APPENDIX A

Description of Common Mine Potential Impacts to Surface Water Hydrology and Water Quality, and the Importance of Flow Measurements

DESCRIPTIONS OF COMMON MINE FACILITIES

Mining operations produce a variety of solid and liquid wastes that often require permanent management. Many mining operations predate environmental consciousness or laws, and at many sites, waste management (to minimize environmental consequences) was not practiced. However, new mining operations are required by various state and federal laws to incorporate sound design and management of waste disposal facilities, as well as monitoring programs incorporating measurements of both discharge and water quality. Abandoned mine sites continue to impact watersheds through rerouting or impoundment of surface and ground water flow, and pollutant loading.

Large mining operations can generate over a billion tons of solid wastes that cover areas exceeding a thousand acres. Even smaller operations must handle and dispose of formidable quantities of materials that can affect large areas. In order to prevent or minimize environmental impacts, waste facilities must be designed and reclaimed in a manner that minimizes or prevents environmental impacts.

The mining method employed and the type of mineral extracted are large factors in determining the volume and types of solid waste facilities developed. The methods employed to beneficiate and process ore are also factors associated with the types of waste produced and the characteristics of waste streams. Flow measurements are often required to monitor direct discharges or storm water runoff from different types of mine facilities, such as waste rock dumps, tailings impoundments, leach pads and process facilities. The remainder of this section provides a summary discussion describing different types of mining and common waste facilities that may exist at mine sites. A more detailed discussion of mining and processing methods can be obtained from SME (1992) and Lacy (1999), and more detailed discussions of the design and management of waste facilities is provided by MEND (1995), SRK (1992), and Vick (1990).

Types of Mines

There two major classes of mining methods, surface and underground. Common surface mining methods include open pit mining, quarrying, glory holing, strip mining, and placer mining.

1. Open pit mining is a surface mining method in which nearly all of the deposit and ore is removed in terrace-like working areas on the side of a pit. Grade and tonnage of materials available determine the size and limits of the pit developed as well as the size and configuration of waste rock dumps. In this type of mining, it is often necessary to blend different ore types to maintain character and grade of the mill feed, or different types of ore (i.e., oxide verses sulfide and low-grade ore) may need to be managed and processed

differently (Lacy, 1999). Oxide and sulfide ores require different types of beneficiation and processing, and some low-grade oxide ores may be processed in a leach pad facility. Open pits are often closed or reclaimed by simply allowing the pit to develop into a pit lake and waste rock dumps are usually closed and reclaimed in place.

2. Quarrying is similar to open-pit mining, however, it is usually restricted to mining dimension stone or prismatic blocks of marble, granite, limestone, sandstone, etc.

3. Surface Glory Hole method is generally performed on hillsides and often used to define irregular deposits of the surface. The method has a mine opening at the surface and ore is removed by gravity through raises connected to adit haulage ways. Ore is transported to the surface or side-hill using tramways (Lacy, 1999). This method generally results in smaller volumes of waste rock removed and deposited in surface dumps.

4. Strip mining is surface mining where reclamation is contemporaneous with extraction. It is applicable to shallow, flat-lying deposits of coal, oil-shale, clay, sand, gravel, and some uranium, phosphate and placer deposits. As the overburden is removed from one portion of a mineral deposit, it is used to fill in the trench left by the previous removal. In this manner, the overburden is continuously refilled to the adjacent previously mined area and reclaimed.

5. Placer mining is a method for the recovery of heavy minerals using water to excavate, transport, and or concentrate the mineral being mined (Lacy, 1999). Placer methods vary greatly depending on the size and characteristics of the deposit being mined. However, placer mining in general, usually affects large areas because the ore bodies are in large alluvial deposits with low-grade, but a high volumes of mineral. The method can be highly visible and create large areas of disturbance. Many historic placer operations created serious impacts to stream channels, hydrologic systems and aquatic habitats.

6. Underground mining methods are generally similar. Ore is extracted from underground stopes, rooms, or panels located at depth. In comparison to surface mining little waste rock is produced and deposited at the surface in surface waste piles on tailings material dumps. Depending on the mineral being extracted, however, tailings and gangue may still be deposited above the surface. Without reclamation, abandoned adits and stopes from underground mining can become sources of acid mine drainage to surface waters which may require treatment and measurements of flow and water quality. This occurs when sulfide bearing minerals (usually pyrite) are exposed to air (oxygen) and ground water discharges to the surface.

Waste Rock Dumps

Waste rock is removed material from above or within the ore body and consists of non-mineralized and low-grade mineralized rock. Waste rock includes granular, broken rock and soils ranging in size from fine sand to large boulders, with the fines content dependent upon the nature of the geologic formation and methods employed during mining. Materials are designated as waste because they contain the target minerals in concentrations that are too low to process, because they contain additional minerals that interfere with processing and metals recovery, or because they contain the target metal in a form that cannot be processed with technology that existed at the time of mining. Waste rock may be acid generating and may contain metals that can be mobilized and transported into the environment. These materials generally require extensive geochemical testing to determine if they can create impacts to the environment over the short or long term. Special engineering designs, waste handling, or closure and reclamation plans may be required for those materials whose characteristics may pose significant risks.

In modern mining operations, waste rock and overburden that cannot be put to beneficial use or that contain compounds that may be detrimental to the environment, generally are placed in a location where they can be physically stabilized. Placement of waste rock is accomplished using a variety of techniques that may include end-, side-hill-, or random-dumping, and dozing. Historic operations generally did not engineer waste rock dumps to be either geotechnically or environmentally stable. Dump designs may vary markedly depending on the nature of the mining operation, the terrain in which materials are being placed, and the era in which mining took place. In steep, mountainous areas, dumps may have faces of a few hundred meters height. Dumps placed as valley-fill deposits often require the construction of rock underdrains to permit the flow of water through the drainage. Dump underdrains are often tied into the mine drainage or storm water drainage systems that convey seepage to treatment facilities and require measurements of flow and water quality. In newly planned mining operations, the materials used to construct these drains should be thoroughly tested to ensure that they will not contribute metals, acid, or other constituents to surface waters.

Dumps that would contain waste rock capable of releasing significant quantities of metals, acidity, or other constituents may require special design features or waste handling practices to minimize the potential for environmental impacts (SRK, 1992; Environment Australia, 1997). Dumps can be designed with features to control or reduce acid generation, control the migration of poor-quality drainage, or collect and treat poor-quality drainage (SRK et al., 1989).

Tailings Impoundments

Most mines dispose of tailings (sand- to silt-sized rock particles from which target minerals have been separated) in engineered impoundments that cover areas ranging from a few acres to more than a thousand acres. These facilities can discharge tailings water either directly from the impounded pool or as seepage of pore fluids. At many mines, clarified decant water, formed as solid particles settle out of suspension, is recycled to the process facility and reused. However, in wet environments, mines may find it necessary to release tailings water to surface streams through permitted discharge points. This is particularly true of impoundments that are used as emergency containment for excess storm runoff from other areas of the mine site. Because tailings may contain acid-generating minerals and a variety of metals, accurate knowledge of pool and seepage discharges under normal operations and during storm events is required to ensure that permit and environmental requirements are met.

Whether tailings impoundments are discharging facilities depends on the environmental and physical setting of the site, the site water balance, the type of embankment, impoundment design, and operational considerations. Tailings embankments can be designed as either water-retention dams and raised embankments (Vick, 1990). In modern impoundments, water-retention dams, which are intended to prohibit horizontal fluid flow, are constructed with impervious cores of earthen materials or concrete to their full height prior to tailings placement. In contrast, raised embankments begin with starter dikes designed to contain the amount of tailings expected during the first few years of production; the embankment is raised periodically as dictated by mine operations. Starter dikes typically permit horizontal flow because they are constructed using materials ranging from natural borrow soils to waste rock to tailings. Seepage discharge typically occurs from one or more points from raised embankments.

Important design features that affect surface discharge and seepage flow include the use of liner systems, seepage control and collection systems, and stream and surface run on diversions. Liner systems, intended to prevent vertical infiltration to ground water, may be installed at sites where mill effluent contains toxic or hazardous constituents. Depending on the permeability of the impoundment foundation, seepage may occur from unlined tailings facilities. The (typically engineered) foundation slope determines the location and number of seepage discharge points. Seepage control is used to protect the structures associated with a tailings facility and to provide barriers that partly or completely contain or direct the lateral subsurface flow of tailings water. Types of commonly used seepage barriers include cutoff trenches, grout curtains, and slurry walls (Vick, 1990). Seepage collection devices include collection wells, ditches, and ponds (Vick, 1990). Stream and run-on diversions may be incorporated into an impoundment if the embankment is constructed in the bottom of a valley having significant drainage from storm runoff or in a valley that produces substantial continual runoff. Diversions can be constructed either as conduits located below the impoundment or as ditches that skirt the perimeter of the impoundment.

Leach Facilities

Some primary ores, notably those of copper and gold, may be processed by heap or dump leaching techniques. Dump leaching is the process of applying a leaching agent (usually water, acid, or cyanide) to piles of ore directly on the ground. Valuable metal(s) are extracted by leaching over a period of months or years. Heap leaching is similar to dump leaching except the ore is placed on lined pads or impoundments in engineered lifts or piles. Ores may be coarsely crushed prior to leaching or may be leached as run-of-mine materials. Spent materials contain lower concentrations of the target mineral, and they may contain other metals, chemical complexes of the target metal, acid-generating minerals, and small quantities of the leach solution. After leaching, the spent ore may be treated by rinsing with fresh water or chemical additives that dilute, neutralize, or chemically decompose leach solutions and metal complexes.

Although the purpose of leach pads and dumps is to recover metals, these facilities cross into the realm of waste management upon closure (Hutchinson and Ellison, 1991). Process solutions have the ability to degrade surface and ground waters should they escape from leach pads and solution storage and conveyance systems. For most facilities, solution containment is achieved through the use of impermeable liners beneath leach pads, sumps, and pregnant and barren solution ponds, and dual-wall piping. Hutchinson and Ellison (1991) describe the types of natural and synthetic liners that are commonly used for these purposes. Regardless of the type of system that would be used, leach pads, solution storage ponds, and solution conveyance systems need to designed to accommodate the added volume of water that occurs during low probability storm events. This makes performing a rigorous analysis of the predicted water balance crucial to project design, and the monitoring of discharge or stream flow and water quality below these facilities critical.

Process Facilities

Mining conducted to extract and recover metals generally require beneficiation processes in which ore is cleaned, concentrated or otherwise processed prior to shipping to the consumer, refiner, smelter, or manufacturer who will extract or use the metal contained in the ore (EPA, 1994). Beneficiation is the separation of valuable minerals from less valuable rock called gangue. The processes and procedures for dressing and beneficiation of the mineral or metal ore are very similar for many metal extraction operations. Ore can be prepared by using operations such as crushing, grinding, washing, drying, sintering, briquetting, pelletizing, or leaching, and concentrated using gravity separation, magnetic separation, flotation or other means (EPA, 1994). A mill includes all ancillary operations and structures necessary for the cleaning and concentrating of the mineral or metal ore. Unless the mined ore is of very high grade, a mill will be located close to the mine to reduce costs of transporting the raw ore for beneficiation.

Leaching is commonly practiced to concentrate gold, copper or other metals. Leaching is the process of extracting a metallic compound from an ore by selectively dissolving the metal in a suitable solvent such as water, sulfuric hydrologic acid, or sodium cyanide solution. The desired metal is then removed from the leach solution by a chemical process, such as precipitation, or by an electrochemical process, such as electrowhinning and solvent extraction (EW/SX).

In modern mining operations, process solutions are not discharged directly from facilities to receiving waters without water treatment. Consequently, the list of chemicals used at a mine site can be extensive and may include flotation reagents, frothing and collection agents, scale inhibitors, flocculents, thickeners, leach solutions, and leachate neutralizing solutions.

Processing activities can release contaminants to surface waters in a variety of ways that include spills of reagent materials or processing fluids (e.g., pipeline ruptures), leaks at processing facilities (e.g., liner tears), storage pond overflows (e.g., during storm events), and facility failures (e.g., slope failure of a leach dump). Contaminant pathways can be direct (release directly to surface waters) or indirect. Examples of indirect contaminant pathways include infiltration to ground water that exchanges with surface water, seepage to soil or bedrock which discharges to surface water, and seepage through or below impoundment dams and berms.

POTENTIAL IMPACTS TO SURFACE WATER HYDROLOGY AND WATER QUALITY

Many surface water hydrological impacts are related to mine construction and the location of facilities. Road construction, logging, and clearing of areas for buildings, mills, and process facilities can reduce infiltration and increase the amount of surface runoff to streams and other surface water bodies. This can increase the peak flow and the total stream discharge associated with a given storm event. Unusually high peak flows can erode stream banks, widen primary flow channels, erode bed materials, deepen and straighten stream channels, and alter channel grade (slope). In turn, these changes in stream morphology can degrade aquatic habitats. Channelization (i.e., straightening) can increase flow velocities in a stream reach, potentially affecting fish passage to upstream reaches during moderate to high stream flows. Increased erosion upstream and the resulting sedimentation downstream can impact spawning gravels, egg survival and emergence of fry, as well as degrade benthic food sources.

Reduced stream flow, caused by withdrawals of surface or ground water for mine operations, can potentially affect aquatic habitats and requirements of aquatic resources. Fish have different flow requirements at different times of the year and these requirements vary for different species. Specific flows are required for spawning, maintenance of fish beds, fry emergence, juvenile rearing habitat, and adult passage. For these reasons, water withdrawals are often mitigated by establishing instream (minimum) flow requirements at critical times of the year. This requires adequate baseline characterization of hydrologic flow conditions throughout the year and characterization of the available habitat(s) associated with the fishery. Withdrawals of surface water can also reduce naturally occurring high flows that occur during high runoff periods. High flow events are often periodically required within a stream to entrain and transport sediments that were deposited during low flow periods when low peak velocities caused sediment deposition. These are known as channel maintenance flows. Channel maintenance flows are periodically required for a channel to maintain sediment transport capacity without aggrading, filling pools, and changing channel morphology, all of which can also affect aquatic habitat

Water quality issues associated with mine exploration, operation and abandonment activities involve the potential discharge of mine water and process solutions, increased loads of metals and other toxic pollutants, and the generation of acid generation from waste rock, spent ore, and mine workings. If these pollutants reach surface waters, toxic conditions could degrade water quality and affect important aquatic species. Potential analytes of concern for mining projects typically include pH, cyanide, and heavy metals. Stream flow effects caused by mining operations relate directly to potential impacts in water quality. It is common for many water quality constituents to correlate inversely with stream flow (i.e., chemical concentration increases with decreasing stream flow). This is usually true for the concentrations of most chemical constituents that occur in higher concentrations in subsurface formations than in surface soils. Some chemical constituents, however, correlate positively with stream flow (increasing concentrations with increasing stream flow). This condition is typical of natural constituents that are associated with surface soils, land applied pollutants, such as pesticides, herbicides, and nitrates, or constituents that are transported as suspended particles.

IMPORTANCE OF FLOW MEASUREMENTS

The accurate measurement and monitoring of stream flow and discharge from mine facilities is extremely important for monitoring programs and programs designed to detect potential impacts to hydrologic, water quality, or aquatic resources. Flow measurements are extremely important for studies evaluating changes in water quality, pollutant loading, and surface and ground water interactions.

Flow measurements are also necessary to estimate flood frequency, both at the mine site and the watershed level. Peak flow data are used to plan or evaluate flood control and engineering structures. Low-flow data are required to estimate water supply dependability and drive water quality standards, NPDES permitting, development of Total Maximum Daily Loads (TMDL), and used in investigations conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Relationships and the importance of flow measurements to each these activities or programs is summarized below. Flow measurements are also important activities that support both basic and applied research being conducted by the MWTP.

Relationships to Hydrogeology

Dewatering of surface and underground mines can deplete aquifers, impact ground water recharge and discharge, and locally change the direction of ground water flow. Drawdown of an aquifer potentially can lead to reduced spring and seep flows and reduced surface water flows in streams that are gaining with respect to ground water. These effects can impact wetlands associated with springs and riparian zones associated with streams. Adequate characterization of ground water and hydrogeology and its relation to surface water flows is often difficult. However, sufficient characterization of surface water flow regimes and interactions with local ground water flows requires accurate analysis of watershed conditions and measurements of stream flow. The identification of influent and effluent stream reaches, and impacts that mining could have on hydrology within a watershed is dependent on accurate stream flow measurements taken synoptically, (e.g., samples collected at approximately the same time) and taken at key locations within a stream.

Water Quality and Pollutant Loading

Many studies designed to assess impacts and pollutant discharges from mine facilities and monitoring programs require water quality sampling taken at appropriate locations and at appropriate time intervals. However, stream flow or discharge measurements are often not required or not conducted in parallel to water quality samples. It should be noted, that constituent concentrations, which are subject to dilution in downstream surface water flows, provide limited information about the behavior of constituents, and specifically, metals in streams. EPA (1996) suggests that this shortcoming can be overcome by considering constituent loads, in which the instantaneous load equals concentration multiplied by stream discharge (e.g., stream flow) as follows:

$$L = C * Q$$

where L is the instantaneous load, C is the constituent concentration, and Q is the measured stream discharge. The constituent load downstream of a tributary inflow (L_D) is equal the sum of the upstream loads (L_U) and contributing tributary (L_T) loads:

$$L_D = L_U + L_T$$

(EPA, 1996). An increase or decrease in load reflects an increase or decrease in the mass of the constituent being transported per unit time. Increases in load along a stream reach can point to sources of contamination that may be recognized (i.e., tributary inflow) or unrecognized (i.e., ground water inflow) during conventional sampling. In contrast, decreases in load suggest that a constituent is being removed by one or more physical, chemical, or biological processes. Physical processes such as sedimentation and sediment transport, chemical processes such as adsorption and colloidal precipitation, and biological processes such as uptake can cause changes in constituent loads. Accurate evaluations of constituent loading, identification of pollutant sources, and analysis pollutant retardation and attenuation factors are dependent on accurate measurements of stream flow (i.e., discharge).

Water Quality Standards and NPDES Permitting

EPA's involvement under the CWA primarily relates to NPDES permitting under Section 402, and to a lesser extent, Section 404 (wetlands/dredge and fill). Under CWA Section 402, all point source discharges (see below) of pollutants to navigable waters of the United States must be permitted under NPDES. Effluent limits in NPDES permits may be technology- or water quality-based. In evaluating mine sources, EPA typically assesses the potential for exceedances of anticipated permit limits. These assessments often require characterization of both discharge quantity and quality and relationships to stream flow.

NPDES permits require the application of technology-based or water-quality-based limits to point source discharges, whichever are more stringent. Each State has water quality standards that are applied to individual streams based on its designated uses. In determining water quality based permit limits for effluent discharges, states generally have provisions for mixing zones. The size of mixing zones is typically determined based on dilution available during low flow conditions. The characteristic low flow condition used for most EPA water quality compliance programs in concert with chronic aquatic life criteria is the lowest 7-day average daily stream flow that occurs with a 10-year return period (i.e., 7Q10L). However, many mine sites discharge to streams with negligible low flows (i.e., available dilution is minimal).

Development of TMDLs

Finally, Section 303(d) of the CWA requires States to identify water bodies that are not meeting their promulgated designated uses. These lists may include hundreds of stream segments, many of which occur in historic or active mining districts and the source of degradation is discharges and increased sedimentation from abandoned mine wastes. Streams or stream segments which do not consistently meet designated uses could require development of a TMDL. A TMDL is a technical plan designed to attain water quality standards. The development of a TMDL requires accurate assessments of stream flow regimes, identification of sources, constituent loading for each source (see Water Quality and Pollutant Loading), identification of low flow regimes, such as the 7Q10L, and the loading capacity, defined as the water quality standard multiplied by a given stream flow. A TMDL is accomplished by establishing loading allocations for the constituent(s) of concern for each identified point source and non-point source occurring in a stream segment. TMDLs are implemented and accomplished by site remediation programs, modification of point source discharges, and other means necessary to achieve specified criteria.

CERCLA Investigations

Mining activities have often caused releases of contaminants or hazardous constituents to the environment, particularly surface and ground water resources. Examples include structural failures of impoundments or waste embankments, contamination by acid mine drainage, seepage from tailings, waste rock dumps, and heap and dump leach facilities, and spills of hazardous chemicals to soils or receiving waters. Remedial investigations (RIs) are often required to identify the nature and extent of contamination and to identify the fate and transport of contaminants in both surface and ground water systems. Feasibility studies (FSs) are then utilized to evaluate and select alternatives for remedial action. Both RI and FS investigations require the identification of sources, the quantification of loading from these sources, and assessments of health risk to both human and ecological receptors. Accurate assessments of stream flow, the characterization of flow regimes, as well as an assessment of the quality of discharges from sources are generally required in support of RI/FS investigations at mine sites. Flow and discharge measurements, therefore, often play an important role in identifying sources, quantifying contaminant loading, and providing assessments of risk.