing sulfide ions. These ions then form insoluble sulfide salts with metals in the wastewater. The resulting insoluble particles are then trapped in the carbon structure and essentially removed by filtration. The Grouse Creek Mine (Hecla) in Idaho currently uses carbon adsorption following hydroxide precipitation for mercury removal.

5.1.5   Biological Treatment

Certain biological processes have been documented as effective technologies for the removal of metals from mining process effluents. Biological treatment systems are based on the addition of bacteria which promote biosorption of toxic heavy metals and suspended solids from process effluents and biodegradation of cyanides. Other mechanisms, such as precipitation, oxidation/reduction, filtration, and bioaccumulation, may be involved in the various types of biological treatment, which range from constructed wetlands to contained reactor systems.

Biological treatment processes offer some advantages over chemical treatment methods, including cost effectiveness, low sludge production, flexible design characteristics, compatibility with effluent-receiving streams, and treatment performance. However, additional treatment may be required to meet effluent discharge limits, and pretreatment may be required since biological processes are sensitive to temperature and other seasonal fluctuations. As discussed in Section 5.2.4, the Homestake Mine uses biological treatment to destroy cyanide as well as removing metals from the effluent . Several mines in Canada are evaluating the use of sulfide-reducing bacteria for wastewater treatment (similar mechanism to chemical sulfide precipitation, except the microbes act as the precipitants).

5.2   Cyanide Destruction

Cyanide is used at some mines during ore processing operations. Cyanide has the ability to create highly soluble metal complexes. For example, the most common process for the

recovery of gold is that of cyanidation, in which gold is leached from the ore by a weak cyanide solution (usually NaCN). Cyanide is also used as a flotation reagent to suppress iron during flotation processes.

With the use of cyanide in ore processing comes the need for additional measures to provide for chemical destruction of cyanide and cyanide-metal complexes in process waters. Cyanide exists in several forms in mine process wastewater, including free cyanide, cyanide-sulfur compounds (thiocyanate) and metal-cyanide complexes. Metal cyanide complexes occur as stable iron and cobalt cyanide complexes and the weak acid dissociable (WAD) metal complexes of cadmium, nickel, zinc, and copper. Cyanide breakdown products such as ammonia, nitrites, and nitrates may also be present. As with metals removal, it is important to determine the form of cyanide and cyanide-metal complexes present in the wastewater. The selection of a cyanide destruction technology will depend upon the characteristics of the wastewater and treatment goals.

The mining industry uses a number of treatment processes to destroy cyanide. This section describes the more prevalent technologies, including alkaline chlorination, hydrogen peroxide treatment, and sulfur dioxide/air treatment. Detailed information on the chemistry of cyanide, technologies discussed in the following subsections, and other methods for cyanide treatment can be found in Smith and Mudder (1991). The cyanide destruction processes discussed accomplish two objectives: breakdown of the metal-cyanide bonds and destruction of cyanide. Depending upon treatment goals, cyanide destruction may be followed by precipitation or other metals removal processes (Section 5.1) and/or solid-liquid separation (Section 5.3) to remove metals.

5.2.1 Alkaline Chlorination Process

The destruction of free and WAD cyanide is commonly accomplished through the chemical process known as alkaline chlorination. The alkaline chlorination process destroys cyanide through oxidation by chlorine under alkaline conditions. The chlorine can be supplied in either a liquid form or a solid form as sodium or calcium hypochlorite.

Under ambient conditions, alkaline chlorination will remove all forms of cyanide, excluding the extremely stable iron and cobalt cyanide complexes. Under ideal conditions, cyanide can be reduced to below 1 ppm. Additional measures, such as increasing temperatures or introducing ultraviolet light, must be implemented in the alkaline chlorination process to reduce the concentrations of iron cyanide complexes. These measures are not often used because of the associated increase in cost. As a result, alkaline chlorination is limited to wastewater containing low concentrations of complexed iron cyanides.

When evaluating the feasibility of the alkaline chlorination process, additional consideration must be given to the residual chlorine and chloramines found in the effluent. The residual chlorine and chloramines (formed through the reaction of chlorine with ammonia in the solution) are significant concerns because they are extremely toxic to aquatic life.

Advantages of alkaline chlorination are that it is a well established and widely used technology that effectively destroys free and WAD cyanide, using chlorine, which is readily available worldwide. Disadvantages of alkaline chlorination include high reagent costs, the addition of TDS to the wastewater (due to the addition of alkaline salts to raise the pH), the need for careful pH control, and the problem that iron cyanide complexes are not removed. Also, the end products of alkaline chlorination, including residual chlorine and chloramines are extremely toxic to aquatic life and must be removed.

5.2.2 Hydrogen Peroxide Process

Hydrogen peroxide (H_2O_2) is a strong oxidizing agent that is capable of reducing free and WAD cyanide to concentrations well below 1 ppm (Roeber et al., 1995). The hydrogen peroxide process operates under alkaline conditions to rapidly oxidize free and complexed cyanide to cyanate while in the presence of a metal catalyst such as copper, iron, aluminum or nickel. Subsequently, the cyanate is hydrolyzed to form carbonate and ammonia (Knorre and Griffiths, 1985). During the destruction of metal cyanide complexes by hydrogen peroxide, liberated metals are precipitated as metal hydroxides. The required hydrogen peroxide dosage depends on the WAD cyanide concentration in the wastewater, the strength of the hydrogen peroxide solution, and the rate of mass transfer of hydrogen peroxide to the wastewater (Roeber et al., 1995).

Although more costly than chlorination, hydrogen peroxide treatment, does not contribute TDS to the wastewater since it reduces to water. Additional advantages of hydrogen peroxide treatment is that iron complexed cyanides are destroyed and metals are removed through precipitation (although additional metals removal may still be required).

5.2.3 Sulfur Dioxide/Air Process

Two patented versions of the sulphur dioxide/air cyanide destruction process include one marketed by Inco and another by Noranda, Inc. (Smith and Mudder, 1991). The Inco process uses a mixture of sulphur dioxide (SO_2), sodium sulfite (Na_2SO_3) or sodium meta-bisulphite ($Na_2S_2O_5$) and air within a controlled pH range to destroy cyanide (Roeber et al., 1995). The Noranda process differs in that pure sulphur dioxide is utilized and air is not required.

In the Inco process, both free and complexed cyanide are oxidized to produce cyanate. Hydrolysis of the cyanate results in the formation of carbon dioxide and ammonia. Iron cyanide complexes are reduced to the ferrous state and continuously precipitated as insoluble metal ferrocyanide salts of copper, nickel, or zinc . The Inco process also removes thiocyanate, but only after cyanide has been eliminated. Normal operations will result in approximately 10 to 20 percent of influent thiocyanate levels (Smith and Mudder, 1991).

In the Noranda process, pure sulphur dioxide or industrial grade liquid sulphur dioxide is fed into a solution or slurry to lower the pH levels to 7.0 to 9.0 (Smith and Mudder, 1991). Subsequently, a copper sulphate solution is added at a rate which yields desired cyanide concentrations.

Advantages of the sulfur dioxide/air cyanide destruction processes are that all forms of cyanide are removed and metals are removed through precipitation (although additional metals removal may be required, depending upon treatment goals). Disadvantages include high reagent costs, the potential for production of high levels of TDS in the effluent, and strict process control is required.

5.2.4   Biological Treatment of Cyanide

Biological destruction of cyanide occurs by oxidative breakdown of cyanide and cyanide complexes and subsequent chemical complexation (adsorption/precipitation) of free metals within the biomass. The Homestake Mine in Lead, South Dakota, has successfully operated a biological wastewater treatment plant since 1984. This plant removes cyanide as well as heavy metals by maintaining an oxygenated wastewater environment for a short retention time to adsorb the metals in the biomass or biofilm. Bioadsorption of the metals is similar to the use of activated carbon; however, the number and complexity of binding sites are much larger on the biological cell walls (Whitlock, 1989). Five-year averages from 1984 through 1988 for effluent from the Homestake wastewater treatment plant yielded removal rates of 94 to 97% for copper, 99 to 100% for thiocyanate, 96 to 98% for total cyanide, 98 to 100% for WAD cyanide, and 98 to 100% for ammonia conversion to nitrate.

Advantages of biological treatment include low reagent costs compared to other cyanide destruction methods, all forms of cyanide, cyanide complexes, and ammonia are treated, and metals may be removed.   Disadvantages include limited application, and process performance is effected by temperature.   In addition, although the process can result in the removal of cyanide to the ppb level, influent cyanide levels may need to be reduced, due to toxic effects of cyanide on biological systems.

5.2.5   Natural Degradation

Cyanide in mine wastewaters will naturally degrade through volatilization, oxidation, photodecomposition, precipitation, hydrolysis, and adsorption to solids.   Factors that affect degradation include cyanide speciation and concentration, temperature, pH, sunlight, bacteria, aeration, and pond conditions (Scott, 1985). Simovic et al. (1995) found that volatilization and metallo-cyanide decay were the most important degradation mechanisms and that temperature, UV light, and aeration were the key factors in the degradation process. Volatilization typically occurs more rapidly than metal complex degradation.

Historically, natural degradation in tailings ponds was the most common method for cyanide removal. Currently, natural degradation may be used where tailings pond water is recycled, but it is likely not suitable for tailings ponds that discharge. A major difficulty of natural degradation is that operators cannot control the time required for cyanide destruction. Furthermore, natural degradation may not achieve the detoxification levels now required by regulatory agencies (often 0.2 ppm WAD cyanide). Results of studies completed to date have shown widely varied cyanide reductions. Simovic et al. (1985) developed a model to determine natural cyanide degradation in gold mill effluents and indicated that total cyanide levels could be

reduced to 1-10 ppm (WAD cyanide removals were not provided). Scott (1985), generally found that natural degradation could reduce WAD cyanide levels to 0.42 - 42 ppm (depending on influent concentration). Several Canadian mines have designed tailings ponds to enhance the natural degradation processes. For example, at the Lupin Mine in Canada, Echo Bay Mines uses natural degradation as the only treatment method. In 1991, average total cyanide concentrations in untreated tailings at this site were reduced from 166 mg/l to 0.019 mg/l in the effluent. However, the retention time in the tailings impoundments is two years (EPA, 1994).

5.3   Solid-Liquid Separation

Solid-liquid separation is required after most of the metals treatment and cyanide destruction processes. For example, after metals in the wastewater have been precipitated (e.g., as metal hydroxides or metal sulfides), they must be removed from the wastewater prior to discharge or recycle/reuse. The separation of these solids occurs through a combination of flocculation, settling, and, if necessary, filtration. Flocculation, settling, and filtration are widely used technologies in wastewater treatment. A thorough discussion of these technologies can be found in Metcalf and Eddy, Inc. (1979). The following briefly summarizes these three steps:

(1) coagulation (the reduction of electrically repulsive forces on a particle's surface) and flocculation (the agglomeration of particles through adsorption);
(2) gravity separation (settling); and
(3) filtration.

In the first step, chemical coagulants are added to the wastewater under controlled conditions of concentration, pH, mixing time, and temperature. Precipitated metal compounds adsorb onto the coagulant and agglomerate to form flocs. Agglomeration increases the effective diameter of the metal particles, which increases their settling rate. Since particle agglomeration is induced by particle contact, flocculation generally occurs through mechanical mixing. After agglomeration, the flocs are pumped to a clarifier, where an appropriate time is permitted for settling (step 2). The particles settling within the clarifier produce an underflow sludge that must be removed for additional treatment or disposal (see Section 5.4). Alternately settling may occur in a pond or series of ponds.

A common approach currently being applied at mine sites is the high-density sludge (HDS) process. The HDS process is similar to conventional lime neutralization and settling process, however, a portion of the settled solids in the clarifier is recycled back to the precipitation cell where the sludge is again mixed with lime. Mixing of recycled sludge and lime yields a high density sludge consisting of relatively large particles that settle quickly. The HDS process has two advantages over conventional lime treatment and settling. First, recycling sludge increases the sludge density which, in turn, results in a significant reduction in the volume of sludge requiring dewatering and disposal. Second, the recirculated sludge results in additional precipitation and adsorption reactions which increase metals removal efficiency.

To further enhance the removal of metals from wastewater, a third step, filtration, is applied if necessary to meet effluent discharge limits. Filtration removes fine particles that lack

sufficient size to settle effectively. Over time, solids will build up on the filter necessitating the removal of accumulated solids. The removal process, termed backwashing, may be done on a batch or continuous basis, depending on the design of the filter.

Early filters used sand as a filter medium and operated in a down-flow mode. That is, water flowed down through a sand bed to an underdrain system which collected the filtered water. Backwashing was accomplished on a batch basis by forcing water upwards from the bottom of the filter, with the filter off-line, with the accumulated material allowed to overflow the filter surface. Newer filters may operate in the upflow mode, with accumulated material removed on a continuous or semi-continuous basis. Newer filters also may contain two or more filtration materials (e.g., anthracite coal and garnet sand) which, through density differences, classify into distinct layers. Each of these media layers provides a different level of porosity, allowing filtration to occur throughout the filter rather than just on the surface. This provides a greater storage capacity for removed materials, allowing longer runs between backwashing. Sand filters are less expensive to construct, but media filters are capable of removing smaller size particles. Determination of which filtration type, if any, is needed at a particular mining site will be based on the characteristics of the wastewater and the effluent discharge limits that apply. Filtration has not been widely applied to date at mining facilities but may need to be considered in the future to meet low effluent limits based on water quality criteria.   The Red Dog Mine (AK), for example currently uses sand filtration prior to discharge from one of its' two treatment plants. In Leadville, Colorado, sand filtration is used in a high density sludge process to treat effluent from historic workings.

5.4   Sludge Removal

Chemical coagulation/precipitation systems produce a sludge that requires management. Waste sludge removed from clarifiers is a liquid typically ranging from 10 to 20 percent solids in suspension. Disposal will usually require some degree of dewatering. The most common methods of dewatering are belt filter presses or plate and frame filter presses. Mechanical sludge dewatering is not generally practiced in the mining industry since sludges are generally disposed of in tailings ponds. Other options for sludge disposal include backfill into mine voids and disposal in an appropriate landfill.

Selection of sludge management techniques depends upon the volume and composition of the sludge and regulatory requirements. Sludge composition is dominated by the coagulant added to the system (e.g., lime), but will also reflect the metals and other insoluble constituents removed from the wastewater.   The stability of metals in the sludge depends on the pH of the sludge remaining high. Disposal into a tailings impoundment may not be advisable since the more neutral pH conditions of the impoundment may cause metals to redissolve into supernatant waters.

Unlike many other wastes from extraction and beneficiation operations, sludges generated from wastewater treatment at mines are not exempt from regulation under Subtitle C of the Resource Conservation and Recovery Act (RCRA). Mine operators that generate sludges that exhibit hazardous waste criteria should exercise care in co-management with exempt wastes

including tailings; such co-management could cause entire units to become hazardous waste management facilities. These issues can also arise from the use of sludge as a source of hydroxide in processing operations. States may further regulate treatment sludges differently from other mining wastes. Treatment sludge may need to be managed at a permitted hazardous waste disposal facility.

Mine operators need to provide data on the expected volumes and chemical and physical characteristics of wastewater treatment sludges, including whether they will exhibit hazardous waste characteristics. Appendix C, *Characterization of Ore, Waste Rock and Tailings*, provides information on approaches to waste characterization. Operators should also describe proposed management practices, including potential impacts associated with co-management scenarios.

6.0 PASSIVE TREATMENT OF MINING WASTEWATERS

Passive water quality treatment is being viewed increasingly as a viable option for the post-closure environment at metal mining sites (Miller, 1996) and has recently been put into operation at an active lead-zinc mine (Gusek et al., 1998). Passive systems achieve improved water quality through a variety of physical, chemical, and biological processes that include acidity reduction and concomitant alkalinity increase (either by bicarbonate addition, sulfate reduction, ferric iron reduction, or a combination), metals removal (by hydroxide or oxide precipitation , plant uptake, sorption onto organic materials, or sulfide precipitation), and sulfate reduction (by microbial action or gypsum precipitation). Studies of natural wetlands systems receiving neutral to acidic metal mine drainage with high metals values have been useful for understanding how passive systems function. Studies of natural wetlands in Colorado and Minnesota found that they removed iron, chromium, cobalt, copper, nickel, and zinc with varying efficiency that depended on influent water quality, residence time, water temperature, the distribution of flow within the wetland cells, sorptive capacity of the peat, and depth of removal (Eger et al.,1993; Balistrieri, 1995; Walton-Day, 1996).

Passive treatment systems do not require routine maintenance, energy supply, or backup systems and are more cost-effective to operate over long time periods. However, they are sensitive to seasonal fluctuations (e.g., cold temperatures, increased loadings caused by increased precipitation) and may be unable to consistently achieve low effluent limits. The next section briefly describes three of the technologies most commonly used at metal mines: aerobic wetlands, anaerobic wetlands/bioreactors, and anoxic limestone drains.

6.1 Commonly Used Technologies

Constructed wetlands were initially designed as simple, rather empirical structures that outwardly mimicked natural systems (Skousen et al., 1994). Recently constructed wetlands have complex designs intended to produce specific chemical effects at each step of the treatment process (e.g., Brodie, 1993; Cambridge, 1995; Wildeman and Updegraff, 1997). Flow rates, residence times, redox conditions, cation-exchange capacities, alkalinity production, and metal uptake in the wetlands are controlled by wetland size, flow path, substrate composition, and

vegetation type (Wildeman et al., 1993). Substrate compositions vary widely among constructed wetlands; several authors (e.g., Brodie et al., 1988; Howard et al., 1989; Gross et al., 1993) have evaluated substrate performance. Limestone is commonly used as a substrate below the organic matter to add alkalinity. Commonly used plants include cattails (*Typha spp.*; the most widely used wetland plant), *Sphagnum*, bulrushes (*Scirpus spp.)*, sedge (*Carex spp.*), and algae (*Cladophora*). Most plants are relatively tolerant of high metal concentrations and acidity but they vary in their ability to accumulate or take up metals from wetland waters and sediments (e.g., Duggan et al., 1992; Sengupta, 1993; Garbutt et al., 1994; Erickson et al., 1996). An important effect of wetland plants is their ability to stimulate microbial processes, add oxygen, raise pH, and supply organic nutrients (Kleinmann, 1991; Wildeman and Updegraff, 1997).

Aerobic wetlands systems utilize oxidizing reactions to precipitate manganese and iron oxyhydroxides that sorb selenium and arsenic from influent waters (Gusek, 1995; Wildeman and Updegraff, 1997). These systems, which also can be used to remove WAD cyanide, operate most effectively when influent pH exceeds about 5.5.

Anaerobic wetlands and bioreactors (facilities that have a cap precluding oxygen infiltration) use bacterially mediated sulfate reduction to precipitate iron, copper, lead, zinc, cadmium, and nickel as sulfide minerals and to reduce uranium and radium to insoluble forms (Gusek, 1995; Wildeman and Updegraff, 1997). Bacterial action has the added benefit of raising pH by producing bicarbonate alkalinity. Anaerobic systems can function with influent pH levels of less than 2.5.

Anoxic limestone drains (ALD) are used to intercept ground water and direct it through a buried bed of limestone. In recent years, ALDs have been widely used to pre-treat AMD prior to anaerobic wetlands treatment in order to add alkalinity in the form of bicarbonate (HCO_3^-) that improves effluent quality and extends the effective life of wetlands treatment. Their intent is to add sufficient alkalinity so that effluent waters do not re-acidify upon aeration and ferric iron hydrolysis. In theory, the anoxic conditions maintained in an ALD permit dissolution of limestone without concomitant armoring by sulfates or metal hydroxides (Skousen, 1991). In practice, however, aluminum hydroxide and gypsum (calcium sulfate) may precipitate and eventually clog the drain (Skousen, 1991; Ziemkiewicz et al., 1994), forcing influent water to flow over the drain and escape treatment. Consequently, flow rates need to be high enough to flush precipitating minerals through the drain. The effectiveness of an ALD as a passive treatment option depends on influent water quality (Skousen, 1991; Brodie et al., 1993). ALDs function most efficiently when influent waters have moderate to low dissolved oxygen contents (<2 mg/L), low ferric/ferrous iron ratios, dissolved aluminum concentrations less than 25 mg/L, and sulfate concentrations less than 2,000 mg/L (Hedin and Watzlaf, 1994; Ziemkiewicz et al., 1994).

6.2   Passive System Design

Important design factors for passive treatment systems include hydraulics (flow rate, flow path, and residence time), longevity of the carbon source, rate of supply of carbon, temperature, and metals load. Wetland size and treatment components are determined from the influent flow,

water chemistry, and calculated loadings (Hedin and Nairn, 1992). Sizing criteria for wetlands constructed at eastern coal mines were developed by Hedin et al. (1994) and Hellier et al. (1994). Their values should be used as a minimum guideline for passive treatment systems that would be constructed at higher elevations (such as at many metal mines in the western U.S.) where biological and chemical processes are likely to operate at slower rates (Sengupta, 1993). Mean annual temperature and seasonal temperature variations are other factors that affect the efficiency of a passive treatment system by influencing bacterial activity and wetland plant growth.

The carbon source and its replenishment are particularly important since carbon is a vital nutrient required to maintain bacterial populations in anaerobic systems. In general, anaerobic cells have a projected life of 20 to 100 years, after which the organic substrate will need to be replaced. Anoxic limestone drains have a projected life of 30 years before limestone replacement. At present, it is unclear how long aerobic cells will function properly; however, depending on metal loads, mineral precipitation may require replacement of substrate materials. Consequently, passive treatment is not a "walk away" technology that will work as designed in perpetuity. Despite their high front-end costs, the low maintenance costs (primarily periodic sampling and substrate replacement) makes them an attractive post-closure option. Passive wetlands systems also have the potential to provide habitat, however, the environmental impact of such habitat must be evaluated (e.g., to demonstrate that terrestrial and aquatic animals inhabiting the wetlands will not bioaccumlate metals).

6.3   Example Passive Systems at Metal Mines

Passive systems can be designed to treat runoff and seepage from waste rock dumps, tailings piles, and spent ore heaps, and drainage from adits and historic mine facilities. The technology was developed to treat acidic waters generated from abandoned coal mines in the eastern U.S. and has gained widespread acceptance for this application (more than 600 passive systems were constructed and operating in 1996; Gusek, 1998b). Metals levels in the low parts per million or high parts per billion range are typically achieved. At coal mines, acidic waters contain high concentrations of sulfate, aluminum, iron, and manganese, but few other metals. Only recently has passive treatment technology been used to treat acidic to neutral waters draining from metal mining sites. These technological applications are still under development. In addition to high concentrations of TDS and sulfate, metal mine waters may contain a variety of metals in moderate to high concentrations. The presence of numerous trace metals complicates the geochemical system design.

Several examples of the use of passive systems at mine sites is shown in Table E-2. In addition to the facilities shown in Table E-2, passive treatment is being employed at several other inactive or historic sites described in the references of the previous two sections. The mines in Table E-2 and referenced in the previous sections represent historic sites and ongoing remediation projects. The only active mine that EPA is aware of that is using passive treatment to meet NPDES permit effluent limits is the West Fork Mine in Missouri. Overall, a major challenge to using passive systems is maintaining system performance, at all times, and under all operating conditions. At present, passive systems appear to be a viable alternative only under

limited conditions or when used in combination with other treatment approaches.

Table E-2. Example Passive Treatment Facilities at Metal Mines			
Mine	*Influent Characteristics*	*Passive Technologies Used*	*Effluent Characteristics*
Wheal Jane, UK Underground Sn-Cu Inactive	3,500 gpm, pH = 3.8; Cd = 0.006 mg/L; Cu = 1.05 mg/L; Zn = 3.1 mg/L	Anaerobic cell ➜ ALD ➜ Aerobic Cell ➜ Anaerobic Cell ➜ Rock Filter	Not available.
West Fork, MO Underground Pb- Zn Active	1,200 gpm, pH = 7.9; Pb = 0.4 mg/L; Zn = 0.36 mg/L; Cu = 0.037 mg/L	Settling Pond ➜ Anaerobic Cell ➜ Rock Filter ➜ Aeration Pond	pH = 7.2; Pb = 0.04 mg/L; Zn = 0.07 mg/L; Cu = <0.008 mg/L.
Ferris-Haggarty, WY Underground Cu Abandoned	20 to 480 gpm; pH = 4 to 7; Cu =2.0 to 6.5 mg/L; Significant seasonal variations.	Pilot Anaerobic Test Cell	pH = neutral; Cu = 0.05 mg/L.
Sources: Wheal Jane: Cambridge, 1995; West Fork: Gusek et al., 1998a; Ferris Haggarty: Reisinger and Gusek, 1998.			

7.0   TREATABILITY TESTING

Each individual mining wastewater is a unique blend of metals, hardness, pH, TDS, and trace components. Under actual production conditions, the composition will continually vary to at least some degree. The complexity of the wastewater matrix limits the extent to which experience (e.g., treatment effectiveness) gained at one facility can be directly applied to another.

Although theoretical chemistry may indicate how a specific waste can be treated, the complex matrix that exists at a specific site may limit the applicability of theoretical data to actual conditions. Consequently, a treatability study is required prior to treatment system design. Prior to treatment system selection and design it is essential to characterize the wastewater and identify desired effluent quality (treatment goals).   It is critical that wastewater characterization and wastewater samples utilized in treatability studies are representative of the range of operating conditions that will occur during the life of the mine and/or after closure. Also, a site-specific analysis showing that the treatment system is capable of consistently meeting regulatory or permit limits under the range of operating conditions is needed for NEPA analysis and permitting. Appendix C, *Characterization of Ore, Waste Rock and Tailings* and Appendix D, *Effluent Quality* provided additional details on waste/ wastewater characterization.

The use of laboratory and pilot-scale treatability testing is necessary to select a process(es) that will consistently meet treatment goals. Treatability testing provides valuable

design data that can reduce capital investment, ensure greater reliability, and minimize operating costs. It has the further benefit of expediting the regulatory permitting process by providing assurance to the regulators that the proposed treatment system will meet environmental quality objectives.

Treatability studies may range from laboratory bench-scale tests, involving the batch tests of samples less than a liter in size, to field-scale pilot tests conducted at flow rates of a million gallons per day. As a rule of thumb, design data from a test system can only be scaled up by a factor of 10 to 20. Thus, the use of several test systems of progressively larger size may be required to ensure the validity of a full-scale design.

In certain situations, more extensive testing would be required beyond that typical of either laboratory or pilot-scale testing. Those situations can include:

- where innovative treatment technologies are proposed (e.g., biological treatment, passive treatment)
- where site conditions are extreme (e.g., extreme variations in wastewater flow due to precipitation, cold temperatures)
- where treatment goals are different than is normally practiced for the technology (e.g., effluent limits are very low).

7.1   Laboratory Testing

Treatability testing is necessary for all stages of a treatment train (e.g., the chemical/biological treatment stage, the clarification and settling stage, filtration, and sludge characteristics). Laboratory-scale testing is most useful for screening different treatment processes. Laboratory testing is usually done on samples shipped directly to the laboratory. Samples may be obtained from the mine site, in the case of mine drainage or site runoff, or from mining process design studies conducted to evaluate milling or extraction processes. Laboratory testing can be done through bench-scale batch tests, or by continuous flow-through tests. Selection of a test type depends on the goals of the test. Batch tests are less expensive and quicker to conduct, but may provide less realistic results than flow-through tests.

Bench-scale tests typically are conducted using sample volumes of 1 liter or less. These studies can be performed quickly and relatively inexpensively. Such tests are often used to screen different treatment methods over a range of wastewater compositions and test conditions (e.g., varying pH, reagent dosages, etc.). Use of different materials in the tests versus at the mine may cause discrepancies. For instance, because filtration through membrane or paper filters is typically used to represent the effects of full-scale clarification, bench-scale tests may overestimate the efficiency of full-scale clarification.

Continuous flow-through tests typically are done at flow rates measured in milliliters per minute. Cyanide destruction chemistry can be effectively evaluated in studies of this type. Testing time may range from hours to days. Continuous flow-through tests are useful to estimate reaction times that are more representative of full-scale performance than batch tests.

7.2   Pilot-Scale Testing

Pilot-scale tests are useful for optimizing the most promising treatment processes that are identified in laboratory-scale testing. Pilot-scale tests may or may not be conducted on-site, depending on the objectives of the test. The best place for conducting initial optimization pilot-scale tests might be concurrent with the pilot-scale metallurgical testing

Pilot-scale tests require large volumes of wastewater—flow rates may range from 5 gpm to 100 gpm or more. Studies are typically conducted for periods of a month to as long as a year depending upon the treatment process being tested.   The capital cost for test equipment is significantly greater than lab-scale testing, although in some cases test units may be leased from equipment suppliers. Conducting tests outdoors will allow for the influence of ambient temperature variations to be evaluated, although it should be noted that above grade, steel units may be more susceptible to freezing than permanent, in-ground tankage.

At the pilot-scale, clarifiers and filters will perform more like full-scale units. Wind effects on exposed pilot-scale clarifiers will be more representative of full-scale units, although they may be magnified by the smaller scale. Reaction kinetics will approximate full-scale performance. Considerations for designing a pilot plant testing program are shown in Table E-3.

Table E-3. Pilot-Scale Treatment Design
Setting Up A Pilot Testing Program
1.   Clearly identify the objectives of the study. If there are multiple objectives, separate the program into phases of study.
2.   Identify the parameters to be analyzed for the experiment. For parameters such as metals that may be present in both soluble and colloidal forms, always run both total and dissolved forms. Collect all samples needed for system evaluation. If the workload or analytical costs are excessive, do all tests, but less frequently.
3.   Replicate feed conditions (i.e., temperature, pH, variations in composition, etc.) as closely as possible. Evaluate the test until under the range of flow loadings that are expected under full-scale operation.
4.   Understand the dependence of the prime study unit on ancillary equipment performance. Failure to destroy cyanide will impair the performance of coagulation systems. Incomplete pretreatment of ion exchange or reverse osmosis feed water my impact performance due to clogging of the test unit.
5.   Operate the pilot facility for a sufficient period to determine the variability of the parameters studied.

8.0   WASTEWATER DISPOSAL

The following subsections describe several alternatives for disposal of wastewaters. Depending upon environmental and regulatory concerns, wastewater may require some level of treatment in conjunction using these practices.

8.1   Surface Water Discharge

Depending upon the site water balance and regulatory constraints, a mine may propose to discharge wastewater to a nearby water body. Discharge of wastewater to waters of the U.S. is regulated under the NPDES program. The main text of the Source Book, Appendix B - *Receiving Waters*, and Appendix D - *Effluent Quality* describe the NPDES program and information related to their proposed surface water discharges that mine proponents must collect to fulfill NPDES permitting requirements. In general the following information related to surface water discharges should be provided to the regulatory agencies for NEPA analyses and permitting decisions:

- Characterization of effluent discharge flow and quality over range of proposed operating conditions and closure (see Appendix D).
- Description of water balance over range of operating conditions and closure (see Appendix A).
- Description of any wastewater treatment and ability of the treatment to achieve treatment goals (effluent limits) over the range of effluent variability (see Section 7).
- Description of outfall location and wastewater discharge system (e.g., pipeline, diffuser, etc.)
- Characterization of receiving water flow and quality, including seasonal variations (see Appendix B).
- Projected impacts on surface water resources (see Appendix B and Appendix G).
- Monitoring plans for the receiving water and effluent.

8.2   Land Application

An alternative to wastewater treatment and direct discharge to surface water is land application. Land application of mining wastewaters is not generally subject to Federal regulation. However, States may have specific permitting requirements for these activities, including protecting ground water resources. The appropriate State agency should be contacted to determine data needs for land application permitting.

In the mining industry, land application is most commonly used for spent cyanide leach solutions. Such solutions are typically neutralized prior to application. If land application is not properly accomplished, it can pose threats to surrounding ground and surface water resources. In general, land application will be governed by the agronomic uptake, and this information should be available through agricultural support agencies.

If a mine operator proposes to use land application as a water management method, the

following information should be provided for NEPA analyses and permitting:

- Expected composition data for the wastewater proposed for land application
- Proposed schedule for land application (e.g., seasonal, climate, or soil moisture limits)
- Land application procedures and rates (relative to agronomic uptake rates)
- Climatic data (precipitation and evapotranspiration rates)
- Area and topography of the land application site
- Chemical and physical soil characteristics, particularly infiltration rates and cation exchange capacity
- Proximity to surface water
- Depth to and characteristics of underlying ground water resources,
- Specific BMPs to avoid ponding and overland flow
- Projected impacts on ground water quality (and any potential indirect effects on surface water),
- Wastewater and ground water monitoring plan (e.g., using lysimeters) that will demonstrate compliance with regulations and enable early detection of any adverse impacts and corrective actions.

It is essential to have an accurate water balance for the site (see Appendix A, *Hydrology*), including understanding precipitation versus evaporation versus infiltration rates. Mine operators should project the potential effects on ground water quality and surface water resources, taking into account any assumptions related to soil adsorption or other attenuation, for the full range of operating conditions anticipated.

8.3   Evaporation/Infiltration

Infiltration and/or evaporation basins can be used to avoid or minimize direct surface water discharges. Successful use of such basins depends on wastewater volume, facility design and determining an accurate water balance. Any measures used to promote infiltration (bottom materials) or evaporation (spraying/misting) should be specifically described along with predications as to evaporation and infiltration rates. Operators must demonstrate the ability to maintain sufficient freeboard in basins under all operating and climatic conditions. Facilities proposing to use these basins need to predict potential direct impacts on underlying ground water and any possible indirect effects on surface water through recharge. Operational and environmental monitoring plans should allow for early detection of effects and corrective actions.

8.4   Underground Injection

Another alternative for wastewater disposal is underground injection. Underground injection can eliminate the need for direct discharge to surface water. However, this practice poses potential risks to underlying ground water quality. At the Federal level, injection of wastewater from mining operations is regulated under the Underground Injection Control (UIC) Program of the Safe Drinking Water Act. As Class V wells, injection operations do not require

individual permits. However, operators typically must demonstrate compliance with drinking water standards for wells that could be used as drinking water sources. This may require water treatment prior to injection. In addition, states generally have regulations and permitting requirements that address ground water protection. Mine operators proposing to use underground injection should provide the following information:

- Expected composition and volume of wastewater to be injected,
- Ground water characterization (aquifer delineation, composition of aquifer material, flow rate, direction, porosity, conductivity, water quality, and uses),
- Storage capacity and transmisitivity of the aquifer,
- Well construction (depth, construction materials, and QA/QC),
- Injection methods (volumes and timing), and
- Projected impacts on ground water quality (and any potential indirect effects on surface water).
- Wastewater and ground water monitoring plan that will demonstrate compliance with regulations and enable early detection of any adverse impacts and corrective actions.

It is essential that the aquifer have sufficient capacity to receive the injected water (to avoid upwellings). In addition, operators must demonstrate proper construction methods and quality assurance. A particular concern associated with recently permitted underground injection at the Pogo Mine in Alaska was potential effects on permafrost. Operators should also ensure that injected waters are compatible with aquifer materials. For example, it would not generally be appropriate to inject acidic waste into a limestone formation.

9.0   STORM WATER MANAGEMENT AND BEST MANAGEMENT PRACTICES

Storm water control and best management practices (BMPs) provide alternatives that can reduce or eliminate the need for wastewater treatment and discharge. A primary goal of BMPs is to prevent or minimize the generation and the potential for release of pollutants from industrial facilities to waters of the U.S. This may be accomplished by minimizing the contact between water and potential pollutant sources. For example, Section 6 of Appendix H, *Erosion and Sedimentation*, describes some BMPs for erosion control. While these are primarily related to sedimentation, many also apply to preventing contamination from other pollutants. Other BMPs should be utilized for spill prevention, proper management of chemicals, proper management of solid wastes, etc.   EPA has published several guidance manuals on storm water management, development of pollution prevention plans, and BMPs, including:

- *Storm Water Management for Industrial Activities - Developing Pollution Prevention Plans and Best Management Practices.* 1992. EPA No. 833-R-92-002.

- *Storm Water Management for Construction Activities - Developing Pollution Prevention Plans and Best Management Practices.* 1992. EPA No. 833-R2-92-001

- *Guidance Manual for Developing Best Management Practices (BMP).* 1993. EPA

No. 833-B-93-004.8

Some states have also developed BMP guidance documents. For example, the Idaho Department of State Lands published *Manual for Best Management Practices for the Mining Industry in Idaho*, November 1992.

Mine operators should describe the types of BMPs to be used for wastewater and storm water management, their design and predicted effectiveness, how they will be maintained throughout the life of the project, and measures to monitor their actual performance. As discussed in Section 2 of the Source Book, general and individual NPDES permits for storm water discharges typically require development and implementation of BMP plans and/or storm water pollution prevention plans. In addition, process water NPDES permits may include specific BMP requirements and/or require preparation of BMP plans.

10.0   WASTEWATER MANAGEMENT KEY ISSUES

This Appendix has summarized alternatives for wastewater management and disposal, including treatment and other options. Key issues emphasized related to wastewater management include:

- Every attempt should be made to minimize wastewater generation and the need for discharge. Mine proponents will need to demonstrate that proposed wastewater management practices will limit environmental impacts and meet all applicable regulatory requirements.

- Estimated wastewater volumes must be based on an accurate site water balance (see Appendix A, *Hydrology*). Wastewater volume and composition needs to be projected under all operational and climatic conditions (see Appendix C, *Characterization of Ore, Waste Rock and Tailings* and Appendix D, *Effluent Quality*).

- All assumptions related to pollutant removal through treatment need to be supported through proven performance at other mines and industrial facilities and treatability studies. Operators must specifically demonstrate that any proposed wastewater discharges will not cause exceedances of applicable surface water quality standards, see Section 2.0 of the Source Book and Appendix B, *Receiving Waters*.

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