EPA AND HARDROCK MINING:
A SOURCE BOOK FOR INDUSTRY IN THE NORTHWEST AND ALASKA

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Region 10
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TITLE AND DISCLAIMER

Title

Title: *EPA and Hardrock Mining: A Source Book for Industry in the Northwest and Alaska*

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This document is not intended, nor can it be relied on, to create any rights enforceable by any party in litigation with the United States. Any mention of company or product name is not to be considered an endorsement by the U.S. Government or by the Environmental Protection Agency. This document describes information needed by EPA to evaluate and make regulatory decisions on hardrock mines; as a result, the document is general in nature and applicants should not view anything in this guidance as 'mandatory' or prescriptive. A draft of this document was made available for review by Federal and State agencies, by public interest groups, and by interested members of the public. EPA then revised the draft and prepared this final document by addressing those comments as deemed appropriate by EPA. Commenters are identified, and both comments and EPA responses to those comments, are presented in Appendix J.

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1.0 INTRODUCTION

1.1 Purpose of this Document

This 'Source Book' was prepared by the Environmental Protection Agency (EPA) Region 10 to provide guidance on the Clean Water Act (CWA) permitting processes and associated National Environmental Policy Act (NEPA) environmental review requirements for new metal mining operations in Alaska, Idaho, Oregon, and Washington.[1] This guidance has three specific purposes. First, it is intended to explain the specific requirements of the CWA as they may pertain to new mines. It is hoped that a better understanding of EPA's mandates and authorities will provide a basis for understanding why certain information is often requested as part of the CWA permitting processes. Second, this document describes the types of information that EPA Region 10 generally needs to process permit applications and perform environmental reviews in an efficient and timely manner. By articulating these information needs, EPA hopes that the mining industry will realize time and cost savings during the permitting process by avoiding surprises, false starts, and the need for additional gathering and/or analysis of technical data. Finally, the guidance is intended to promote predictability and consistency within Region 10 to ensure mine development, operation, and closure occur in an environmentally sound manner.

Given the unique character of each mining operation and the wide variety of environments in which they may operate, it is impractical for the Region to develop specific detailed instructions that would apply to all sites. Consequently, this document is general in nature and applicants should not view anything in this guidance as 'mandatory' or prescriptive. However, there are several questions that follow naturally from the discussions contained herein and that will be asked of most applicants. Among the most important are: Will there be a discharge of wastewater during operations and/or closure? Will the discharge meet water quality standards? What is the long-term risk of surface and ground water contamination? Will reclamation restore the integrity of aquatic and terrestrial ecosystems affected by the project? How can unacceptable environmental impacts be avoided or mitigated?

1.2 Problem Statement

There is general agreement among interested parties that it is becoming increasingly difficult to permit new mines. Mining operations typically are complex undertakings that may be situated in or near complex and sensitive environments. Predicting how a particular mine may affect the environment during its active life and following closure is no simple task. In EPA Region 10, new mines present a significant challenge for those who develop CWA Section 402 National Pollutant Discharge Elimination System (NPDES) permits, review public notices and mitigation plans for CWA Section 404 Dredge and Fill permits, and review or prepare Environmental Impact Statements (EISs) pursuant to the National Environmental Policy Act (NEPA). Common pitfalls and problems at mines in Region 10 include water balances that do

[1]This Source Book is intended to address "hardrock" mines but not placer mines or sand and gravel operations.

not properly bracket high and low flows, underestimating water treatment needs, using laboratory detection limits that are too high, using inappropriate modeling approaches, failure to consider temporary shutdowns and post-closure scenarios, and overall data quality problems (e.g., non-representative samples). The challenge lies largely in determining with a reasonable degree of certainty what measures are needed to assure that a technically complex operation, which is often highly exposed to the variable forces of nature, will remain in compliance with applicable laws and regulations throughout active mining as well as during and following closure.

EPA Region 10 encompasses Alaska, Washington, Oregon, and Idaho, states with environments that range from temperate coastal rainforest to alpine mountain tundra to semi-arid high plateau to Arctic Ocean. Methods to characterize such diverse environments vary widely, often depending on how much information is readily available for a particular location. Also, these environments provide habitat to a range of threatened, endangered, and sensitive species, including several species of anadromous fish (e.g., salmon, steelhead). As such, the CWA permitting processes often require consultation pursuant to the Endangered Species Act (ESA) with the U.S. Fish and Wildlife Service (USFWS) and/or the National Marine Fisheries Service (NMFS). This can be a time-consuming process. Since much of the mining that occurs in Region 10 is located on Federal lands administered by the U.S. Forest Service, Bureau of Land Management, and National Park Service, proper coordination with these Federal land management agencies, who more often than not have the lead for EIS preparation, is also necessary to ensure a smooth process. Mining also may occur on State land and Tribal land in any of the states in Region 10. Regardless of land ownership and mineral or other land use rights, there are often numerous authorities at these levels that must be integrated into the overall permitting of any proposed mine. It is hoped that this document will be helpful to these agencies in understanding EPA's authorities, information, and coordination needs in order to reach permit decisions in a timely manner.

1.3 General Suggestions for Completing the Permitting Process

Many applicants may feel that CWA permitting and associated NEPA processes are tests of endurance. This does not have to be the case. In EPA Region 10's experience, many applicants who encounter delays in acquiring mine permits have either not provided the types of data and analyses to demonstrate how their proposed operation may affect the environment during and after operation and/or they have not adequately considered feasible options that may be more "environmentally friendly." A common problem is that applicants do not collect data that satisfy the environmental permitting process. For example, metal constituents in surface water samples may be measured using methods with detection limits that are higher than water quality criteria values. Other examples would be when geochemical or hydrological and hydrogeological studies are conducted only to satisfy objectives associated with mine development and not to help evaluate potential environmental impacts as well.

Applicants can help to minimize delays during NEPA and CWA permit application processes by considering the following general suggestions:

- Evaluate possible environmental data requirements and initiate environmental planning on the front end.

- Collect data to meet specific environmental objectives or requirements, and collect them at the required levels of detail and precision.

- Provide adequate data and analyses for all proposed alternatives.

- Be flexible when choosing facility designs, locations, and technologies.

- Propose use of treatment, disposal, and reclamation technologies with demonstrated records of success.

- Use appropriately conservative and justifiable assumptions and interpretations.

- Be pro-active in resolving potential environmental problems.

- Establish open lines of communication with the federal and state regulatory and land management agencies that will oversee the processing of the permit application(s) very early in the process, not after data are collected and planning is near completion. Maintain these lines of communication throughout the review and permitting process, and then throughout the life of the mine as well as through the closure phase.

- Review data collection plans and data quality objectives with the appropriate regulatory agency *prior* to gathering the data.

Because the CWA permitting and NEPA review processes typically require an applicant to provide a variety of data at different levels of detail and precision, applicants are likely to realize cost savings by evaluating their potential data needs from the outset of a proposed project. This will enable a complete and coherent set of data to be collected efficiently and at the required levels of precision, while avoiding data gaps or overlap. In order to specifically evaluate potential impacts to surface and ground water resources, applicants may need to study an area larger than that required for the mining operation; a common approach is to use a watershed perspective.

Applicants are encouraged to evaluate different mine layouts, facility designs, and technologies in an effort to minimize the potential for environmental impact during and following operation. If newly developed or unproven treatment or disposal technologies are proposed to be used, applicants can expect to be asked to provide the results of bench- or pilot-scale tests conducted to evaluate the effectiveness of the technology and to institute more detailed monitoring to demonstrate their effectiveness.

Finally, applicants will find that impact analyses often require assumptions of future conditions, waste behavior, and land uses. This is especially true for interpretations, extrapolations, and modeling of geochemical test results and site hydrology evaluations (e.g., water balances). In all cases, applicants should aim to be conservative in their judgment of future conditions and waste behavior and be able to justify their assumptions and interpretations. As with data collection, applicants are strongly encouraged to discuss sampling and data analysis plans, including assumptions and uncertainties, with the appropriate regulators prior to performing the analyses.

1.4 Organization of this Source Book

The remainder of the main text of the source book describes the major environmental programs that apply to hardrock mining, and the types of information that EPA needs in order to issue permits, conduct reviews, and otherwise fulfill its legal obligations. Sections 2.0 and 3.0 describe Clean Water Act programs: section 2.0 provides an overview of NPDES permitting, including many of the major components of the NPDES program, and section 3.0 describes the §404 program, under which dredge and fill activities are permitted. Section 4.0 covers the National Environmental Policy Act, which requires an analysis of the environmental impacts of proposed Federal actions, including the issuance of permits. Section 5.0 covers the requirements of the Clean Air Act and the Endangered Species Act. Finally, section 6.0 summarizes the types of effects that mining can have, and the types of analyses and information that EPA expects from project proponents in applications for permits and in documents and other materials that have to be reviewed and/or approved by EPA.

The Source Book includes nine technical appendices that describe the major issues that must be understood and addressed in order to understand and control the impacts from mining operations. Technical appendices include the following:

- Appendix A: Hydrology
- Appendix B: Receiving Waters
- Appendix C: Characterization of Ore, Waste Rock, and Tailings
- Appendix D: Effluent Quality
- Appendix E: Wastewater Management
- Appendix F: Solid Waste Management
- Appendix G: Aquatic Resources
- Appendix H Erosion and Sedimentation
- Appendix I Wetlands

2.0 INTRODUCTION TO NPDES PERMITTING (CWA SECTION 402)

The objective of the Clean Water Act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (§101(a)). This is to be accomplished through the control of both point and nonpoint sources of pollution (§101(a)(7)). A number of interrelated provisions of the Act establish the structure by which the goals of the Act are to be achieved. Within this overall structure, a variety of Federal and State programs are implemented to meet the Act's requirements. Under Section 402 of the Clean Water Act, all point source discharges (see Section 2.1 for definitions) of pollutants to navigable waters of the United States must be permitted under the National Pollutant Discharge Elimination System (NPDES). NPDES permits are issued by EPA or authorized states. In Region 10, Oregon and Washington are currently authorized to implement the NPDES program, and these states issue NPDES permits that are subject to EPA review. EPA is responsible for issuing NPDES permits in Idaho and Alaska.

Figure 1 shows the NPDES permitting process. The process is summarized in the following text. The time required to complete each step in Figure 1 varies widely and depends on a number of factors, notably the timeliness and completeness of information provided by the applicant. Readers are referred to the *U.S. EPA NPDES Permit Writers' Manual* (EPA 1996) for more information. The primary regulations developed by EPA to implement and administer the NPDES Program are found in 40 CFR Part 122.

The NPDES application process formally begins upon submission of the application to EPA Region 10 and proceeds through a number of steps required by 40 CFR 122. Prospective applicants are encouraged to correspond with and, if appropriate, meet with Region 10 staff prior to preparing and submitting the application. Application requirements are prescribed in 40 CFR 122.21, but it is always beneficial if an open dialogue is established early to ensure that information needs are fully met, particularly information that supports both the NPDES program and NEPA. This is especially true for large complex operations, proposed operations in sensitive environments or on water quality-limited waters, or where there may be special concerns by EPA or other agencies.

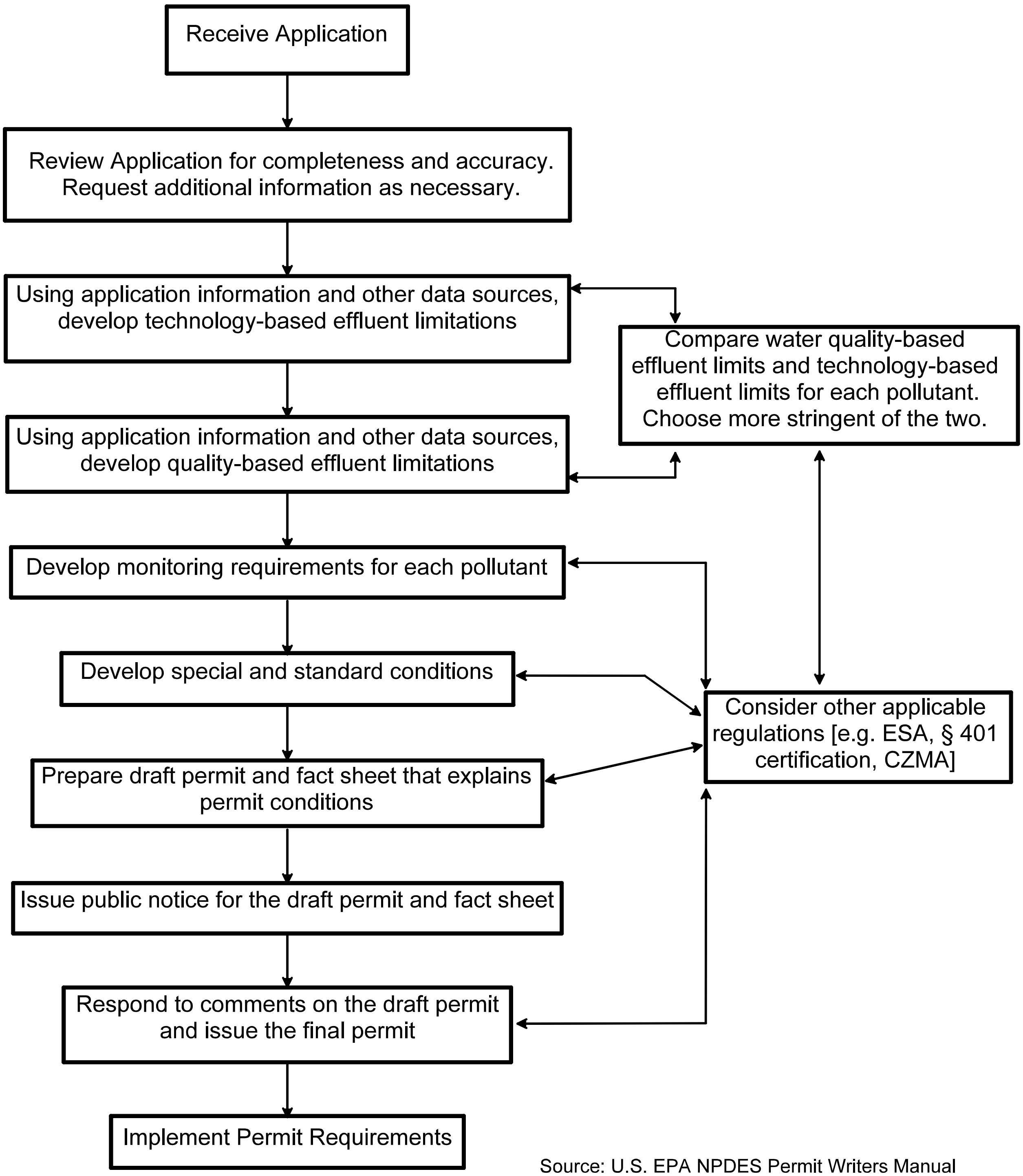
In general, applicants must submit an application at least 180 days prior to discharge or permit expiration, or if a new source, prior to construction (see Section 2.1 for definition of a new source). Section 2.5 provides a summary of the information EPA typically expects to be submitted with the application. Upon receipt of an NPDES permit application, EPA conducts an initial review for completeness. In the past, EPA has found that initial applications found to be significantly incomplete inevitably result in delays in the permitting process.

Upon finding that an NPDES permit application is complete, EPA begins determining draft permit limits and conditions. The following summarizes the major components included in NPDES permits.

- Identification and authorization of the discharge.

- Effluent limitations. Effluent limitations are restrictions on the quantity, rates, and/or concentrations of pollutants that are discharged from point sources. Effluent limits are either technology-based (based on technology-based effluent limitation guidelines) or water quality-based (based on water quality standards). In determining the need for effluent limits, EPA assesses the applicable technology-based limits and the potential for exceedances of water quality standards. Because data supplied by the permittee is critical in developing effluent limitations and most of the permit writer's time is spent in developing effluent limitations, the processes for developing effluent limitations are described in Sections 2.3 (technology-based limits) and 2.4 (water quality-based permitting).

Figure 1. NPDES Permitting Process



Source: U.S. EPA NPDES Permit Writers Manual

- Monitoring and reporting requirements. Permittees are required to monitor waste streams and receiving waters to allow EPA (and/or states) to monitor changes in water quality, to evaluate wastewater treatment efficiency, and determine compliance with permit limits.

- Special Conditions. Conditions are developed to supplement effluent limitations. Examples include best management practices (BMPs), additional monitoring activities, ambient stream surveys, etc.

- Standard Conditions. Pre-established conditions are included in all NPDES permits. These conditions delineate the legal, administrative, and procedural requirements of the NPDES permit.

To accompany each draft permit, EPA prepares a fact sheet that provides facility background information, describes anticipated discharge composition and flow, describes receiving waters, and provides the basis for the proposed effluent limitation(s), monitoring requirements, and other permit conditions. The fact sheet also documents that the permit complies with other applicable statutes (e.g., the Endangered Species Act and Coastal Zone Management Act).

Draft permits are subject to a public comment period of at least 30 days. If requested by interested parties, EPA may hold a public hearing. At the end of the public comment period, EPA prepares a final permit along with supplementary documentation that responds to public comments. The final permit then includes an effective date after which the permittee must comply with all permit requirements. NPDES permits, whether issued by EPA or an authorized state, have a clear expiration date, which may be up to five years after issuance. Prior to the expiration date, permittees need to apply for new permits.

Before EPA can issue a permit in Idaho or Alaska, the state must certify that the discharge authorized in the permit will comply with state water quality standards (this is known as a 401 certification after the CWA section that requires it). Section 2.3 discusses state water quality standards provisions important to permitting.

EPA is not obligated to issue an NPDES permit to any mine operator. EPA may reject a permit application if the agency believes that discharges would not comply with Clean Water Act provisions and/or anticipated permit conditions. For example, EPA would not issue a permit to facility where proposed discharges are not expected to meet technology- or water quality-based effluent limitations (see 40 CFR 122.4 *Prohibitions*).

The following sections describe key aspects of the NPDES permitting process for mining discharges. Section 2.1 describes when an NPDES permit is needed. Section 2.2 discusses the technology-based effluent limitation guidelines which are national standards that apply to effluent discharges from hardrock mines. Section 2.3 summarizes key aspects of water quality standards related to NPDES permitting and describes how water-quality based effluent limits are developed. Section 2.4 describes storm water permitting and Section 2.5 provides an overview of the information that EPA needs in order to issue an NPDES permit.

Because of the complexities and site-specific factors associated with projecting NPDES permit requirements, EPA strongly recommends that mine operators coordinate with EPA and states early in the planning process. This will assist in evaluating options for wastewater management practices and identifying NPDES information needs.

2.1 When is an NPDES Permit Needed?

As noted in Section 2.0, NPDES permits are required for any discharge of pollutant from a point source to waters of the U.S. The term "point source" is defined very broadly under the Clean Water Act, in part because it has been refined through over 25 years of litigation. It means any discernible, confined and discrete conveyance, such as a pipe, ditch, channel, tunnel, conduit, discrete fissure, or container (see 40 CFR 122.2). Similarly, the term "water of the U.S." is defined very broadly under the Clean Water Act and through years of litigation. It means navigable waters, tributaries to navigable waters, interstate waters, the oceans out to 200 miles, and intrastate waters which are used by interstate travelers for recreation or other purposes, as a source of fish or shellfish sold in interstate commerce, or for industrial purposes by industries engaged in interstate commerce.

Given these broad definitions, nearly any discharge from a mine could be considered a point source. In general, three discrete categories of discharges from mining operations require NPDES permits: process wastewater, mine drainage, and storm water. Definitions of each are provided in Table 1. Notably, tailings may not be discharged into water of the U.S., including marine waters. NPDES permit applicants are encouraged to communicate with EPA or an authorized state to determine how to categorize discharges and to discuss the permitting process.

For new dischargers, EPA's NPDES regulations [40 CFR § 122.21(a)] require prospective dischargers (in States without an approved NPDES program) to submit, prior to beginning onsite construction, information to the EPA Region that will allow a determination by EPA of whether the facility is a "new source". "New source" is defined as any building, structure, facility, or installation from which there is or may be a discharge of pollutants, the construction of which commenced after promulgation of applicable new source performance standards (see Section 2.2 for discussion of new source performance standards). Specific criteria that EPA uses to determine whether or not a discharge is a new source are in 40 CFR § 122.29. In general, most new mining operations are defined as new sources. Construction at existing facilities may represent a new source depending upon the age of the facility.

If the facility is determined to be a new source, 40 CFR 122.29(c) provides that the issuance of the NPDES permit is subject to the environmental review requirements of NEPA, and thus to EPA's NEPA regulations at 40 CFR Part 6 Subpart F. In cases where NEPA applies, EPA expects the permit applicant to begin the environmental review process by preparing an Environmental Information Document (EID) with the NPDES permit application (see Section 4.0). In preparing a draft new source NPDES permit, the administrative record on which the

Table 1. Categories of Discharges from Mines	
Process wastewater	"...any water which, during manufacturing or processing, comes into direct contact with or results from the production or use of any raw material, intermediate product, finished product, byproduct, or waste product." (40 CFR 122.22) See Section 2.3 for discussion of effluent limitation guidelines applicable to process wastewaters.
Mine drainage	"...any water drained, pumped, or siphoned from a mine." (40 CFR 440.132) [See Table 3 for definition of "mine."] See Section 2.3 for discussion of effluent limitation guidelines applicable to mine drainage.
Storm water (associated with industrial activity)	"... the discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. ...[T]he term includes, but is not limited to, storm water discharges from industrial plant yards; immediate access roads and rail lines used or traveled by carriers of raw materials, manufactured products, waste material, or byproducts used or created by the facility; material handling sites; refuse sites; sites used for the application or disposal of process waste waters (as defined at 40 CFR part 401); sites used for the storage and maintenance of material handling equipment; sites used for residual treatment, storage, or disposal; shipping and receiving areas; manufacturing buildings; storage areas (including tank farms) for raw materials, and intermediate and finished products; and areas where industrial activity has taken place in the past and significant materials remain and are exposed to storm water.... For the purposes of this paragraph, material handling activities include the storage, loading and unloading, transportation, or conveyance of any raw material, intermediate product, finished product, byproduct or waste product. The term excludes areas located on plant lands separate from the plant's industrial activities, such as office buildings and accompanying parking lots as long as the drainage from the excluded areas is not mixed with storm water drained from the above described areas." (40 CFR 122.26(b)(14). Note that a permit is NOT required for "...discharges of storm water runoff from mining operations ... which are not contaminated by contact with or that has not come into contact with, any overburden, raw material, intermediate products, finished product, byproduct or waste products located on the site of such operations." (40 CFR 126(a)(2)) See Section 2.4 for a discussion of storm water permitting.

draft permit is based must include the EID prepared by the applicant, the environmental assessment (and, if applicable, the FNSI) prepared by EPA, and/or the environmental impact statement (EIS) or supplement, if applicable. In addition, public notice for a draft new source NPDES permit for which an EIS must be prepared cannot take place until the draft EIS is issued [40 CFR Part 124.10(b)]. It is also important for applicants to recognize that 40 CFR 122.4(i) prohibits issuance of a NPDES permit to a new source or a new discharger if the discharge from its construction or operation will cause or contribute to the violation of water quality standards. Thus EPA places a very strong emphasis on demonstrating within the NEPA process that the proposed mining operation will be able to comply with applicable water quality standards during construction, operation and through closure.

2.2 Technology-based National Effluent Limitation Guidelines

Section 301(b)(2) of the Clean Water Act requires technology-based controls on effluents. These technology-based controls are established in effluent limitation guidelines (ELGs). Section 304(b) of the Clean Water Act requires EPA to promulgate regulations providing ELGs that set forth the degree of effluent reduction attainable through the application of the "best practicable control technology currently available" (BPT) and the "best available technology economically achievable" (BAT). For new industrial dischargers (new sources), §§304(c) and 306 require EPA to promulgate "new source performance standards" (NSPS) based on "best available demonstrated technology." To move toward the Act's goals of eliminating the discharge of all pollutants, existing industrial discharges were required to achieve these ELGs by specific dates: BPT ELGs by 1977 and BAT by 1983. All new sources are required to meet NSPS from their inception.

The current ELGs for the ore mining and dressing industry were promulgated by EPA in 1978 (BPT) and 1982 (BAT and NSPS). The ELGs for the ore mining and dressing industry are found at 40 CFR Part 440, which applies generally to facilities classified with Standard Industrial Classification (SIC) code 10; this includes and is limited to the mining and milling of metalliferous ores (this discussion does not include placer gold mines, for which the ELGs at 40 CFR Part 440 Subpart M were promulgated in 1989 and take a somewhat different form than the rest of Part 440). Other than gold placer mining, EPA has divided the ore mining and dressing category into 11 subcategories based on the type of ore mined and milled. The subcategories for which EPA has established ELGs for one or more types of discharges are shown in Table 2.

For the various subcategories, there are ELGs for two types of discharges: "mine drainage" and “process” wastewater. The latter generally includes effluent from mills (such as water contained in tailings) and other concentration (or, in RCRA terms, “beneficiation”) operations, such as dump and heap leach operations. See Table 1 for definitions of mine drainage and process wastewater. The ELGs specify numeric limitations, and contain various applicability conditions and exemptions. For certain mills in some subcategories, the NSPS ELGs allow no discharge except in net precipitation areas, where so-called “zero discharge” facilities may discharge <u>only</u> the volume of water that represents the excess of annual precipitation over annual evaporation. Under certain conditions, Part 440 provides a "storm exemption" from applicable ELGs for discharges from qualifying facilities in all subcategories. Tables 2 and 3 provide an overview of the requirements of Part 440. Table 2 shows the types of ELGs that have been promulgated for the various subcategories and the types of limits established for these categories. Table 3 presents certain definitions (e.g., of "mine”) as well as a summary of the storm exemption.

It is worth noting that ELGs are established for only a limited number of the pollutants that are likely or known to be present in the discharge from metal mines and mills (for example, the ELGs establish concentration limits for only one or a few metal pollutants, although a suite of heavy metals may generally co-occur in discharges). Compliance with the ELGs is intended to ensure that other metals present in the discharge are adequately treated. The ELGs’ technology-based concentration levels are considered the baseline for discharges.

A semantic distinction is also worth noting. Although the ELGs establish technology-based limits, neither the ELGs nor other regulations require the use of any particular technology, and this fact is often misunderstood. Rather, the ELGs require that discharges achieve at least a comparable level of treatment as the technology on which the limit is based.

Any applicable limitations and conditions that are specified in the ELGs must be incorporated into the NPDES permit. Therefore, it is critical that permit applicants adequately characterize their operations and discharges so that it can be determined which ELGs apply. Predicting a water balance and maintaining proper water management are critical to ensuring compliance with the "zero discharge" provisions of certain of the ELGs. Water balance issues are discussed in more detail in Appendices A and E. As noted throughout this document, early consultation with EPA is strongly recommended. With the advent of the storm water program (section 2.4), consultation with EPA to ensure discharges are correctly characterized has become even more important.

Figure 2 gives an example of the care with which discharges must be examined and characterized in order to determine their regulatory classification. As can be seen, both the source of discharge and the ways in which discharges are managed (segregated versus mixed, for example) affect the regulatory classification and thus the applicable standards and requirements.

For discharges or pollutants not covered by the ELGs, EPA uses Best Professional Judgement (BPJ) to develop technology-based limits. In addition, when technology-based limits cannot be defined or will not ensure compliance with applicable water quality standards for the receiving waters, permit writers develop more stringent water quality-based limits (see section 2.3).

Information on implementation of ELGs in permits can be found in the *Permit Writers Manual*. More information on the development of ELGs for the ore mining and dressing industry is found in *The Development Document for Effluent Limitations Guidelines and Standard for the Ore Mining and Dressing Point Source Category* (EPA 440/1-82/061).

2.3 Water Quality Standards and Water Quality-Based Permitting

In addition to the technology-based limits discussed in the previous section, EPA evaluates proposed discharges to determine compliance with Section 301(b)(1)(C) of the CWA. This section of the Act requires the establishment of limitations in permits necessary to meet water quality standards. In deciding whether or not water quality-based effluent limits are needed, EPA first determines whether the discharge would cause, has the reasonable potential to cause, or would contribute to an excursion of water quality criteria. If a "reasonable potential" exists, then

Table 2. Industry Sectors and Types of Applicable Limits 40 CFR Part 440

Industry sectors covered by subparts	Types of limits placed on discharges
Subpart (Subcategory): A Iron ore B Aluminum ore (bauxite) C Uranium, Radium, and Vanadium ores D Mercury ore E Titanium ore F Tungsten ore G Nickel ore H Vanadium ore (when mined alone) I Antimony ore--reserved J Copper, Lead, Zinc, Gold, Silver, and Molybdenum ores (except gold/silver placer, which is in subpart M) K Platinum ores	Subparts A, B, C, D, E, F, G, H, J, K: Numeric limits on mine drainage. Subparts A, C, E, F, G, H, J, K: Numeric limits on process waste water discharges from certain mills Subparts A, C, D, J: Zero discharge allowed from certain mills except, if precipitation exceeds evaporation on annual basis. Such facilities may discharge the difference (net precipitation) and discharges must meet mine drainage limits. Subpart J: Zero discharge allowed from certain mills, except that discharge may be allowed if contaminant buildup in recycle water interferes with ore recovery; this requires operator to make such a demonstration.

Table 3. Selected Definitions and Provisions in 40 CFR Part 440

Selected Definitions
§440.132 "Active mining area" "a place where work or other activity related to the extraction, removal, or recovery of metal ore is being conducted, except with respect to surface mines, any area of land on or in which grading has been completed to return the earth to desired contour and reclamation work has begun." "Mine" Active mining area, including "all land...used in or resulting from the work of extracting metal ore or minerals from their natural deposits by any means or methods,..."
Selected Provisions
§440.131(b) and (c) Storm exemption for discharge and no discharge facilities in subcategories A,B,C,D,E,F,G-H,J,K: Facilities designed/constructed/maintained to contain or treat normal process water and 10-year/24-hour precipitation may qualify for exemption from ELG limits. 10-year/24-hour volume includes runoff from all active mine areas that is not diverted. Development document provides details on qualifying for "excursion:" 12 other paragraphs describing meaning of "contain" and "treat" and further explaining the scope of storm exemption.

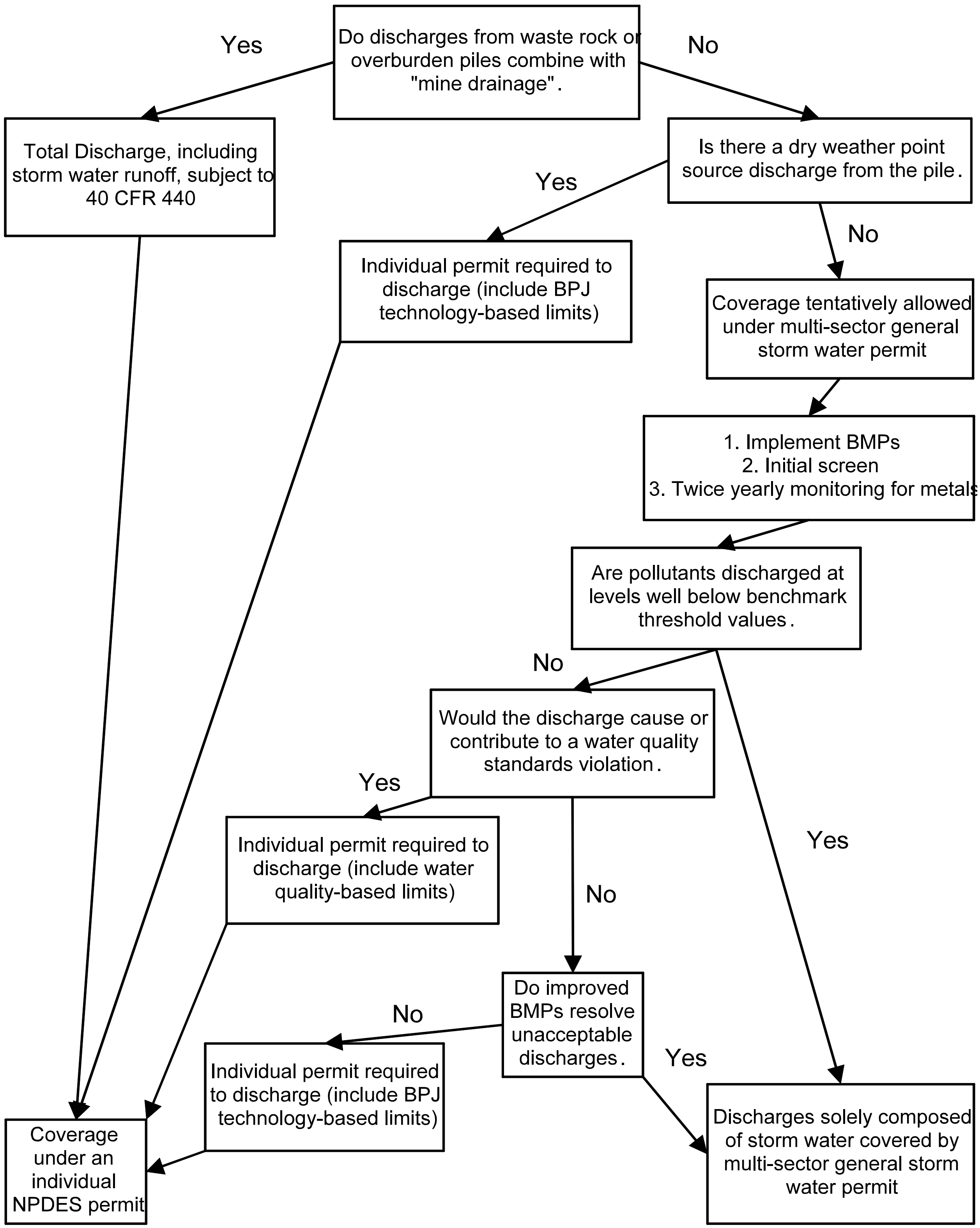


Figure 2. Example of Discharge Classification Depending on Wastewater Source and Management

water quality-based effluent limits are calculated for that parameter. The permitted effluent limit for a particular pollutant will be the more stringent of either the technology-based or water quality-based limit.

Where there is a "reasonable potential", EPA also develops water quality-based effluent limits for whole effluent toxicity (WET). WET is defined as the total toxic effect of an effluent measured directly with a toxicity test. WET is a useful parameter for assessing and protecting against impacts upon water quality caused by the aggregate effect of a mixture of pollutants in the effluent. EPA develops water quality-based effluent limits according to the guidance in *Technical Support Document for Water Quality-Based Toxics Control* (EPA 1991; also called the "TSD"). More general information on water quality-based permitting can be found in the *Permit Writers Manual*. Information used to determine the need for and to develop water quality-based effluent limits includes:

- Applicable receiving water quality standards
- Characteristics and variability of the effluent
- Characteristics and variability of the receiving water
- Where appropriate, dilution of the effluent in the receiving water (mixing zone)

Because the receiving water quality standards are key to developing water quality-based effluent limits, a brief discussion of water quality standards and mixing zones is presented below. Various provisions of water quality standards are also discussed in Appendices B and D.

Water Quality Standards. Under Section 303(c) of the Clean Water Act, States are required to develop water quality standards to protect public health, enhance the quality of water, and serve the purposes of the Clean Water Act. EPA's regulations for State development of water quality standards are at 40 CFR Part 131. All 50 states have developed water quality standards that EPA has approved.

EPA has found that correctly identifying applicable water quality standards often poses significant challenges for mine project proponents. Since many projects will include direct or indirect discharges to surface waters, knowing the applicable standards is essential to determining whether a project will adversely affect the environment and whether there is a need for water quality-based effluent limits. Baseline monitoring programs and evaluation of potential impacts to surface water should be tailored towards being able to determine whether standards will be met.

Water quality standards consist of three major components:

- **Designated Uses:** All water bodies in a State are classified based on expected designated uses. Typical designated uses include public water supply, recreation, and propagation of fish and wildlife. Different segments of a water body may have different uses. This is important because both impact predictions and water quality-based effluent limits must consider downstream uses.

- **Water Quality Criteria:** Section 303 of the Clean Water Act requires states to adopt criteria sufficient to protect the designated uses for State waters. These criteria may be numeric or narrative. Numeric water quality criteria are typically expressed as levels, constituent concentrations, or toxicity units. Narrative criteria are statements that describe water quality goals, e.g., "free of objectionable color, taste, or odor" or "free from toxics in toxic amounts." EPA requires States to develop mechanisms to implement narrative criteria. For water bodies with multiple designated uses, multiple criteria also apply. The most stringent of the applicable criteria is used to develop water quality-based effluent limits.

  Of note for mining sites is that water quality criteria for some metals are hardness dependent. Also, some state water quality criteria for metals are presented in different forms (total, total recoverable, or dissolved). However, NPDES regulations require that permit limits be expressed as total recoverable. Where the criteria are different, EPA uses default translators to translate between total and dissolved. EPA uses default translators unless the permittee develops approvable site-specific translators (see Appendix B).

- **Anti-degradation:** Each State must adopt an anti-degradation policy. State policies must incorporate three components. First, existing uses must be maintained and protected. Second, where water quality is higher than necessary to protect designated uses, that quality must be maintained and protected unless degradation is shown to be necessary for social and economic reasons and other alternatives are not available. Third, waters that are designated as Outstanding Resource Waters may not be degraded. In states that have approved NPDES permit programs the states will incorporate compliance with their anti-degradation policy as a part of the permitting process. For states without an approved NPDES program, where EPA will be issuing the permit, EPA will require the affected state to determine compliance with the state's anti-degradation policy and provide EPA with certification of compliance. Applicants should consult with the appropriate state agency and be prepared to demonstrate that the proposed project will comply with the state's anti-degradation policy.

Mine operators should initially obtain the applicable State water quality standards and regulations. These can be obtained directly from State agencies. Most are also now available from State government websites on the Internet. Each State must review its water quality standards every three years, although more frequent changes to standards and regulations are common. Operators must obtain the most recent standards and remain up-to-date on changes throughout the permitting process. This further emphasizes the need for frequent communication with State agency personnel to anticipate potential standard modifications that could affect project planning and evaluation.

Mixing Zones. Mixing zones allow for concentrations of pollutants to exceed water quality criteria in small areas immediately around discharge points prior to full mixing of effluent and the receiving waters. Under the Clean Water Act, States have the authority to determine whether they will allow mixing zones and under what conditions. As such, each State has different mixing zone provisions. The sizes of mixing zones are often determined based on low flow stream conditions, i.e., when the least dilution is available in the receiving water. In addition, available dilution is dependent on background constituent concentrations. A discharger must apply to the appropriate state agency for a mixing zone and the state must certify the mixing zone for EPA to use it in developing permit limitations. A mass balance, modeling, or other mixing zone assessment is generally required to support a mixing zone application. In addition, some states may require a biological assessment to support the mixing zone. EPA consults with states early on in the NEPA process, and NEPA documents generally display effluent criteria based on various dilution scenarios. EPA also generally sends preliminary draft permits to states for pre-certification. Mixing zones are discussed in more detail in Appendix B.

Site-specific Criteria and Reclassification. States typically have provisions for establishing site-specific criteria for individual constituents in a specific water body. Such criteria often allow for higher constituent concentrations than state-wide criteria because the individual water body can be demonstrated to achieve designated uses at the higher levels. Mine operators who elect to pursue site-specific criteria will be required to provide extensive chemical and biological testing for the water body. They need to work closely with State agencies in developing any requests for site-specific criteria. In addition, EPA needs to be consulted because site-specific criteria require EPA approval since they represent changes to the State water quality standards. Modifications to state standards also require public involvement.

If a water body is not being used for a designated use, mine operators can pursue re-classification. The criteria under which a designated use may be removed are generally defined at 40 CFR Part 131.10(g). Requests for re-classification are also complex and require close coordination with State agencies and EPA. In addition, 40 CFR Part 131.10(h) specifies where designated uses cannot be removed. Specifically, designated uses cannot be removed if they are existing uses, unless more protective uses are applied.

Total Maximum Daily Load (TMDL). Section 303(d) of the CWA requires States to identify water bodies that are not meeting their assigned designated uses (e.g., water bodies that exceed the water quality criteria). Section 303(d) also requires states to develop TMDLs (total maximum daily loads) for these water quality-limited water bodies. A TMDL is a determination of the amount of a pollutant, or property of a pollutant, from point, nonpoint, and natural background sources, including a margin of safety, that may be discharged to a water-limited water body. The TMDL defines waste load allocations for point sources that discharge to the water body. These waste load allocations are developed into permit limits. New mine proponents should ascertain whether surface waters in the project vicinity have been included on the 303(d) list and, if that is the case, the reasons for not attainting the water body's designated uses. If there are listed water bodies, coordination with EPA and State agencies is essential to determine the status of any TMDLs and how the listing could affect NPDES permit requirements.

2.4 Storm Water

In addition to the development of effluent limits and conditions for discharges of wastewater, the NPDES Program also includes provisions for control of storm water discharges. As indicated in section 2.1, storm water associated with industrial activity includes any discharges from conveyances directly related to manufacturing, processing or raw materials storage areas at industrial facilities. On August 7, 1998, EPA published in the *Federal Register* a further clarification of the applicability of the effluent guideline requirements for mine drainage and the applicability of EPA's storm water regulations to runoff from waste rock and overburden piles (63 FR 42533-42548). Figure 2 illustrates how discharge from a waste rock pile may be classified as either wastewater (i.e., mine drainage) or storm water. In summary, EPA's storm water regulations generally apply to most storm water discharges from active and inactive mine sites where the storm water discharges are not commingled with process/mill water or mine drainage.

Storm water associated with industrial activity at mine sites may be permitted in two ways, either by an individual facility-specific NPDES permit or by a general permit. Facilities may be required to or may request to be covered under an individual permit. For example, the facility may wish to consolidate the control of both process water and storm water discharges under a single comprehensive individual NPDES permit. In other cases, EPA or a delegated state may require an individual permit to address facility-specific conditions (e.g., the necessity for water quality-based limits for discharges to streams in certain cases.)

Unlike discharges of process wastewater where numerical effluent limits (technology-based and/or water quality-based) are used to control the discharge of pollutants, the primary permit condition used to address discharges of pollutants in a facility's storm water is a site-specific pollution prevention plan or best management practices (BMP) plan. All individual permits for storm water discharges issued by EPA will include a requirement to develop a BMP plan. BMPs are defined in 40 CFR 122.2 as "... schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce pollution of 'waters of the United States.' BMPs also include treatment requirements, operating procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal or drainage from raw material storage." See Appendix E and H for more information on development of a BMP Plan. Beyond the BMP plan, permits may include other requirements (such as monitoring) based on the Best Professional Judgment (BPJ) of the permit writer and as necessary to ensure compliance with water quality standards.

EPA has determined that certain categories of discharges, including many categories of storm water discharges, are more appropriately controlled by a "general" permit rather than by individual permits for each discharge. General permits are issued under the provisions of 40 CFR 122.28 and contain eligibility requirements as well as the specific requirements that applicants must follow in order to have their discharges authorized under the permit. A mining facility may elect to have any storm water discharges authorized under an EPA or State NPDES permitting authority-issued general permit (depending on the mine's location). Mining sites within EPA's jurisdiction may seek permit coverage under the *Multi-Sector General Permit for Storm Water Discharges Associated with Industrial Activities*, following the sector-specific requirements for Mining Activities. This EPA permit is commonly referred to as the *MSGP*, and the most recent version issued by EPA is referred to as the *MSGP-2000*. The sections of the

MSGP-2000 applicable to hardrock mining facilities primarily include requirements for a site-specific Storm Water Pollution Prevention Plan (SWPPP) which incorporates BMPs and applicable monitoring provisions. As required by the August 7, 1998 *Federal Register*, storm water discharges from waste rock and overburden must be more extensively tested prior to submitting an application as well as during the permit term (i.e., during years two and four of the five-year permit coverage). This includes sampling and analysis for metals.

EPA's MSGP includes three types of monitoring: analytical or chemical monitoring, compliance monitoring for effluent guidelines compliance, and visual examinations for storm water discharges. The analytical monitoring requirements contained in the MSGP include "benchmarks," that is, pollutant concentrations which EPA has determined represent a level of concern. The level of concern is a concentration at which a storm water discharge could potentially impair, or contribute to impairing water quality or affect human health from ingestion of water or fish. The benchmarks are also viewed by EPA as a level that, if below, a facility presents little potential for water quality concern. As such, the benchmarks also provide an appropriate level to determine whether a facility's storm water pollution prevention measures are being successfully implemented. The benchmarks are not effluent limitations and should not be interpreted or adopted as such. These values are merely levels which EPA has used to determine if a storm water discharge from any given facility merits further monitoring to ensure that the facility has been successful in implementing a SWPPP. For more detail on the monitoring requirements for hardrock mining facilities, refer to Part 6.G of the MSGP-2000, and the EPA discussion of the monitoring requirements for industrial storm water discharges published in the Federal Register (65 FR 64766 - 64773, October 30, 2000).

In areas where EPA is the permitting authority (e.g., Idaho and Alaska), the MSGP authorizes storm water discharges from the actual ore processing operation at the mine site. In contrast, any clearing, grading and excavation activities conducted as part of the exploration and construction phase of a mining operation must be permitted under the most recent issuance of the EPA Construction General Permit if the area disturbed is one or more acres, because discharges from such areas are best managed under the construction-related BMPs and requirements contained in the Construction General Permit. Exploration/construction operations of less than one acre can be covered by the Multi-Sector General Permit. See Part 6.G.5 of the MSGP and the most current EPA-issued Construction General Permit for further details.

Most general permits contain eligibility restrictions—that is, the permit prohibits certain discharges from coverage (see Part 1.2 of the EPA-issued MSGP-2000 for further details). EPA (and authorized states) also have the discretion to deny general permit coverage to any discharge and require an individual permit. Therefore, the Agency recommends that mine operators coordinate with EPA or their state NPDES permitting authority prior to submitting an application or request for permit coverage.

2.5 Information Needs for NPDES Permitting

In order to issue an NPDES permit, EPA and authorized States need extensive information about the proposed facility and the anticipated discharges. Application and information requirements are specified in the following sections of the regulations:

- 40 CFR 122.21(f): Information requirements for all applicants.
- 40 CFR 122.21(g): Application requirements for all existing dischargers.
- 40 CFR 122.21(h): Application requirements for facilities that discharge only non-process wastewater.
- 40 CFR 122.21(k): Application requirements for new sources and new discharges.
- 40 CFR 122.26(c): Application requirements for facilities that discharge storm water associated with industrial activity.

Table 4 identifies the various forms that these sections require to be submitted and the types of information required by each. Copies of the forms may be obtained from EPA and authorized states[2].

Table 4. EPA Forms Required for NPDES Application

Form number	*Applicant*	*Information type*
EPA 3510-1 (Form 1)	All new permits and renewals	Basic information on the facility, location, owner, etc.
EPA 3510-2C (Form 2C)	Existing dischargers	Detailed information on discharge sources, locations, volumes, sources, treatment, characterization.
EPA 3510-2D (Form 2D)	New sources and discharges	Similar to Form 2C, but some data may have to be estimated.
EPA 3510-2E (Form 2E)	Discharges of non-process wastewater	Information on discharge, chemistry, treatment, etc
EPA 3510-2F (Form 2F)	Storm water associated with industrial activity (individual permit)	Detailed information on storm water sources and characteristics.
EPA 3510-6	Storm water associated with industrial activity (general permit)	Notice of Intent for discharge(s) to be covered under multi-sector general permit (see section 2.4)

[2] Forms also are available via the Internet at http://www.epa.gov/owm/npdes.htm or http://www.epa.gov/owm/swlib.htm.

Table 5 provides an overview of the types of information generally needed to develop an NPDES permit. The table references the Source Book appendices where additional details regarding information needs may be found. The magnitude and extent of the information needs described in Table 5 may depend on site-specific factors. Permit applicants should consult with EPA and the certifying State agency early in the planning process to ensure that appropriate data is collected. This is particularly the case where the permittee applies for a mixing zone, elects to develop translators or site-specific criteria, or where threatened or endangered species may be present.

Table 5. Overview of Information Needs for NPDES Permitting

Information Type	*Data Needs*	*Source Book Appendix*
Description of wastewater management and water balance	Outfall locations and topographic map	n/a
	Identification of sources of pollutants and sources of wastewater	Appendix E and F
	Hydrologic characterization, water balance	Appendix A
	Description of wastewater treatment	Appendix E
Effluent characteristics and variability	Flow, chemical, physical and WET characterization	Appendix D
Receiving water characteristics and variability	Flow, chemical, physical, and biological characterization	Appendix B
Storm water characterization	Topographic map	
	Flow, chemical analysis, physical analysis	Appendix D
	Description of BMPs	Appendix E
Determination of available dilution	Mixing zone assessment, modeling	Appendix B
Site-specific assessments	Aquatic resources characterization	Appendix G
	Development of translators	Appendix B
	Development of site-specific criteria	Appendix B

3.0 DISCHARGE OF DREDGED OR FILL MATERIAL TO WATERS OF THE U.S. (SECTION 404)

Section 404 of the Clean Water Act addresses the placement of dredged or fill material into waters of the U.S. and has become the principal tool in the preservation of wetland ecosystems. Wetlands subject to regulation under Section 404 are those areas that meet the criteria defined in the 1987 Corps of Engineers' Wetland Delineation Manual. Section 404 regulatory authority is shared between the EPA and the Corps of Engineers (COE or Corps). Section 404(a) establishes the authority for the COE to issue permits for discharges of dredged or fill materials into "waters of the U.S." at specified disposal sites. Permitted disposal sites must comply with EPA's §404(b)(1) guidelines. In addition, §404(c) gives EPA "veto" authority to prevent or reverse COE permit issuance at specified disposal sites. In practice, EPA only exercises its veto power in rare instances where the proposed disposal site is of significant resource value, and where EPA and the COE cannot resolve disputes through the normal public notice review process.

Section 404(e) establishes that the Corps may issue general permits on a State, regional, or National basis for categories of activities that the Secretary of the Army deems similar in nature, cause only minimal adverse environmental effects, and have only a minimal cumulative adverse effect on the environment. General permits may be issued following public notice and a period for public comment; the permits must be based on the §404(b)(1) guidelines and establish conditions that apply to the authorized activity. Exceptions to §404 requirements are established in §404(f) and conditionally include the construction of temporary roads for moving mining equipment. Applicants are strongly encouraged to check with the local COE District office regarding general permits and special conditions that may be in effect in the area in which they propose to mine. Often there are state-specific conditions imposed, particularly with respect to Nationwide Permits.

The process of issuing an individual §404 permit begins with a permit application. The application typically contains information describing the project, project area, and project purpose; wetlands and other "waters of the U.S." that could potentially be directly or indirectly impacted; and mitigation, monitoring and maintenance plans. The §404(b)(1) Guidelines require the proponent to demonstrate that the selected project alternative is the least environmentally damaging practicable alternative. It is important to note that the preferred alternative selected during the NEPA analysis may not be the least environmentally damaging practicable alternative. In addition, it should be noted that an alternative does not necessarily have to involve only land currently owned or controlled by the proponent. It can involve actions (mitigation, for example) on land that could be easily obtained by the proponent.

It is thus important to avoid and/or minimize all impacts to wetlands and other waters of the U.S. to the fullest extent possible. For proposed fill in 'special aquatic sites', which include wetlands, there is a rebuttable presumption against the need to fill for non-water dependent activities. A Memorandum of Agreement (MOA) between the COE and EPA, dated February 6, 1990, establishes the policy and procedure in determining the type and level of mitigation necessary to comply with the §404(b)(1) Guidelines. The MOA sets 'no net loss' of wetland functions and values as a national goal and defines the types of mitigation, for practical purposes, as minimization and compensatory. Although compensatory mitigation is often the focus of project proponents, from a regulatory perspective, avoidance and minimization should be the focus of any project with the potential to impact wetlands and other waters of the United States. A project description submitted as part of an environmental impact assessment or permit application should clearly demonstrate how avoidance and minimization have been addressed.

The COE evaluates the application based on requirements of the CWA, including the §404(b)(1) guidelines, and based on comments received from public notice reviewers, which typically includes EPA. Since the issuance of §404 permits are subject to NEPA review, the

COE then prepares an environmental assessment or, in some cases, an EIS (or contributes to another agency's EIS as a cooperating agency) and issues a statement of finding. A permit is then issued or denied based on the finding. EPA may exercise its veto authority (§404(c)) at anytime during the permit application process, or even prior to a permit application being filed. It should be noted that the §404(b)(1) guidelines limit issuance of §404 permits for non-water dependent projects (including mines) to the "least environmentally damaging practicable alternative." The term "practicable" is defined [40 CFR230.3(q)] as "available and capable of being done after taking into consideration cost, existing technology and logistics in light of overall project purposes."

As was recommended above for NPDES permit applications, it is highly advisable for applicants for §404 permits to consult with the Corps of Engineers and other appropriate regulatory and resource agencies prior to submission of the application. This facilitates a mutual understanding of the resource issues of concern and can enable early identification of alternatives that avoid and/or minimize impacts and allows for early input on mitigation requirements and design. This early consultation can significantly reduce the time that might otherwise be necessary. If the proposed project involves siting a tailings impoundment where there are or may be wetlands or other waters of the U.S., applicants should consult with both the Corps and EPA regarding procedures for authorization to site a non-jurisdictional waste treatment system in waters of the U.S. Also, in May 2002 EPA and the Corps promulgated a final rule [Federal Register: May 9, 2002 (Volume 67, Number 90)] regarding the definition of fill material that includes certain mining wastes that are not subject to NPDES effluent guidelines (e.g., waste rock). Applicants are strongly encouraged to consult with the Corps and EPA regarding the proper regulatory tool (404 permit vs. NPDES permit) for authorizing the placement of such material in wetlands or other waters of the U.S.

The Corps has released a number of Regulatory Guidance Letters that were most recently published in the *Federal Register* on March 22, 1999 (61 FR 13783-13788). These can be accessed through the COE website at http://www.usace.army.mil, which also includes extensive information on COE regulatory programs. Appendix I - *Wetlands* contains information related to wetlands terminology, characterization, and impact assessment.

Enforcement authority is divided between the Corps and EPA: the Corps provides enforcement action for operations discharging in violation of an approved permit while EPA has primary authority over any operation discharging dredged or fill materials without a §404 permit.

4.0 THE NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act (NEPA) of 1969 became law on January 1, 1970 (Pub. L. 91-190, 42 U.S.C. 4321 *et seq.*). NEPA serves as the basic national charter for environmental protection. The law requires every federal agency to analyze and describe potential environmental effects that could arise from any action or legislation proposed by that agency. NEPA provides for public participation through public notices of intent, the solicitation of public comment, and as appropriate, public hearings. A key element of public participation is scoping, at which time the public can identify the key issues of concern.

The general framework for implementing NEPA requirements is presented in regulations issued by the Council on Environmental Quality (CEQ) which may be found at 40 CFR Parts 1500-1508. In general, the analysis and identification of the impacts of proposed federal actions, and alternatives to those actions, are presented in environmental assessments (EAs) and/or, for "major federal actions significantly affecting the quality of the human environment," in Environmental Impact Statements (EISs). Each of these terms is defined in CEQ's regulations (40 CFR Part 1508). Over the past 25 years, the NEPA framework for environmental review of proposed Federal actions has been substantially refined, based on further congressional directives, action by CEQ, and an extensive body of case law.

Each federal agency has developed its own rules for NEPA compliance that are consistent with the CEQ regulations but address its own specific missions and program activities. EPA's NEPA regulations can be found at 40 CFR Part 6.

4.1 EPA's NEPA Role

Under NEPA, EPA can serve as a lead agency, cooperating agency, or reviewing agency. Most EPA decisions and actions are not subject to NEPA, or the decision making process that leads to proposed EPA actions has been determined to be functionally equivalent to that required by NEPA. The major exception to this in the case of mining is the issuance by EPA of NPDES permits subject to new source performance standards (see section 4.2). The decision whether to issue such a permit is subject to NEPA, and thus the potential environmental impacts of permit issuance must be analyzed and documented in an EA and/or EIS. Where an EIS is required, EPA is either the lead or, more commonly, a cooperating agency in preparing the EIS. EPA recognizes that many other federal, state, and local authorities have jurisdiction over various components of a mine's location, construction, operation, and closure. Regardless of EPA's role under NEPA, EPA tries to work collaboratively with other involved agencies.

Lead Agency. In some instances, delineated at 40 CFR 1501.5, more than one agency's action is subject to NEPA. In such cases, one of the agencies becomes the lead agency (or there are co-lead agencies). When an EPA action is subject to NEPA, EPA generally serves as the lead agency for proposed projects that do not involve federal lands but that include actions over which EPA has jurisdiction by law. For example, EPA would likely be the lead agency under NEPA for a proposed project on private lands that requires a new source NPDES permit in a State where EPA is the NPDES permitting authority (see 40 CFR, Part 6, Subpart F). EPA can also serve as a lead agency when tribal lands and public lands are involved and where EPA's permitting authority is broader in scope than another agency's. In addition, EPA is responsible for NEPA review to support proposed legislation that significantly affects environmental quality as outlined in 40 CFR 6.102(b). As described in 40 CFR 6.604(g), EPA may prepare NEPA documentation using agency staff, by contracting with a consulting firm, or by using a 'third party agreement' between the applicant, EPA, and a contracting firm. The 'third party' approach is most often used for large mine projects where EPA is the lead agency. Under this approach, the EPA is responsible for directing the contracting firm while the applicant pays the costs. The responsibilities of lead agencies are outlined in 40 CFR § 1501.5.

Cooperating Agency. Federal agencies that have jurisdiction by law, but that are not lead agencies, may be cooperating agencies upon request by the lead agency (40 CFR 1501.6). As a cooperating agency, EPA participates in the scoping process and, upon request of the lead agency, may assume responsibilities for developing information and preparing portions of NEPA documents pertaining to the agency's areas of expertise. For example, EPA generally serves as a cooperating agency whenever a mine that is proposed on National Forest Service or Bureau of Land Management land requires an EPA NPDES permit. Depending on the types of expertise available to the Forest Service, EPA may play a significant role in efforts to predict effluent quality and evaluate potential water quality impacts.

Reviewing Agency. Under Section 309 of the Clean Air Act, EPA is required to review and comment in writing on all major Federal actions. The Agency reviews and prepares written comment on every draft EIS prepared by other agencies, and assigns a rating to the environmental impact of the proposed action and to the adequacy of the draft EIS (see section 4.3). The comments are available to the public, and the ratings and a synopsis of the comments are published in the *Federal Register*. When EPA has serious concerns about the impacts of the proposal or the adequacy of the EIS, the Agency consults with the lead agency. EPA also reviews final EISs, particularly ones where significant issues were raised in earlier comments. EPA comments on final EISs, but not its ratings, are made available to the public and a synopsis of comments is published in the *Federal Register*.

If EPA's review of a final EIS determines that a proposed action is or remains "unsatisfactory from the standpoint of public health or welfare or environmental quality," EPA may refer the matter to the Council on Environmental Quality in accordance with 40 CFR Part 1504.

4.2 EPA Requirements for Environmental Review Under NEPA and the CWA

40 CFR Part 6 outlines EPA's policies and processes for identifying and analyzing the environmental impacts of EPA-related activities and for preparing and processing EISs. Subpart A of the Procedures provides an overview of the Agency's purpose and policy, institutional responsibilities, and general procedures for conducting reviews. Subpart A outlines EPA's basic hierarchy of NEPA compliance documentation as follows:

- **Environmental Information Document (EID):** a document prepared by applicants, grantees, or permittees and submitted to EPA. This document should be sufficient in scope to enable EPA to prepare an environmental assessment.

- **Environmental Assessment (EA):** a concise document prepared by EPA, or by a contractor under EPA's direction, that provides sufficient data and analysis to determine whether an EIS or finding of no significant impact is warranted.

- **Notice of Intent (NOI):** announces the Agency's intent to prepare an EIS. The NOI, which is published in the Federal Register, reflects the Agency's finding that the proposed action may result in "significant" adverse environmental impacts on the human environment.

- **Environmental Impact Statement (EIS):** a formal and detailed analysis of alternatives including the proposed action, undertaken according to CEQ requirements and EPA procedures. Guidelines that describe the focus and intent of EISs are provided in 40 CFR 1502.2. EISs must provide rigorous, unbiased analyses of potential impacts from the proposed action and its alternatives, determine whether unavoidable adverse environmental impacts would occur, and describe any irreversible and irretrievable commitments of resources. The treatment of environmental impact, which generally receives close scrutiny, must consider connected actions, cumulative actions, and similar actions (40 CFR 1508.25).

- **Finding of No Significant Impact (FNSI):** a concise document that presents EPA's finding that the action analyzed in an EA (either as proposed or with alterations or mitigating measures) will not result in significant impacts. The FNSI is made available for public review, and is typically attached to the EA and included in the administrative record for the proposed action.

- **Record of Decision (ROD):** a statement published in the *Federal Register* that describes the course of action to be taken by an Agency following the completion of an EIS. The ROD typically includes a description of those mitigating measures that will be taken to make the selected alternative environmentally acceptable.

- **Monitoring:** EPA is responsible for assuring that decisions on any action where a final EIS is prepared are properly implemented.

Subpart B of EPA's Procedures provides a detailed discussion of the contents of EISs. This subpart specifies the format and contents of an executive summary, the body of the EIS, material incorporated by reference and a list of preparers.

Subpart C of the Procedures describes requirements related to coordination and other environmental review and consultation requirements. NEPA compliance involves addressing a number of particular issues, including: (1) landmarks, historical, and archaeological sites; (2) wetlands, floodplains, important farmlands, coastal zones, wild and scenic rivers, fish and wildlife, and endangered species; and (3) air quality. Formal consultation with other agencies may be required, particularly in the case of potential impacts to threatened and endangered species and potential impacts on historic or archaeological resources. Section 5.2 discusses the Endangered Species Act consultation process.

Subpart D of the Procedures presents requirements related to public and other Federal agency involvement. NEPA includes a strong emphasis on public involvement in the review process. Requirements are very specific with regard to public notification, convening of public meetings and hearings, and filing of key documents prepared as part of the review process.

Subpart F presents environmental review procedures for the New Source NPDES Program. This Subpart specifies that the requirements summarized above (Subparts A through D) apply when two basic conditions are met: (1) the proposed permittee is determined to be a new source under NPDES permit regulations (see Section 2.1); and (2) the permit would be issued within a State where EPA is the permitting authority (i.e., that State does not have an approved NPDES program in accordance with section 402(b) of the CWA. In EPA Region 10, Alaska and Idaho do not have approved NPDES programs). This Subpart also states that the processing and review of an applicant's NPDES permit application must proceed concurrently with environmental review under NEPA. Procedures for the environmental review process are outlined. Subpart F also provides criteria for determining when EISs must be prepared, as well as rules relating to the preparation of RODs and monitoring of compliance with provisions incorporated within the NPDES permit. Additional information that is not relevant to the New Source process can be found in Subparts E, G, H, I, and J of the Procedures.

Of particular importance to new source NPDES permit applicants is preparing the Environmental Information Document (EID). It is highly recommended that applicants confer with EPA regarding the scope of the EID as a well prepared EID will make the ensuing NEPA process run much more smoothly. In general, an EID should address the following (adapted from EPA Region 6, *EID Handbook*, 1995):

- An effective **description of the project**, with an emphasis on project features which cause environmental changes, and with alternatives to those features.

- A concise description of the **environmental setting** where the project takes place, with an emphasis on resources which are highly valued, very sensitive to change and/or certain to be affected by the project.

- Evidence that the project has been designed and located, and will be built and operated, to reasonably **minimize adverse environmental changes** and to improve environmental benefits.

- The applicant's own assessment of **environmental impacts or changes.**

- Discussion of **cumulative environmental effects** which would result from interaction with other activities in the same watershed, same airshed or same economic region.

- Documentation that necessary **coordination** regarding special resources has taken place with certain Federal and state agencies (e.g., Corps of Engineers, U.S. Fish and Wildlife Service, State Historic Preservation Officer).

Section 6 of this *Source Book* provides guidance on information needs related to NEPA analyses.

4.3 When is an EIS Required?

The determination of whether or not an EIS is required is important as it impacts the nature and extent of data that needs to be collected and analyses that need to be performed to determine the environmental impacts of a proposed project (and project alternatives). NEPA requires that an EIS be prepared for "major" Federal actions "significantly affecting the quality of the human environment." Generally, the determination of the need for an EIS hinges on finding that the proposed action would result in significant adverse impacts.

EPA's procedures provide general guidelines and specific criteria for making this determination (40 CFR 6.605). General guidelines are (40 CFR 6.605(a)):

- EPA shall consider both short- and long-term effects, direct and indirect effects, and beneficial and adverse environmental impacts as defined in 40 CFR § 1508.8.

- If EPA is proposing to issue a number of new source NPDES permits within a limited time span and in the same general geographic area, EPA must consider preparing a programmatic EIS. In this case, the broad cumulative impacts of the proposals would be addressed in an initial comprehensive document, while other EISs or EAs would be prepared to address issues associated with site-specific proposed actions.

EPA's specific criteria for preparing EISs for proposed new source NPDES permits are found in 40 CFR 6.605(b):

- The new source will induce or accelerate significant changes in industrial, commercial, agricultural, or residential land use concentrations or distributions, which have the potential for significant effects. Factors that should influence this determination include the nature and extent of vacant land subject to increased development pressure as a result of the new source, increases in population that may be induced, the nature of land use controls in the area, and changes in the availability or demand for energy.

- The new source will directly, or through induced development, have significant adverse effects on local air quality, noise levels, floodplains, surface water or ground water quality or quantity, or fish and wildlife and their habitats.

- Any part of the new source will have significant adverse effect on the habitat of threatened and endangered species listed either Federally or by the State.

- The issuance of the new source permit would result in a significant direct adverse impact on a property listed or eligible for listing in the National Register of Historic Places.

- The issuance of the new source permit would result in significant adverse efforts on parklands, wetlands, wild and scenic rivers, reservoirs or other important water bodies, navigation projects, or agricultural lands.

The determination of significance can be challenging. CEQ provides some guidance in the form of a two-step conceptual framework which involves considering the context for a proposed action and its intensity (40 CFR 1508.27). Context can be considered at several levels, including the region, affected interests, and the locality. Intensity "refers to the severity of the impact." CEQ lists a number of factors to be considered when judging severity, including:

- Effects on public health and safety
- Unique characteristics of the geographic area
- The degree to which effects are likely to be controversial
- The degree to which effects are uncertain or involve unique or uncertain risks
- Cumulative effect of the action
- Whether the action would threaten a violation of Federal, State, or local law or regulation

The nature of the mining industry can make it particularly difficult to assess significance. Potential impacts are often uncertain, they often are delayed in time from the permitting action, and they can be quite controversial. In addition, impacts may occur in environments previously degraded by mining or other activities, or environments where naturally occurring pollutants contribute to environmental degradation. It is also important to note that impacts may be both beneficial and adverse. There may be a significant effect even if, on balance, the effect will be beneficial.

In general, it is essential for applicants to coordinate with EPA early in the planning process to determine the data needed in order for EPA to prepare an EIS. Section 6 describes the general information needed for EISs on new mining proposals.

5.0 OTHER AUTHORITIES

5.1 Clean Air Act

Clean Air Act (CAA) provisions apply to a wide range of emissions sources from mine sites, including stack/point sources and fugitive sources. Fugitive emissions are generally defined as sources that are not easily controlled (e.g., conveyors can be controlled while open piles cannot). CAA requirements are generally applied through several different types of programs. These requirements can be described by three categories: (1) new source permits, including prevention of significant deterioration (PSD) and non-attainment permits, (2) new source performance standards (NSPSs), and (3) State Implementation Plan (SIPs) requirements for non-attainment areas. Title V of the 1990 CAA Amendments provides for consolidation of different CAA requirements into single facility permits. EPA's permitting authority is generally limited to "major" sources. States generally have exclusive permitting authority under CAA Section 110A(2)c for minor sources. Beyond permitting, EPA must evaluate compliance with applicable air quality requirements for all new or modified sources associated with proposed actions that are subject to NEPA.

Where an operator proposes a new point source or modifications to an existing point source, the entire facility must be reviewed for air quality impacts. Separate requirements apply to major and minor sources. Major source determinations are based on the emissions of six parameters from point sources, including: NO_x, SO_2, CO, VOCs, particulates, and lead. Most facilities are major sources if they emit more than 250 tons per year of any of these pollutants. Comparison of source emissions with these threshold values includes expected reductions to be provided by proposed control measures. Mines with complex oxidation processes or smelters generally trigger at least one of the threshold values for the six parameters and are typically sources subject to the PSD program.

There are two categories of new source reviews/permits: PSD analyses/permits for facilities in attainment areas, and non-attainment analyses/permits for facilities located in non-attainment areas. Non-attainment is measured through compliance with the National Ambient Air Quality Standards (NAAQS) for the six pollutants. A facility in a non-attainment area may undergo a combination of both PSD and non-attainment analyses: PSD for pollutants that are achieving ambient air quality standards and non-attainment analyses for specific pollutants that are causing the non-attainment designation.

PSD requirements include the use of Best Available Control Technology (BACT) for all emissions sources, stack/point source emissions and fugitives. In addition, total emissions from a site must not cause exceedances of NAAQS. EPA ensures compliance with NAAQS through pollutant "increments." The applicable increments for a site depend on facility location. There are nationwide increments for "Class I" and "Class II" areas. Class I areas lie within 50 kilometers of federally protected lands such as National Parks. More stringent increments may be established on an airshed-specific basis depending on background air quality and number and types of sources. In general, facilities that only affect Class II areas do not present issues related to BACT not meeting the increments. However, facilities located within or that can affect Class I areas often present difficulties, because the national Class I increments are very stringent and individual areas can establish even more stringent air quality related values (AQRVs). Modeling is used under PSD to determine compliance with Class I and II increments.

5.1.1 New Source Performance Standards

As noted above, the PSD and minor source programs address facility-wide air emissions. Under CAA Sections 111/112, EPA has also established minimum national new source performance standards (NSPSs) for emissions of certain pollutants discharged from specific types of industrial units and operations. This includes metallic mineral processing (40 CFR Part 60 Subpart LL) and non-metallic mineral processing (40 CFR Part 60 Subpart 670). Mineral processing is generally defined as extraction and beneficiation operations associated with transport and beneficiation of ore, including conveyor belt transfer points, screens, crushers, storage bins, thermal dryers, and truck and railroad loading and unloading. Underground operations are excluded. The NSPSs include opacity and particulate matter limits from each point source. In addition, there is an opacity standard for particulate matter that escapes from containment systems.

5.1.2 Specific Sources

Table 6 summarizes the applicability of specific Clean Air Act programs to individual sources at mining operations, generally in the context of whether emissions are fugitive or stack emissions, and mobile or stationary sources.

Table 6. Potential Emission Sources at Mine Sites

Source	*Applicability/Authorities*
Overburden, Waste Rock, Tailings, and Spent Ore	Fugitive and mobile sources (vehicles); except for Hazardous Air Pollutants (HAPs), EPA has limited authority to control fugitives unless there is a major point source; for major new sources, can require BACT, LAERs, and other controls needed to comply with PSD/non-attainment requirements; emissions from uranium mill tailings, asbestos mine wastes, and phosphate rock (radionuclides) specifically covered by National Emission Standards for Hazardous Air Pollutants (NESHAPs).
Land Application	Wet process, little or no CAA applicability
Waste Materials Re-use	Primary CAA applicability is NESHAP)requirements for asbestos and radionuclides emissions related to re-use of waste materials containing asbestos; phosphate rock containing radionuclides; etc.
Chemical Storage	For wet storage, little or no CAA applicability; for dry, considered fugitives as discussed under waste rock, tailings, and spent ore above
Ore Handling and Piles	Open piles - fugitives; Covered storage piles/areas and conveyors - point sources; conveyor transfer points, covered storage areas, truck and railroad unloading areas covered by NSPS (opacity and particulates)
Heap and Dump Leaches	Mostly wet and not relevant; where dry, fugitives
Process Ponds	Wet - little or no applicability
Mine Pit	Major source of fugitive and vehicle emissions, new technology-based standards for off-road vehicles to be established under Title II; two current interpretations for vehicles - (1) national - subject to stationary source permitting as point source, EPA authority largely dependant on major/minor determination, and (2) Region X - mobile source, exempted from permitting, but considered by EPA under NEPA.
Underground Workings	EPA policy decision that all vents from underground mines are stationary sources and must be evaluated under NEPA and CAA; permitted as point sources; uncertain how widely applied
Blasting	Above ground - fugitives, underground - see underground workings
Vehicle Use	See mine pits above, haul roads also major sources of fugitives
Construction	Exempted from permitting as temporary activity; SIPs typically have generally applicable requirements (e.g., must not cause nuisance)

Table 6. Potential Emission Sources at Mine Sites	
Source	*Applicability/Authorities*
Reclamation/Post-reclamation	Theoretically should be covered under new source permitting, major/minor source issue effects authority; could also be addressed as part of permit modification; may not be being considered
Inactive/Abandoned Mines	Except under CERCLA, ongoing activity should be same regulatory and permitting requirements as active operations; CERCLA actions exempted from permitting but still must meet standards (PSD, NSPS, etc.)
Generators	Point sources, may bring some entire mine sites into major source requirements; also lower major source threshold for PSD/non-attainment analysis may arise if greater than about 75 Mw
Note: Some fugitive sources (overburden, land application, etc.) are generally only evaluated when making a major source determination.	

5.2 Endangered Species Act

The Endangered Species Act of 1973 (ESA) requires Federal agencies to "insure that any action authorized, funded, or carried out by such agency is not likely to jeopardize the continued existence of any listed species or result in the destruction or adverse modification of critical habitat of such species." The purpose of the Act is "to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved" and "to provide a program for the conservation of such endangered species and threatened species . . ."

Section 7 of the Act, as amended, outlines procedures for interagency cooperation to conserve Federally listed species and designated critical habitats. Section 7(a)(1) requires Federal agencies to use their authorities to further the conservation of listed species. Section 7(a)(2) requires Federal agencies to consult with the U.S. Fish and Wildlife Service (FWS) and/or National Marine Fisheries Service (NMFS; hereafter referred to together as the Services) to ensure that they are not undertaking, funding, permitting, or authorizing actions likely to jeopardize the continued existence of listed species or adversely modify designated critical habitat. For example, EPA will consult with the Services in the issuance of NPDES permits as well as preparation of NEPA documentation.

The roles and responsibilities of the Services in implementing the Act were described by the Department of the Interior and the Department of Commerce in a 1974 Memorandum of Understanding. NMFS is responsible for listed species that occur in marine environments, including anadromous fish species such as salmon and steelhead that migrate from freshwater to marine environments during a portion of their life cycle. The FWS is responsible for listed species that are inland or nonmarine species. If listed salmon and trout species (e.g., bull trout) occur within a project study area, both Services would be responsible for completing Section 7 procedures. The Services also have joint jurisdiction over some listed species (FWS and NMFS, 1998).

The Section 7 consultation process is designed to assist Federal agencies in complying with the Act. Figures 3A and 3B describe typical steps in the consultation process. Most consultation is undertaken informally. First, a general description of the proposed action and a formal request for a list of proposed, candidate and listed endangered and threatened species potentially affected by the proposed action are submitted to the Services by the lead Federal agency. The Services respond with a list of proposed, candidate, and listed species and/or habitat that occur within the project study area. Although the inclusion of candidate species is not required by law, the Services consider candidates when making natural resource decisions. If no species or habitat are present, consultation ends. If species and/or habitat are present and a project involves major construction activity, a Biological Assessment (BA) must be prepared by the Federal Agency. The BA identifies the project, summarizes the biology of the listed species, analyzes the impacts of the proposed action, and determines if there is likely to be an effect (either beneficial or adverse) on any listed species. The BA is then filed with the Services. If species and/or habitat are present and the project involves actions other than "major construction activity," the Federal agency must still evaluate the potential for adverse effects and consult with the Services. This may consist of preparing a Biological Evaluation (BE) or other type of report to evaluate these effects.

If the BA or BE concludes that the proposed agency action "is likely to adversely affect" any of the T&E species, formal consultation with the Services is required.

Formal consultation involves a more detailed review of the proposed action by the Services. The formal consultation process determines whether a proposed agency action(s) is likely to jeopardize the continued existence of a listed species or destroy or adversely modify critical habitat. It also determines the amount or extent of anticipated incidental take of a listed species. After collecting the best available scientific and commercial information on the listed species, and reviewing the Federal Agency's BA or BE, the Services prepare a Biological Opinion (BO) that analyzes the impacts of the proposed action on the listed species. Three possible conclusions are made in the BO: the proposed action (1) may promote the continued existence of the species; (2) is not likely to jeopardize the continued existence of the species; or (3) is likely to jeopardize the continued existence of the species. When the Services make a determination that the proposed action is likely to jeopardize the continued existence of the species, reasonable and prudent alternatives must be included in the BO. Reasonable and prudent alternatives are alternative actions that can be implemented in a manner consistent with the scope of the Federal agency's action, that are economically and technologically feasible, and that the Services believe would avoid jeopardy or adverse modification to the listed species, or critical habitat, respectively. The BO may also include reasonable and prudent measures to minimize impacts (i.e., amount or extent, or incidental take).

Concurrent with planning for permitting and NEPA review, it is essential that proposed mine operators work with the lead agency and the Services to plan for ESA compliance.

Biological surveys need to fully address the presence of proposed, candidate, threatened, and endangered species and/or their habitat. Potential impacts need to be considered in preparing plans of operations and permit applications. The lead agency will be responsible for ensuring that final plans of operations/permitted activities are consistent with the findings of the Biological Opinion. Specific reasonable and prudent measures and alternatives as well as monitoring requirements identified in the Biological Opinion may be incorporated directly into NPDES or other permits and Records of Decision issued by EPA.

Non-Federal representatives (e.g., proposed mine operators) may participate in the informal consultation process, including preparing draft BAs. The lead agency must designate such representatives in writing to the Services. Regardless, ultimate responsibility for compliance with Section 7 requirements remains with the lead agency (e.g., assuring that draft BAs are technically sound). More information about the Act and consultation process is found in the Endangered Species Consultation Handbook published by the Services in March 1998. This document is available from the USFWS website.

5.3 Resource Conservation and Recovery Act (RCRA)

Under the provisions of RCRA §3001(b)(1), solid waste from the extraction, beneficiation, and processing of ores and minerals is exempt from regulation as hazardous waste under RCRA Subtitle C. This section was added to RCRA in 1980 and is known as the "Mining Waste Exclusion" or the "Bevill Amendment"– several other categories of wastes were also excluded, and collectively these wastes are known as "special wastes." This provision precluded EPA from regulating these wastes until the Agency had performed a study and submitted a Report to Congress, as directed by §8002(f) and (p), and determined either to promulgate regulations under Subtitle C (that is, to regulate the wastes as hazardous wastes) or that such regulations were unwarranted (that is, to continue the Exclusion of the wastes from such regulation). EPA subsequently modified its final hazardous waste regulations to reflect this new

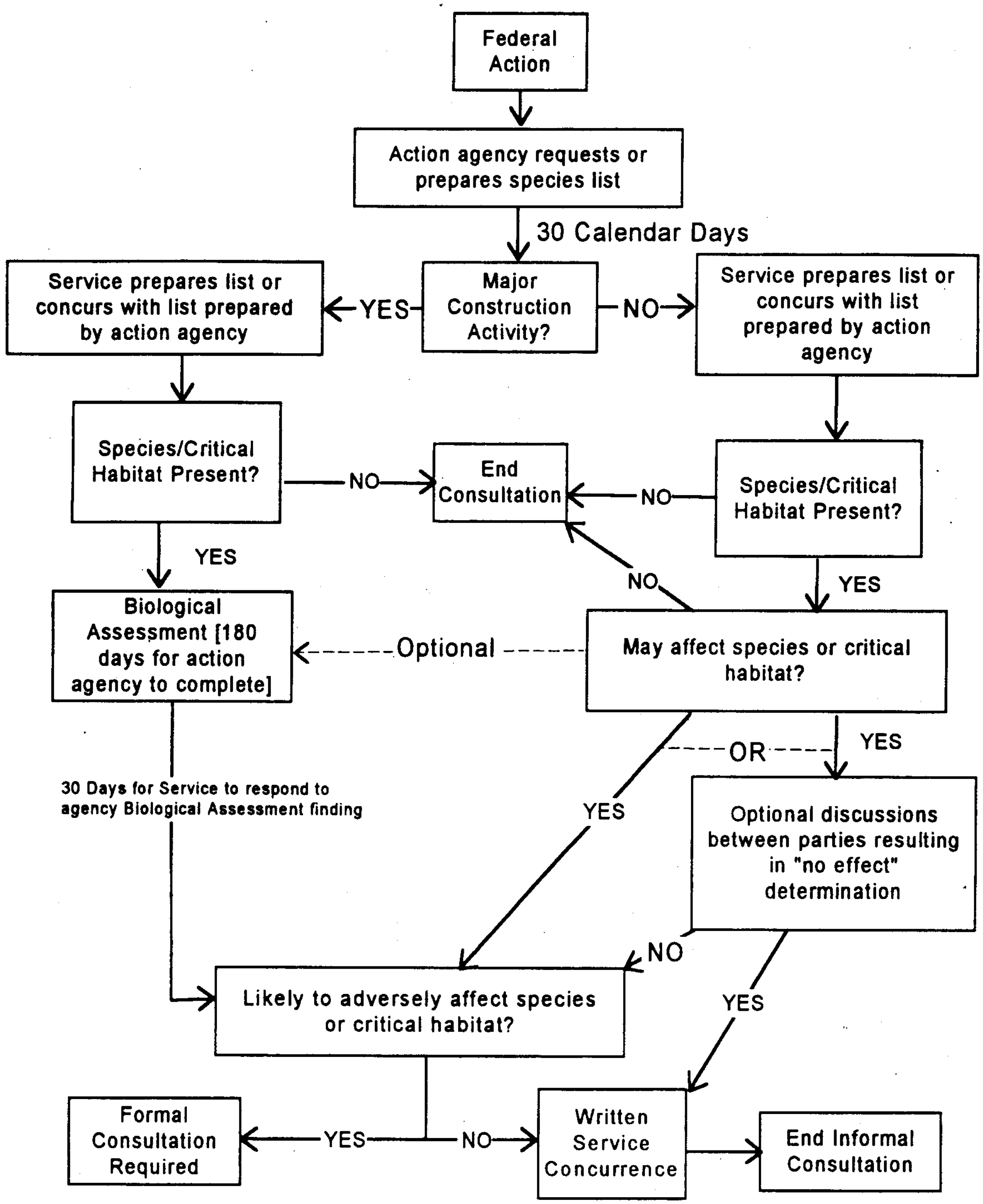


Figure 3A. Informal Consultation Under the Endangered Species Act

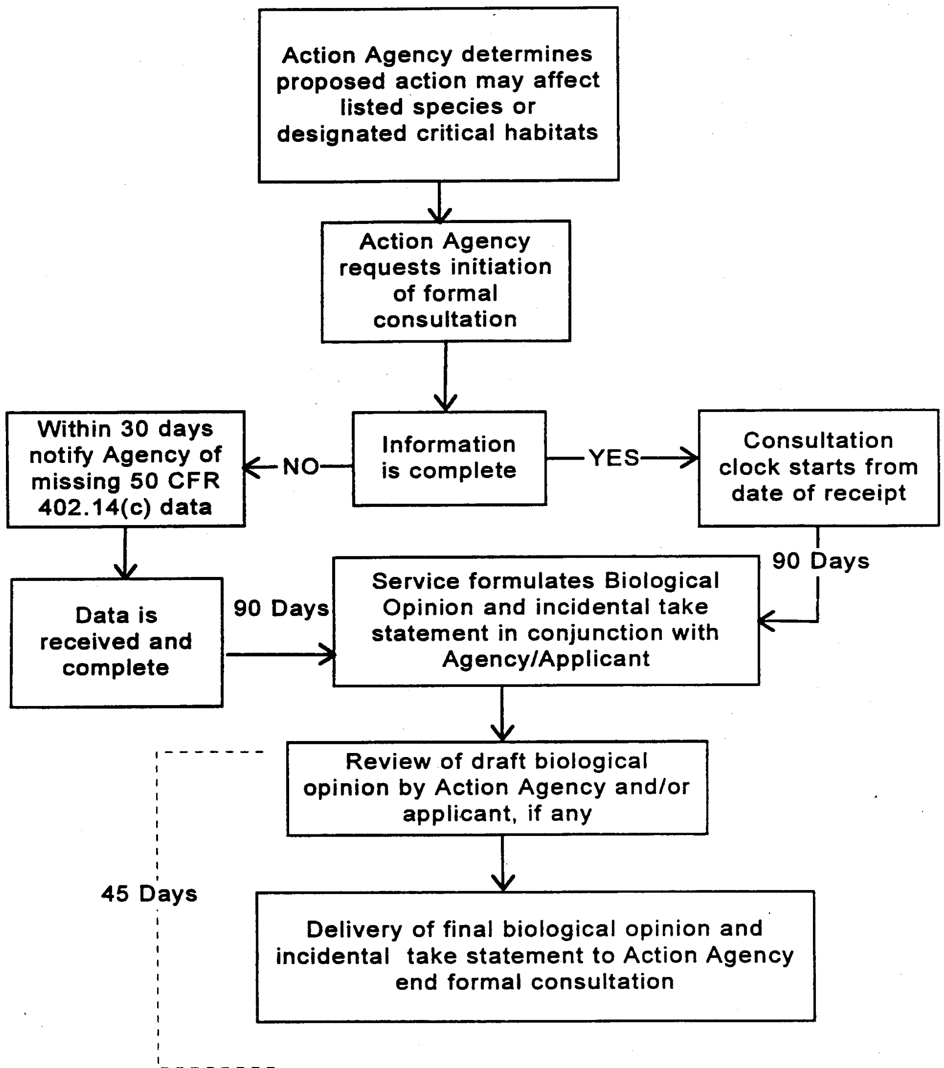


Figure 3B. Formal Consultation Under the Endangered Species Act
(USFWS and NMFS, *Endangered Species Consultation Handbook, 1998)*

exemption, and issued a preliminary interpretation of the scope of the exemption. Over the next decade, there followed litigation, Reports to Congress, and rulemakings. These are not described in detail here, but rather only the key decisions are highlighted.

In 1985, EPA submitted the first Report to Congress, which addressed wastes from mineral extraction and beneficiation. On July 3, 1986 (51 FR 24496), EPA published the regulatory determination for these wastes, which stated that regulation of these wastes as hazardous wastes was unwarranted.

In the late 1980s, EPA proposed and promulgated a series of rules that redefined the boundaries of the Exclusion for mineral processing wastes. These rulemaking notices provided explicit criteria for making key distinctions between mineral beneficiation and processing and for determining whether specific mineral processing wastes met certain other criteria and were thus eligible for the Exclusion. The full rulemaking process was completed with the promulgation of final rules on September 1, 1989 (54 FR 36592) and January 23, 1990 (54 FR 2322).

Of all mineral processing wastes, only 20 were found to meet the newly promulgated special waste criteria; all other mineral processing wastes were removed from the Mining Waste Exclusion. On July 30, 1990, EPA submitted a Report to Congress on these 20 wastes. Subseqently, EPA made a regulatory determination that regulation of these wastes as hazardous wastes was unwarranted.

As a result of the rulemaking process, all but 20 mineral processing wastes lost their special waste status, and assumed the same regulatory status as any other industrial solid waste. Therefore, if they exhibit one or more characteristics of hazardous waste, or are listed as hazardous waste, they must be managed in accordance with RCRA Subtitle C or equivalent State standards.

EPA considers these wastes to be “newly identified” since they were brought into the RCRA Subtitle C system after the date of enactment of the Hazardous and Solid Waste Act (HSWA) Amendments on November 8, 1984. EPA declined to include newly identified wastes within the scope of the Land Disposal Restrictions (LDR) for Subtitle C characteristic hazardous wastes (the “Third Third” rule) published on June 1, 1990, deciding instead to promulgate additional treatment standards (Best Demonstrated Available Technology, or BDAT) in several phases that would be completed in 1997 (55 FR 22667). EPA subsequently developed BDAT treatment standards that must be met for characteristic hazardous mineral processing wastes.

5.4 Coastal Zone Management Act

For mining operations proposed in areas that lie within a particular state’s coastal zone, a consistency determination with respect to that state’s Coastal Zone Management Plan (CZMP) will likely be required. The state agency responsible for implementing the federal Coastal Zone

Management Act in that particular state must concur that the proposed operation is consistent with the state's CZMP. The state's concurrence with the consistency determination may in turn require coordination with other state permitting agencies as well as at the local level where elements of such plans are often developed. Prospective mine operators are encouraged to identify and contact the appropriate state officials early in the mine planning process so that the CZMP consistency determination can run concurrent with other regulatory processes. State government websites are a good source of information for state regulatory programs, including coastal zone planning requirements.

5.5 State Authorities

EPA is not responsible for implementing all or even most environmental programs. All Federal environmental programs, including the Clean Water Act, the Clean Air Act, and many other statutes, provide for State assumption of implementation authority upon passage of conforming laws, development of appropriate regulations, and establishment of adequate mechanisms for implementation. Table 7 shows the delegation status of all the major Federal environmental programs in EPA Region 10, as of early 2003. Because NEPA is not a regulatory program but rather places an obligation on Federal agencies to comply, there is no "authority" that can be delegated under NEPA.

Table 7. Delegation and Authorization of Federal Environmental Programs to States in EPA Region 10 (see note 1)

Statute/Program	*Alaska*	*Idaho*	*Oregon*	*Washington*
Clean Air Act				
NSPS	Partial delegation	Partial delegation	Partial delegation	Partial delegation
NESHAPS	Partial delegation	Partial delegation	Partial delegation	Partial delegation
NSR	Full delegation	Full delegation	Full delegation	Full delegation
PSD	Full delegation	Full delegation	Full delegation	Partial delegation
MACT NESHAPS	Partial delegation	Partial delegation	Partial delegation	Partial delegation
Acid Rain	n/a	Full delegation	Full delegation	Full delegation
Title V (note 2)	Interim approved	Interim approved	Full delegation	Full delegation
SIPS (note 3)	Ongoing approvals	ongoing approvals	Ongoing approvals	Ongoing approvals
Clean Water Act				
NPDES permitting	Not delegated	Not delegated	Full delegation	Full delegation
Pretreatment	Not delegated	Not delegated	Full delegation	Full delegation
Sludge	Not delegated	Not delegated	Not delegated	Not delegated

Table 7. Delegation and Authorization of Federal Environmental Programs to States in EPA Region 10 (see note 1)

Statute/Program	*Alaska*	*Idaho*	*Oregon*	*Washington*
Federal facilities	Not delegated	Not delegated	Full delegation	Not delegated
Wetlands	Not delegated	Not delegated	Not delegated	Not delegated
Emergency Planning and Community Right-to-know Act				
§§311 & 312	Not delegated	Not delegated	Not delegated	Not delegated
Federal Insecticide, Fungicide, and Rodenticide Act				
Enforcement (note 4)	Full delegation	Full delegation	Full delegation	Full delegation
Resource Conservation and Recovery Act				
Base program (note 5)	Not delegated	Full delegation	Full delegation	Full delegation
Corrective action	Not delegated	Full delegation	Full delegation	Full delegation
Boilers & Industrial Furnaces	Not delegated	Full delegation	Full delegation	Not delegated
Toxicity Characteristics Rule	Not delegated	Full delegation	Full delegation	Full delegation
Land Disposal Restrictions	Not delegated	Partial delegation	Partial delegation	Partial delegation
Underground Storage Tanks	Not delegated	Not delegated	Not delegated	Full delegation
Safe Drinking Water Act				
UIC Class II wells	Full delegation	n/a	Full delegation	n/a
UIC Class I, III, IV, V	n/a	Full delegation	Full delegation	Full delegation
PWS	Full delegation	Full delegation	Full delegation	Full delegation
Toxic Substances Control Act				
Lead	Not delegated	Not delegated	Full delegation	Not delegated

Notes:
n/a = not applicable
1 Partial and full delegations of programs to States do not apply in Indian Country, where EPA retains full responsibility
2 Generally, States are implementing and carrying out a majority of the program but are constantly updating their rules and EPA must approve before the State can fully implement.
3 Interim approved means EPA has approved the State to implement but some revisions are needed before the final/full approval can be given.
4 FIFRA delegation is for use violations only. Other Federal violations are referred to EPA.
5 pre-HSWA program

Besides Federal programs that may be delegated to States, many States implement programs specific to mining operations that have no direct EPA nexus. These generally require State permits for various aspects of mining operations and closure, oversight of most or all aspects of mining operations, and reclamation of mine sites to State- and site-specific standards. All States in EPA Region 10 have laws that require hardrock mining reclamation, and that require some sort of financial assurance that reclamation can be achieved at the end of active operations.

These programs are not described in this Source Book, since EPA has no direct role in their implementation. Most States have placed detailed information on these programs on their websites.

EPA notes, however, that state permit programs, including bonding programs, can be an important factor in providing mitigation for predicted impacts, and can be crucial in ensuring that proposed mitigation measures will actually be implemented. For these reasons, EPA considers State regulatory and permit requirements, as well as bonding requirements, to be important factors in its evaluation of potential impacts under NEPA

6.0 EPA EXPECTATIONS FOR MINING IMPACT ASSESSMENT

As discussed in Section 4, EPA's primary direct responsibilities in Region 10 typically relate to NPDES new source permitting of mines under the CWA and associated NEPA review. At the same time, many of the most significant issues regarding potential environmental impacts from new mining operations involve water resources, aquatic habitat, jurisdictional wetlands and other waters of the U.S. Consequently, EPA expects applicants to have a thorough understanding of the hydrological and aquatic environment in which they are proposing to work. The NEPA review and CWA permitting processes will require that an applicant collect a variety of data, conduct different types of analyses, and develop preliminary facility and operational designs to define potential consequences on water resources. Examples of the types of data, testing, and analysis that may be required are given in Tables 8 through 11. Tables 8 through 11 in turn refer to the technical appendices for more details. A general discussion of information needs related to predicting impacts to surface water, ground water, and wetlands resources are presented in the following sections.

6.1 Impacts to Surface and Ground Water Hydrology

Applicants need to address whether and to what extent their proposed project will affect the surface water and ground water hydrology at the mine site and within the watershed. To determine potential hydrological impacts will require collection and analyses of a variety of meteorological and hydrological data (see Table 8), preparation of operation phase and closure phase water balances (see Table 11), and wastewater and storm water management plans. Information regarding surface water discharge, precipitation, and the duration and intensity of storm events are especially critical to this process. This is because most proposed sites are located in mountainous, coastal, or subarctic areas where there are significant annual and seasonal variations in climate that make it difficult to develop data sets that are representative and statistically significant. To overcome the problems associated with high short-term data variability requires a long-term record. However, most sites are likely to be proposed in remote areas for which long-term records of discharge and climate are unlikely to be available either for the watershed of interest or for nearby watersheds possessing similar physical characteristics. Consequently, in order to gather data for as long as possible, applicants should establish stations to monitor stream discharge and meteorological conditions during the early stages of site exploration. Information and analyses necessary to determining impacts to surface water and ground water hydrology is discussed in the following sections and in more detail in Appendix A, *Hydrology*.

6.1.1 Surface Water Hydrology

A proposed mining project can impact the quantity and velocity of surface water flow by altering natural drainage patterns and the infiltration/runoff relationships in a watershed; discharging storm water and wastewater; impounding water; changing the character of gaining and losing stream reaches through mine dewatering; mining through stream channels and flood plains; and by diverting, re-routing, and channelizing streams. Importantly, many mining activities have the potential to alter the equilibrium balance between flow and sediment transport in streams (Johnson, 1997). Altering this equilibrium causes stream gradients, channel geometries, channel patterns, and stream banks to adjust to new equilibrium conditions that reflect new erosion and sediment transport characteristics (Johnson, 1997). Such changes can disrupt aquatic habitats both upstream and downstream of a mine. The creation of waste dumps, tailings impoundments, mine pits and other facilities that become permanent features of the post-mining landscape can cause fundamental changes in the physical characteristics of a watershed (O'Hearn, 1997). Consequently, applicants may be required to assess the effect of these changes on the post-mining hydrological environment.

Most applicants will be required to complete hydrological studies and a site water balance in order to predict impacts to surface water hydrology. These studies and their associated data needs are summarized below and are described in more detail in Appendix A, *Hydrology.*

The *hydrological study* should provide a baseline from which to measure or predict relevant changes that might occur as a consequence of the proposed action and its alternatives. In order to place the project within the context of its watershed, the study should have a scope that extends beyond the boundaries of the proposed mine site. As part of the study, applicants should:

- Characterize both surface and subsurface flow regimes and surface-ground water interactions on a seasonal or monthly basis. Identify critical low flow conditions.

Table 8. Data Needs for NEPA Review and CWA Permits

Resource Area	*Data Needs*	*Appendix*
Climate	Average annual precipitation; Monthly precipitation distribution; Mean monthly temperature; Mean monthly evaporation; Storm characteristics (precipitation rates); Orographic effects.	A
Geology and Soils	Lithology and mineralogy of rocks, soils, and alluvial deposits; Rock unit distribution; Structural relations; Fracture distribution & characteristics; Alteration and mineralization, including vertical and lateral changes; Surface-subsurface relationships; Topography and slopes; Soil cover (depth and type).	C
Surface Water Hydrology	Watershed delineation; Flood plain delineation; Identification of special designation waters; Stream gradient, channel morphology, channel pattern; Stream flow/sediment transport relations; Stream flows (average monthly flow, critical low flows); Flood frequency; Precipitation/infiltration/ runoff relations; Gaining/losing reaches; Surface water usage.	A, B
Ground Water Hydrogeology	Aquifer delineation; Aquifer characterization (storage, direction of flow, gradient, permeability, transmissivity); Water table elevation and its variability; Recharge zones; Confining layers; Seeps & springs; Depth of permafrost thaw; Ground water usage.	A, F
Surface Water and Ground Water Quality	Background surface and ground water quality; Existing surface and ground water quality; Relationship of surface water quality to changes in flow	A,B
Effluent Quality	Expected quality of effluents and variability of effluent quality over range of operating conditions; Expected flow of effluent and variability of flow over range of operating and climatic conditions	D
Wetlands & Waters of the U.S.	Delineation of wetlands & waters of the U.S.; Wetlands classification; Designation of riparian habitat & corridors; Narrative descriptions that include nature, extent, functions, and value.	I
Aquatic	Fish and macroinvertebrate population and diversity data; Aquatic habitat characterization; aquatic mammals and amphibians; Threatened, endangered, or sensitive species.	G

- Distinguish the effects that any current or historic activities, including mining activities, have had on the hydrology of the project area

- Determine the extent to which different physical variables within the watershed control hydrological processes

- Prepare an analysis of meteorological records that describes the seasonal variability, frequency, and intensity of storm events.

The baseline study should provide adequate data to evaluate whether the proposed mine operation and considered alternatives could alter the hydrology of a watershed. This analysis requires characterization of several watershed geomorphological and other characteristics, such as basin slope, vegetative cover, soil type and land use conditions. In addition, applicants need to demonstrate how construction of the proposed mine and its associated facilities might alter runoff responses to both average and extreme precipitation events. Impacts to seasonal flow regimes and channel morphology (i.e., channel bed and bank erosion and sediment transport capacity) that can be caused by stream diversions, channelization, and altered drainage patterns need to be defined. Effects on surface water discharge, and impacts to spring-fed wetlands or stream reaches from mine dewatering activities should also be quantified.

Applicants must determine whether their proposed operation will result in discharges to waters of the U.S.. An accurate assessment is accomplished by developing a thorough understanding of local and regional hydrology and formulating a reliable water balance. An adequate water balance superimposes the flow of process system waters (i.e., the process circuit) on the natural hydrology within the watershed and describes the management of storm runoff, flood flows, and process and storm water discharges on a seasonal or monthly basis. The water balance should cover the range of hydrologic conditions (extreme and average) and potential variations or disruptions in process flows (e.g., temporary suspension of operations as well as closure). The site water balance is used to determine whether a proposed mine would have a net gaining system that may require continual or periodic discharges.

Table 9. Testing Needs for NEPA Review and CWA Permits

Resource Area	*Testing Needs*	*Appendix*
Solid waste characterization (e.g., Waste Rock, spent heap leach & Tailings)	Grain-size distribution; mineralogy, Total and sulfide sulfur content; Acid generating potential; Acid neutralizing potential; Kinetic test; leach tests; Total metals content; Leachate compositions; Tailings water compositions.	C
Rock, Soils & Sediment Characterization	Proctor moisture/density; Atterberg limits; Grain-size analysis; Direct shear; Permeability; Total metals content; Acid generating potential; Acid neutralizing potential; leach tests.	C,F
Water Quality Characterization	Major cation and anion concentrations; Metals concentrations (total and dissolved); pH; conductivity; Redox potential; Temperature; Total hardness; Total alkalinity; TDS; TSS; Dissolved oxygen, Whole effluent toxicity (WET) tests.	A,B, D
Hydrologic Characterization	*In situ* hydraulic conductivity; Monitor well logs; Drawdown studies; Aquifer transmissivity and storage.	A

Table 10. Preliminary Design Needs for NEPA Review and CWA Permits		
Resource Area	*Preliminary Design Needs*	*Appendix*
Mine Operation	Mine plan; Facilities layout.	-
Infrastructure	Road locations and construction; Stream crossings; Fuel storage; Borrow areas; Water and wastewater treatment plants.	-
Beneficiation	Mineral processing methodology; Reagent storage; Facility construction; Conveyance systems; Ore and concentrate stockpiles.	-
Waste Disposal	Tailings impoundments and piles; Waste rock and spent ore dumps; Overburden storage areas.	F
Process Water Management	Process water flow chart; Storage ponds; Conveyance structures; water balances	D,E
Storm Water Management	Diversion structures; Conveyance structures; Retention ponds.	E
Closure and Reclamation	Best Management Practices; Heap leach neutralization and rinsing; Revegetation mixes; Grading and recontouring; Natural and synthetic covers; Facility removal; Pit wall or mine tunnel stabilization.	E, F, H

Methods to measure and predict hydrological impacts and develop a site water balance are described in Appendix A, *Hydrology*. Region 10 recognizes that many mines proposed in northern and central Alaska are likely to be situated in areas underlain by permafrost. In these terrains, stream flow and precipitation-infiltration-runoff relations vary seasonally due to winter freeze. Applicants proposing to work in these areas should give special consideration to their unique hydrological characteristics and to seasonal variations.

6.1.2 Ground Water Hydrogeology

A proposed mining operation can impact the availability and flow of ground water by locally lowering the water table through dewatering operations; disrupting aquifers; locally removing confining layers; and altering zones of natural recharge (Brown, 1997). Mining activities also create opportunities for ground water contamination by exposing aquifers and puncturing aquitards. Alteration of ground water flow direction or reduction in the water table or potentiometric surface can potentially impact wetlands, aquatic habitats, and stream discharge characteristics.

Most applicants will be required to submit a detailed hydrogeologic study of the region in which they are proposing to operate. This study and its associated data needs are summarized below and described in detail in Appendix A, *Hydrology.*

Table 11. Data Analysis Needs for NEPA Review and CWA Permits

Resource Area	*Data Analysis Needs*	*Appendix*
Waste Rock & Tailings Disposal Impact	Predict short- and long-term acid generating potential and metals leachability; rates of seepage and run-off; predict stability of piles, impoundments, and backfill	C,F
Surface Water & Ground Water Quality Impact	Statistical analysis of water quality data; Estimated effluent discharge composition; Estimated seepage composition; Projected effects of discharge on ground and surface water quality; Estimated pit-lake water quality; Projected likelihood of ground and surface water quality impacts from spill events. Ground-water models used to assess impacts should be updated annually through operations and the impacts determination should be modified if the model changes significantly.	A,B,D
Hydrological Impacts	Facility water balance; Design storm models; Watershed model (e.g., HEC-1); Flow duration curves; Pit lake development model; Ground water flow model (e.g., MODFLOW); Storm water flow model; Sediment erosion and transport model; Dewatering, drawdown, and recovery; Changes in recharge characteristics.	A,H
Wetlands & Aquatic Life Impact	Calculated impacted acreage by wetland type, loss of function and value. Potential impacts on fish and macroinvertebrate populations through toxicity, reduced flow, and habitat loss.	B,I,G

The *hydrogeological study* should provide a baseline from which to measure or predict changes that might occur as a consequence of the proposed action and its alternatives. The boundaries of the study have to be defined on site specific basin, and may need to encompass the entire watershed. As part of the study, applicants should:

- Identify aquifers and confining layers and their vertical and lateral extent
- Determine the types of aquifers (confined or unconfined), aquifer characteristics such as hydraulic conductivity, primary and secondary porosity, storage coefficients, and hydraulic gradient, and hydraulic communication, if any, with surface water or other ground waters

- Characterize each confining layer and its physical properties
- Determine the depth to water, the configuration of the water table or potentiometric surface, and the hydraulic gradient and flow direction
- Where required, quantify the seasonality of ground water flow in permafrost terrains
- Distinguish the effects that any current or historic activities, including mining activities, may have had on the hydrogeology of the project area.

Region 10 expects applicants to provide analyses of potential impacts to ground water resources caused by water use and mine dewatering. Dewatering of surface and underground mines can deplete aquifers, impact ground water recharge and discharge, and locally change the direction of ground water flow. For these reasons, data collected for hydrogeological studies should be used to conduct an analysis of the potential impacts of drawdown. This analysis should determine the extent that ground water levels or specific yield would be affected and whether lowering of the water table or reducing the potentiometric surface would impact spring flow, wetlands, gaining stream reaches, or other ground water users. In some cases, an analysis of geotechnical effects caused by drawdown may be required to adequately design mine facilities, impoundments, embankments, and foundations. For example, dewatering a comparatively thick, unconsolidated alluvial aquifer that overlies an undulating bedrock surface, could cause differential compaction, consolidation, and uneven surface subsidence. These effects could threaten the geotechnical stability of facilities such as tailing dams and the integrity of engineered structures such as process pond liners. Data collected during dewatering operations should also be used to predict the rate at which the ground water system is expected to recover following active operations.

Hydrogeologic studies conducted in terrain underlain by permafrost will need to characterize the conditions unique to this sensitive environment. Included are the seasonality of ground water flow in the near surface environment, the depth of annual thaw, potential connections between shallow and deep (below the permafrost layer) ground waters, the importance of vegetative layers, and the potential for mining-induced thawing of frozen materials (either by excavation of insulating vegetation or rock layers or construction of permanent facilities such as tailings impoundments).

The hydrogeologic study should provide a basis for assessing the recovery of the ground water regime following mining. This includes estimating the rate at which ground water levels would recover and describing potential effects caused by the formation of pit lakes, the disruption of recharge zones (especially those associated with confined aquifers), the influx of seepage waters from permanent mine facilities (e.g., tailings impoundments), the removal of confining layers, the disruption of aquifer continuity, and the back-filling of mine pits (Siegel, 1997).

6.2 Impacts to Water Quality

Impacts to surface and ground water quality can occur from discharges of storm water, mine drainage, and process water. This section summarizes information needs regarding potential impacts to water quality. Appendices A and B provide detailed guidance for characterizing hydrology and receiving water quality at the appropriate watershed scale.

Two issues that applicants will be required to address during the NEPA review and CWA permitting processes are whether the proposed project is expected to lead to a discharge of wastewater and whether the proposed project would create short- or long-term impacts to surface or ground water quality. EPA places great emphasis on evaluations of potential wastewater discharges because once mining operations have been initiated, discharges often cannot be stopped or reduced if the effluent does not meet water quality standards. Historically, the most problematic discharges occur from major mine components that are exposed to the atmosphere, such as mine pits, waste rock dumps, tailings impoundments, and leach facilities. Because mine wastes will be exposed to the elements long after mine closure, the potential for the release of metals, acid, cyanide, sediment, or other contaminants from a mine site must be accurately analyzed. Evaluating the potential for long-term risk from waste disposal practices is a difficult task but it is of primary importance to demonstrating compliance with the CWA and in disclosing accurate information to the public. Factors associated with evaluating long-term impacts include:

- Characteristics of waste rock, tailings, and other waste materials
- Facility design and construction
- Beneficiation and processing methods
- Local meteorological and hydrological conditions
- Solid waste and wastewater management methods
- Closure and reclamation methods.

Determining potential impacts to water quality typically requires applicants to collect a variety of data, conduct numerous geochemical tests, develop preliminary mine plans and facility designs, and perform different types of data analyses. In general, applicants should anticipate that they may be required to provide studies that characterize:

- Background surface and ground water quality within the watershed hosting the proposed operation

- Background surface water hydrology and ground water hydrogeology in the watershed of interest

- Expected hydrologic, physical, and geochemical behavior of waste rock piles, heap leach piles, and tailings impoundments, and other waste materials during operation and following closure

- Chemical compositions of process waters, mine drainage, and treated and untreated effluent

- Effectiveness of rinsing, neutralization, and closure and reclamation methods employed for these facilities

Each of these items are discussed in the following subsections.

6.2.1 Background and Existing Water Quality

Methods to determine background and existing water quality in a watershed are discussed in Appendix B, *Receiving Waters;* testing needs and data analyses are summarized in Tables 9 and 11, respectively. As described in the appendix, applicants should employ robust statistical techniques to analyze background metals and other constituent concentrations in different portions of a potentially impacted watershed, quantify the magnitude of seasonal variability in water quality and variation associated with high and low stream flow conditions, and evaluate water quality under the conditions of highest risk (i.e., reasonable worst-case conditions). Adequate quality assurance and quality control should be demonstrated. For example, analytical methods employed must be sensitive enough to measure the parameters of concern at levels at or below the water quality criteria.

6.2.2 Regional Hydrology and Hydrogeology

The hydrology and hydrogeology studies described in Section 6.1 should provide data to evaluate potential future water quality impacts. Applicants for NPDES permits should develop a surface water management plan and site water balance that also can be used when evaluating potential water quality impacts.

6.2.3 Hydrology of Mines and Waste Facilities

Predictions of whether and when a mine or waste disposal facility may begin to generate acidic water or to release metals or other constituents are related to the flow of fluids through the facility, the compositions of these fluids, the compositions of the materials with which the fluids are in contact, and the chemical environment in which the fluids exist. Accurate predictions of effluent flow rate and discharge composition require knowledge of waste characteristics, surface and ground water hydrology, effectiveness of proposed surface water and ground water controls, final unit construction and closure methods, climate, geochemical equilibrium, and other variables that may be difficult to determine during the permitting process. Consequently, applicants for mines that could generate acid or mobilize metals should employ facility designs that minimize infiltration and seepage and use conservative estimates for acid generation potential, rainfall, and leachate composition to determine future impacts.

In general, the hydrological and hydrogeological studies described in Section 6.1, and in more detail in Appendix A, will provide data to determine the likelihood that lakes will form in open pits and that underground workings will flood when mining ceases. Although the rate at which lake filling or underground flooding is expected to occur can be estimated from knowledge of pre-mining ground water flow, data collected during actual dewatering operations can be used to provide a clearer picture of the expected post-closure conditions.

The long-term hydrological behavior of waste rock dumps and tailings impoundments depends on factors such as construction method, grain size and sorting of the waste materials, secondary mineral formation, and closure and reclamation methods (Blowes et al., 1991; MEND, 1995; Swanson et al., 1998). Predicting seepage rates can be difficult, especially for facilities that are likely to be partially saturated, such as those located in dry climates (Swanson et al., 1998). Generating acceptable model simulations is even more complicated for facilities constructed in such a way that they are physically heterogeneous (e.g., discontinuous layers of coarse and fine waste rock) (Swanson et al., 1998) or within which layers of secondary mineral cements formed during weathering (Blowes et al., 1991). More detail regarding the prediction of hydrologic impacts of waste rock dumps and tailings impoundments is provided in Appendix F, *Solid Waste Management* and Appendix A*, Hydrology.*

6.2.4 Solid Waste and Materials Characterization and Management

Applicants will need to demonstrate that they have adequately characterized their waste materials and the potential for these materials to contribute to discharges to surface waters and groundwater. Tests commonly used to characterize bulk chemical and physical composition, metals leachability, and acid-generating potential are summarized in Tables 9 and 11 and described in Appendix C, *Characterization of Ore, Waste Rock, and Tailings.* Because there are many different tests available to determine leachability and acid-generating potential and no single accepted way of interpreting test results, applicants should consult with federal and state regulatory agencies to enquire whether specific test methods are preferred.

Applicants should demonstrate that the samples characterized are representative of material that will be produced during operations. There are no set guidelines for determining the number of samples that should be tested. Recent studies suggest that the number of tested samples should be determined by the compositional variability of the materials that will be disposed of (Shields et al., 1998) — this has long been understood in terms of characterizing ore grade, and applicants should apply the same care in characterizing environmental samples. Applicants are expected to describe the variability inherent in different lithological units across the project area (e.g., homogeneous, unzoned granite vs. heterogeneous colluvium) and that may have been imparted to a lithological unit through weathering, hydrothermal alteration, and mineralization. Applicants will need to consider how vertical and lateral changes in the intensity and style of mineralization and host rock alteration affect the acid generating characteristics and metals leachability of each geologic unit at the proposed mine site. Because compositional variability equates primarily to mineralogical variability, applicants can use inexpensive examinations (e.g., mineralogical analysis by x-ray diffraction, possibly followed by petrographic microscope) to quantify the range and median proportions of acid-forming, acid-neutralizing, and metal-bearing constituents in the various lithological units that will be encountered. Testing programs can then focus on characterizing the expected behavior across the compositional range identified for each rock type.

For many large-scale operations, it may be appropriate to formulate composite test samples which represent waste rock and overburden materials as they are likely to be excavated and handled during the mining operation. It is important that composite samples be created in a manner representative of the proposed operation.

Tailings test samples should be taken from pilot-scale metallurgical tests representative of the operation that will be employed during full-scale operation. Applicants should test ore samples that capture the range of ore grades that will be processed during the life of the mine.

Of particular concern to EPA and the public is the potential for waste rock, tailings, and heap leach materials to generate acidity and release metals after protracted exposure to the environment. Tests of several years duration conducted on mine materials indicate that acidification may occur after periods of neutral drainage lasting one to two years (Lapakko et al., 1998), even in the accelerated weathering environment of the lab. Applicants should recognize that static acid-base accounting tests provide information only on the relative proportions of acid-forming and acid-neutralizing components in a sample and provide no information regarding the rates at which these reactions are expected to occur. Information regarding the latter can only be obtained by kinetic tests that are conducted for a sufficiently long time. Kinetic tests typically are conducted for 20-week periods; however, there is a trend toward using longer test times (Price et al. [1997] advocate 40-week tests) that would be viewed favorably by Region 10.

The results of static and kinetic tests are particularly sensitive to the test method and laboratory technique. EPA Region 10 encourages applicants to conduct all tests using the same test method and testing laboratory. In addition, although not specifically stated in most kinetic test procedures, Mills (1998) points out that it is typical for splits of the starting kinetic sample and final leached product to be tested for static acid-base properties and total metals. Mineralogical analyses also should be conducted on these samples because these data can provide important constraints to assist the interpretation of test results.

Interpreting the results of leach tests, static acid-base accounts, and kinetic tests is not straightforward and there are no generally accepted criteria for doing so (see Appendix C). This is because the conditions simulated by the tests inevitably will deviate from the environment in which wastes will be disposed and because many test methodologies require that samples be crushed or ground to particle sizes significantly finer than produced by the mining operation (Doyle et al., 1998; Lapakko et al., 1998). Changes in particle size are particularly important, because crushing alters the exposed surface areas of both acid-forming and acid-neutralizing materials, which in turn affects reaction rates and availability (Lapakko et al., 1998). To ensure that interpretations of geochemical test results are appropriately conservative, applicants should carefully consider the representativeness of the tested samples, the similarities and differences between the test conditions and site environment, and the significance of any temporal changes in leachate compositions noted over the course of the tests. In addition, specialized knowledge is required for proper evaluation of the characterization results, and applicants need to ensure that their data are evaluated by individuals with this knowledge.

Applicants should also provide information useful for predicting impacts on water quality. These include information on the effects of previous mining, pre-mining water quality, and relevant geologic factors (e.g. rock type, effects of surface weathering). This type of information can be particularly valuable in identifying the potential for metals leaching in the absence of acidic conditions.

Management of solid wastes and information needs related to NEPA analyses of potential impacts due to solid waste are discussed in Appendix F, *Solid Waste Management*. Applicants proposing operations that will produce acid- or metals-generating waste rock or tailings should provide design elements that will limit potential environmental impacts from these materials. These could include steps to minimize the production of potentially reactive wastes, separation and special handling of these materials, blending acid-generating and neutralizing materials, and/or reclamation designed to isolate these wastes from the environment.

6.2.5 Wastewater Quality and Management

The NPDES permit process requires applicants to identify sources of wastewater and storm water, describe wastewater and storm water management, provide water balances, and estimate the quantities and compositions of effluents that would be discharged through permitted outfalls throughout the year (see Table 5). Applicants must demonstrate that the wastewater characterization is representative of discharges that will occur over the full range of operating conditions and closure and that any effluent proposed for discharge will not result in water quality standards exceedences in the receiving water. In order to accomplish this, applicants will need to estimate the quantities and compositions of process solutions, tailings water, runoff waters, mine drainage, and treated effluent at the proposed operation and the effectiveness of wastewater management measures (such as treatment).

Wastewater quality and quantity from tailings impoundments and operating heap leach facilities may be determined from analysis of process solutions and tailings waters obtained from pilot-scale metallurgical tests that simulate the proposed processing operations. Discharges from waste rock piles and mine drainage may be predicted based on geochemical testing and modeling. For operations proposed in areas of historic mining activity, samples of mine drainage should be collected from pit lakes, underground workings, tailings ponds, or seeps emanating from existing waste disposal facilities. Where wastewater treatment is proposed, the quality of treated effluent should be determined from pilot-scale tests of the proposed treatment technology. Wastewater management, including discussions of treatment processes, treatability studies, methods for disposal, and data needs for NEPA analyses are discussed in Appendix E, *Wastewater Management.* Methods to predict discharge effluent quality are described in Appendix D, *Effluent Quality.*

6.2.6 Post-Closure Mine and Waste Facility Water Quality

Predictive assessments of post-mining pit lake or underground water quality and tailings impoundment water quality will likely be required by the NEPA process. Predictions may be made based on results of geochemical testing and modeling. There may be a high degree of uncertainty associated with predictive modeling. Stochastic models, those containing information regarding parameter uncertainty, are gaining wider acceptance as predictive tools (Schafer and Lewis, 1998). Where models are used, assumptions and uncertainties associated with the model and input parameters must be identified. It is also beneficial for the Applicant to make sure in advance that the model will be accepted by the regulatory agencies.

Mining activities that disrupt ground water geochemical systems can spur mineral dissolution or precipitation reactions that can alter pre-mining ground water quality in ways that may be difficult to predict (Lewis-Russ, 1997). Mine pits that are backfilled with waste rock and underground workings that are abandoned following ore extraction increase the opportunity for contamination by exposing ground water to fresh rock surfaces that are not in equilibrium with the existing geochemical system. In these situations, applicants should provide an assessment of potential ground water quality impacts in these settings.

More detail regarding predictive water quality models is provided in Appendix D and Appendix A.

6.2.7 Closure and Reclamation Effects

The methods used for facility closure and reclamation can play an important role in determining the potential for long-term contamination. Residual leach fluids or soluble metal complexes that remain in inadequately rinsed or neutralized heaps can lead to seepage of metals-laden acidic or cyanide-rich fluids. However, low permeability caps, covers, and capillary barriers installed following recontouring can lower the risk of long-term contamination by helping to reduce infiltration and chemical flux through the embankment. In addition, adequately established vegetation cover would reduce erosion and aid in the evapotranspiration of water from surface layers. Caps and covers also can help to limit oxygen diffusion into sulfide-bearing waste materials. Grading and recontouring of facility slopes can reduce the potential for long-term erosion, slope failure, and sedimentation in surface waters. Other Best Management Practices (BMPs) may be employed to minimize contamination due to sedimentation and erosion (see Appendix H). Applicants will be required to develop preliminary closure and reclamation plans for NEPA review which should address whether or not an NPDES permit will be required for any post-closure discharges. Closure considerations and related NEPA disclosure needs are discussed in more detail in Appendix F, *Solid Waste Management* and Appendix H, *Erosion and Sedimentation.* In addition, information on expected post-mining water quality should be provided for the NEPA analysis.

6.3 Impacts to Aquatic Resources

Freshwater aquatic resources represent an important component of the environment that must be analyzed for NEPA review and CWA permitting processes. Considerable overlap exists between studies analyzing aquatic resources and those characterizing surface water and ground water quality and hydrology. Many impacts to aquatic resources, including riparian areas, 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 which reaches streams and other surface water bodies while potentially reducing stream base flows. This can increase the peak flow and the total amount of stream discharge which occurs from a given storm event. Unusually high peak flows can cause erosion of stream banks, widening of primary flow channels, erosion of bed materials, channelization, and alteration of the slope of the channel. These impacts can affect and degrade aquatic habitats, including riparian zones. Channelization (i.e., straightening) can increase flow velocities in a channel reach, potentially affecting fish passage to upstream reaches during moderate to high stream flows. Increased erosion and downstream sedimentation can impact spawning gravels, egg survival, and frye emergence, as well as degrade benthic food sources and riparian cover. Flooding can create high velocity flows, scour stream banks and erode or bury gravel substrates. The destruction of cover created by large woody debris and stable banks can impact rearing and resting habitat for fishes. In addition, removing riparian vegetation can reduce shading. The resulting increase in sunlight can raise the temperature at the surface and through the entire water column, and this in turn can have a profound impact on the entire aquatic ecosystem.

Water quality issues associated with mine exploration, operation, and abandonment activities typically involve the potential discharge of mine water and process solutions, increased loads of metals and other toxic pollutants, acid generation from waste rock, spent ore, and mine workings. If these pollutants reach surface waters, toxic conditions could affect important aquatic species.

Studies that are typically required for NEPA review and often CWA §404 permitting include analyses of fish, benthic macroinvertebrates, and the physical parameters, including the riparian zone, that define habitat for aquatic communities. In the NEPA process, aquatic resources, especially fish, often represent significant issues for the proposed action being evaluated. This is because resident and anadromous fisheries represent a concern to the public and governmental agencies such as NMFS, BLM, USFWS, U.S. Forest Service (USFS), Tribal governments, and state wildlife agencies. Many fish species, particularly salmonids (trout and salmon), have important recreational and/or commercial fishery values. Numerous species also are Federally or state-listed species that require protection under the Endangered Species Act. For these reasons, applicants should complete analyses to determine potential impacts to aquatic resources. Appendix G, *Aquatic Resources* provides detailed discussion of data needs and outlines methods to design appropriate studies for aquatic resources.

The *aquatic resources study* should provide a baseline from which to measure or predict relevant changes that might occur as a consequence of the proposed action and its alternatives. As required under NEPA regulations, an impact assessment must analyze both direct, indirect and cumulative impacts to important aquatic resources located within the project study area (Council on Environmental Quality, 1986). The study should have a scope that extends beyond the boundaries of the proposed mine site. Applicants should anticipate that they could be required to provide studies that characterize or evaluate:

- Potential effects of water quality changes on aquatic communities and their habitat that may result from mine operations, including point and non-point source discharges, and changes in flow regimes. Parameters of concern may include heavy metals, pH, total dissolved solids, cyanide and cyanide breakdown products (e.g., ammonia, nitrogen compounds), and overall effluent toxicity.

- Potential effects of sedimentation on aquatic communities and their habitat as a result of construction and operational activities.

- Potential effects of physical disturbance or removal of aquatic habitat and associated riparian area on aquatic biota.

- Potential effects to aquatic biota from spills that occur during the transport or storage of fuel, process chemicals, and other hazardous materials.

- Potential effects of stream flow changes on aquatic habitat and biota that result from water withdrawals (both of ground and surface water), stream diversions, or discharges.

- Potential effects of physical blockages or barriers created by mine construction or operation activities on fish movements. These evaluations should include potential velocity barriers that can be created in diversions, culverts, or road crossings which can affect fish passage through a stream reach.

These types of impact evaluations would normally include background studies that define fish distribution, abundance and species composition, and critical habitat for spawning, frye emergence, and juvenile rearing. These studies need to focus especially on game and species listed as threatened and endangered (T&E) or special status. Fishery habitat studies should include, among other factors, characterization of stream gradients, widths, depths, pool frequency, substrate composition, instream and riparian vegetation, and the presence of large woody debris. Background studies to characterize macroinvertebrate communities should define species composition and abundance and provide community metric data, such as species richness and species diversity.

6.4 Impacts to Wetlands

Studies to define, delineate and determine potential impacts to wetlands and other waters of the U.S. typically have more rigorous requirements than studies conducted to evaluate non-wetlands because jurisdictional wetlands (and other waters of the U.S.) are regulated under Section 404 of the CWA. In general, wetlands are aquatic areas within the landscape that include swamps, marshes, fens, bogs, vernal pools, playas, prairie potholes, and riparian zones. These features are considered to be "jurisdictional wetlands" if they exhibit specific conditions of wetland hydrology, hydric soils and the presence of hydrophytic vegetation, as defined by the accepted delineation method. The regulatory definition of wetlands and the criteria and indicators used to identify them are discussed in detail in Appendix I, *Wetlands and Other Waters of the United States*. Regulatory requirements as specified under §404 of the CWA are discussed in section 3.0.

Wetlands may perform a variety of important physical, chemical and biological functions including ground water recharge or discharge, flood storage, peak flood flow attenuation, shoreline and channel bank anchoring, dissipation of erosive forces, sediment trapping, and nutrient trapping and removal. Wetlands may also provide habitat for numerous plant, wildlife, and fish species, including some that are listed as threatened and endangered (T&E).

Impacts to wetland areas can result from the construction and operation of mine and facilities including construction and use of roads; site preparation for buildings, mills and ancillary facilities; and the construction, use and maintenance of waste and storage facilities, such as tailings impoundments and waste rock dumps. Impacts can occur either directly or indirectly. Direct impacts include the removal or destruction of wetlands through dredging, filling, or draining. Indirect impacts are those associated with increased runoff and erosion from disturbed areas, increased sedimentation, and increased loadings of metals and other toxic pollutants. Mining operations also can impact riparian areas, which may be destroyed or lost by the construction of stream diversions or by altering drainage patterns within a watershed. Mine dewatering activities may impact wetland hydrology and wetland functions by altering regional ground water recharge and discharge characteristics.

Any proposed project or activity with a potential to impact wetlands, either directly or indirectly, will be required to fully characterize this resource to establish baseline conditions, and determine potential impacts. It is important to note that state and local governments may also place restrictions on projects that could impact wetlands, regardless of their jurisdictional status under CWA §404.

The *wetland study* should provide a baseline from which to measure or predict changes that might occur as a consequence of the proposed action and its alternatives. Studies to determine potential impacts to wetlands should be described in terms of acreage of absolute loss (acres filled or drained) and in loss of wetland function. Applicants should anticipate that they may be required to provide studies that characterize or determine:

- The classification of wetlands and their function both within and near the project area

- The acreage of wetlands that will be directly impacted by fill or draining activities

- The extent that changes in hydrology, drainage patterns, or stream discharges would affect the hydrology of identified wetlands and the composition of associated plant species

- The extent to which dewatering activities or ground water withdrawals would affect wetland hydrology and function

- Potential increased sediment loading to identified wetlands

- Fate and transport of spilled process chemicals or hazardous wastes and the potential for spills to impact wetlands

- Potential effects to aquatic and terrestrial wildlife habitat and habitat values from impacted wetlands.

In conducting studies, applicants should specifically evaluate different mine layouts, facility designs, and technologies to study the avoidance and minimization of environmental impacts to wetlands. The Section 404(b)(1) guidelines indicate that 404 permits can only be issued when no practicable alternatives exist that would have fewer adverse impacts to wetlands. Where proposed activities cannot avoid impacts to wetlands, studies must demonstrate that practicable steps have been taken to minimize potential adverse impacts. In some cases, operators have been able to offset lost wetland acreage with developed wetlands, or by upgrading/improving other wetlands.

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APPENDIX A

HYDROLOGY

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Developing a mine plan of operations, designing operational procedures, and designing hydrological control structures and other best management practices (BMPs) to prevent environmental impacts all require accurate knowledge of the variables associated with hydrological conditions at a mine. Of particular importance is proper characterization of baseline hydrological and hydrogeological conditions so that the extent of impacts to hydrologic and other related resources can be minimized or avoided. Mining operations must accurately consider two main hydrologic components when planning operations: (1) process system waters, often referred to as the process circuit, and (2) natural system waters or the natural circuit. The primary goal of this appendix is to outline the methods and analytical procedures commonly used to characterize the natural system waters at a mine site. Included are descriptions of the rationale and methods for characterizing surface water hydrology, ground water hydrogeology, and surface water-ground water interactions. The characterization, handling, and treatment of process system waters are discussed in Appendix E, *Wastewater Management*.

Natural system waters are those associated with the natural hydrological cycle, such as ground water and meteoric water from precipitation, snowmelt, evaporation, and runoff. For mining operations, important data for establishing baseline hydrological conditions include the measurement of precipitation, runoff, and losses or abstractions from precipitation (Barfield et al., 1981). Impact evaluations and the proper design of detention structures, diversions, culverts, pregnant ponds and barren ponds, tailings dams, and other facilities depend on accurate characterization of hydrological parameters.

2.0 HYDROLOGICAL CYCLE

The term "hydrological cycle" generally is used to describe the continual circulation and distribution of water through all elements of the environment. The hydrological cycle is a convenient means for describing the interrelation between six fundamental processes: condensation, precipitation, evapotranspiration, infiltration, surface runoff, and ground water flow.

The hydrological cycle can be viewed as beginning with the evaporation of water from the ocean. Evaporated moisture then collects in the air, and under proper conditions, condenses to form clouds. Ultimately, the clouds may release this water as precipitation which subsequently collects on land and is dispersed in one of three ways. The largest part is temporarily retained in the soil near where it falls. This portion is returned to the atmosphere by evaporation and transpiration by plants (Linsley et al., 1975). Another portion of this water infiltrates through the soil and recharges ground water reservoirs. The final portion of the precipitation runs off the surface and collects in stream channels and lakes. Under the influence of gravity, the ocean receives portions of both the stream flow and ground water flow and the cycle begins again.

Obtaining adequate data for predicting and determining hydrological processes at proposed mining operations presents significant challenges. These processes are very complex and have high variability, making measurement and characterization for predictive purposes difficult. Understanding the hazards and benefits of the hydrological cycle will assist in proper mine operations and contribute to environmental protection. In addition, hydrologic processes are related to other important resources such as water quality, aquatic life, vegetation, wetlands, and terrestrial wildlife.

3.0 HYDROLOGICAL IMPACTS

Characterizing hydrology at a mine site is necessary to identify the area(s) that would be affected by mining activities; determine impacts to the related physical, chemical, and biological resources; and develop appropriate monitoring programs and mitigation measures. Background hydrological conditions should be characterized in order to provide a baseline from which changes can be measured or predicted and to identify environmental conditions that could be potentially impacted by mining activities. The intent of the characterization is to determine the nature and extent of ecological impacts from mining-related changes in the hydrological system. If past or present mining activities have been underway, then the hydrological effects from these sources should be examined. It is important that the scope of evaluating hydrological baseline conditions and hydrological effects of a mine extend beyond actual mine site boundaries in order to place the project in the context of its watershed.

Hydrological studies can be used to predict future impacts from proposed mining activities. Potential mining-related impacts to hydrology can be separated into surface and subsurface systems. Surface and subsurface hydrological systems are likely to interact with one another and they can impact other related resources.

3.1 Surface Impacts

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. A detailed discussion of erosion and sedimentation as related to mining is provided in Appendix H, *Erosion and Sedimentation*.

The location of mining facilities frequently requires the construction of stream diversions and/or storm water ditches that control and divert runoff from upland watersheds. Typically, these structures are used to prevent unpolluted water from contacting potentially degrading materials, such as waste rock, or flooding over disturbed areas and degrading water quality. Drainage control structures also are used to prevent operational difficulties which could occur at the site. Although these structures may mitigate and control potential impacts from flooding or erosion from disturbed areas, they often alter or change natural drainage patterns in a watershed, which, in turn, can impact vegetation resources, wetlands, and wildlife habitat.

The discharge of process waters potentially can affect water quality and lead to impacts to resources such as aquatic life. Parameters associated with wastewater treatment and discharge are discussed in Appendix E, *Wastewater Management;* those associated with the management of solid wastes, such as waste rock and tailings, are discussed in Appendix F, *Solid Waste Management.*

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 total and dissolved metals and most chemical constituents that occur in higher concentrations in subsurface formations than in surface soils. Some chemical constituents, however, correlate positively with stream flow during the beginning stages or "first flush" of a runoff event (i.e., increasing concentrations with increasing stream flow). This condition is sometimes observed with constituents that are associated with surface soils, such as acid salts, or land applied pollutants such as pesticides, herbicides, and nitrates, and constituents that are transported as suspended particles. After this initial increase which is sometimes observed, constituent concentrations generally decrease with the increasing volume of runoff. As described in Appendix B, *Receiving Waters,* water quality data must be collected with consideration given to the varying effects of stream flow at a site.

Withdrawals from streams also can impact aquatic life, particularly fish. Reduced stream flow can potentially affect critical habitat requirements. 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 redds, 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. These impacts are discussed in more detail in Appendix H, *Erosion and Sedimentation*.

3.2 Subsurface Impacts

Potential impacts to ground water flow regimes primarily occur from mine dewatering activities and/or pumping water supply wells (Figure A-1). Dewatering (i.e., pumping ground water from) mine workings, adits, or open pits is required when the mine elevation extends below the potentiometric surface in confined aquifers or below the water table in an unconfined aquifer. Pumping ground water lowers the water table in the immediate area of a well, creating a "cone of depression" which extends radially outward from the well. The radius of drawdown depends on the level that the water table is lowered by the well, the pumping rate, the hydraulic conductivity of the aquifer, and the homogeneity of the aquifer. Water supply wells located close to one another may have cones of depression that overlap, creating a cumulative effect on the drawdown of the water table. When this occurs, the drawdown at a given point becomes the sum of the drawdowns caused by all of the wells (Linsley et al., 1975). A dewatered mine acts as a large diameter well; consequently the water table in an aquifer can be drawn down for a relatively large radial distance. Drawdown can affect the direction of ground water flow by shifting gradients and lines of flow toward the mine or well field.

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 (Figure A-1). These effects can impact wetlands associated with springs and riparian zones associated with streams. A reduction in stream flows can also affect aquatic habitats and fish populations. A regional lowering of the water table can impact neighboring water supply and irrigation wells. Water yields from local wells can be reduced or wells may need to be drilled deeper to account for the decreased elevation of the water table or potentiometric surface. Adequate characterization of ground water and hydrogeology is often difficult, especially for fracture-flow conditions. However, sufficient characterization of hydrogeology is required to predict impacts that could occur on local and regional scales.

In areas where ground and surface waters interact due to varying influent and effluent conditions, mining impacts to ground water quality can result in impacts to surface water quality. The factors associated with interacting ground and surface water and resulting impacts to water quality are discussed in Appendix B, *Receiving Waters.*

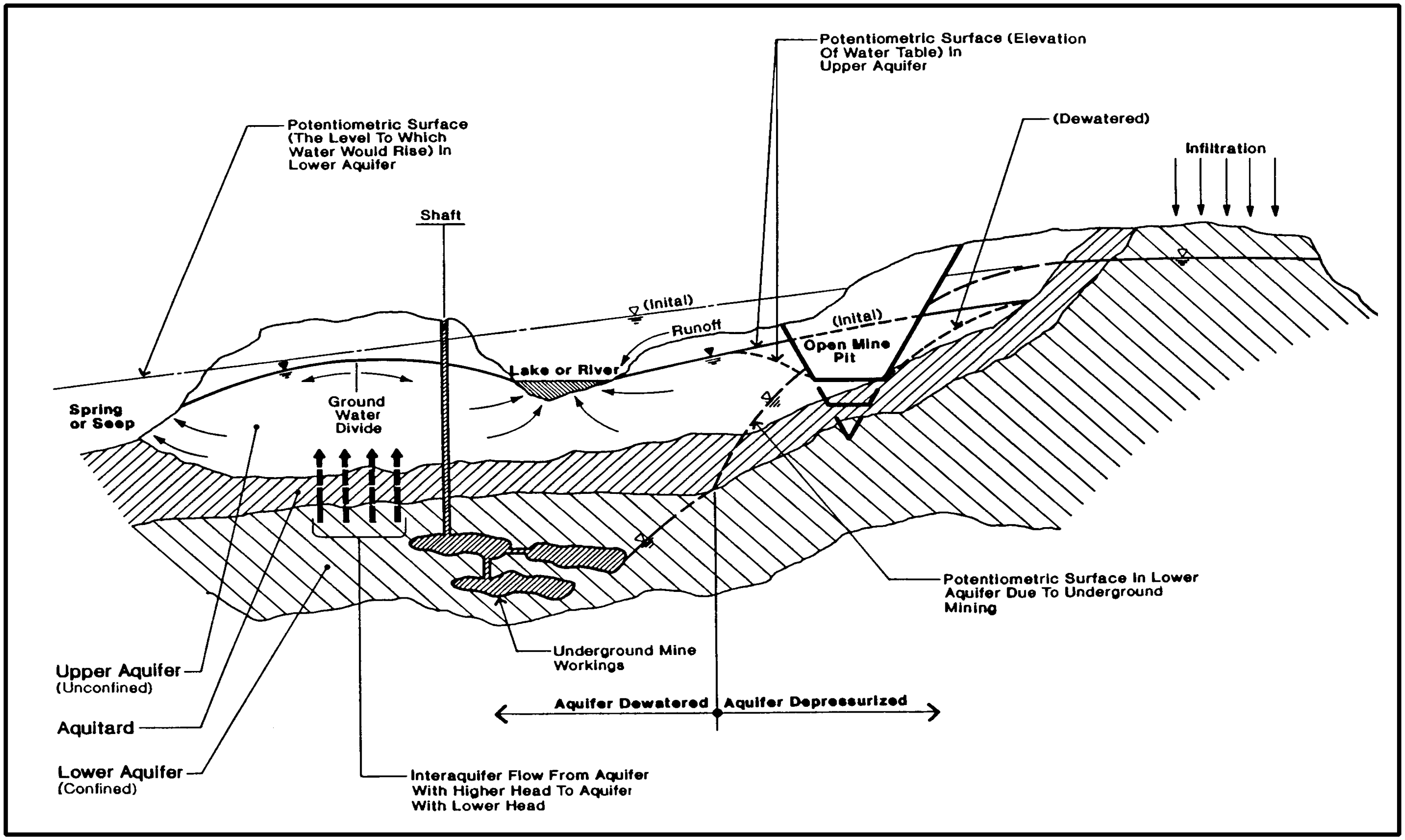


Figure A-1. Ground water flow systems affected by mining (Siegel, 1997).

4.0 METHODS TO MEASURE AND PREDICT HYDROLOGICAL PROCESSES

The design of water collection, storage and treatment facilities at mine sites depends on adequately characterizing the hydrologic system in the vicinity of the site. Precipitation, losses from precipitation (i.e., interception, infiltration, and evapotranspiration) runoff, and stream flow are perhaps the most important parameters to measure during baseline studies. Estimates of the hydrological inputs to a mine and the design of detention structures, retention ponds, culverts, pregnant and barren solution storage ponds, and diversion channels depend on probabilistic determinations of rainfall and runoff events that are developed from historical data. Van Zyl et al. (1988) indicate that short-duration, high-intensity events, large snow-melt events, or extended wet periods are the most important rainfall-runoff events to consider during heap-leach facility design. Unfortunately, rainfall-runoff parameters and probabilistic determinations of future rainfall-runoff events are among the most difficult to accurately determine.

Mines often are located in remote areas or in watersheds lacking historical precipitation and runoff data sufficient to accurately develop return-period and flood-frequency relationships. For this reason, it is important for the hydrologist to incorporate the most rigorous estimates possible given the cost, scope, and data available. Methods for measuring precipitation and runoff and developing probabilistic distribution functions for these data are briefly outlined and compared below. For more detailed information, the reader is referred to Barfield et al. (1981), who provide an excellent compendium of hydrological methods and analyses for mining operations.

4.1 Precipitation

Precipitation depth-duration-frequency information for the United States is available for numerous, widespread climatological stations managed by the U.S. Weather Service and published in atlases by the National Oceanographic and Atmospheric Administration (NOAA). These historical data also are available electronically on magnetic tape and compact disk. Often, these are the only data initially available to mining operations and they serve as the basis for developing probabilistic relationships to use in designing hydrological structures and evaluating inputs for water balance determinations. Actual measurements of precipitation and runoff within the specific watershed of a mine are preferred and should be used whenever possible to develop probabilistic storm frequency relationships and design hydrological structures. Since remote mine areas usually lack the long-term historical data necessary to develop accurate probabilistic relationships, most mine projects need to establish a network of climatological stations and stream-flow monitoring stations to collect records for their watershed(s).

Mean areal precipitation within a watershed or in sub-basins often is used to develop rainfall-runoff probability relationships and for input to other hydrological analyses. The accuracy of these values, or of the historical relationships developed from them, depends on the density of precipitation gages throughout a basin. Studies conducted to analyze precipitation gage density and the errors associated with using these data for estimating runoff and stream flow conclude that a higher density of gages is required where topography is more complex and where convective thunderstorms can be expected to provide significant hydrological input to the system (Eagleson, 1967; Johanson, 1971; Bastin et al., 1984). Linsley et al. (1975) provided the following general guidelines for precipitation station density based on climatic conditions and topography:

- One station per 600 to 900 km^2 (230 to 350 mi^2) in flat regions of temperate, Mediterranean, and tropical zones with relatively high rainfall;

- One station per 100 to 250 km^2 (40 to 100 mi^2) for mountainous regions of temperate, Mediterranean, and tropical zones; and

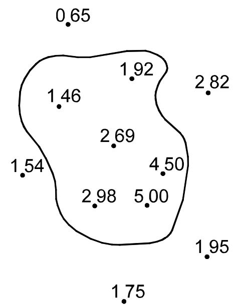
- One station per 25 km^2 (10 mi^2) for small intricate mountainous regions with irregular precipitation.

It is important to note that the accuracy of developed probabilistic distribution functions for rainfall-runoff events for a specific basin will greatly increase over time as the density of gages increases. This is particularly true in basins where brief high-intensity rainfall events can occur in localized areas yet provide significant flow and inputs to a mine operation located lower in the watershed. Three common methods are used to obtain mean areal precipitation from a network of precipitation gages: (1) the arithmetic mean, (2) the Thiessen polygon method, and (3) the isohyetal method. Figure A-2 depicts examples using these methods. The arithmetic mean is a simple average of the stations and is considered the easiest to apply but the least accurate. The other methods apply weighting criteria based on the distances between rain gages (Barfield et al., 1981). The Thiessen method determines weighted areas for each gage based on polygons drawn by perpendicular bisectors between gages. The weighting factor for the isohyetal method is determined by the area of the watershed enclosed between adjacent isohyetes or lines of constant rainfall. The isohyetal method is considered the most accurate of the three methods; however, the Thiessen method has an advantage in that weighting factors for precipitation gages remain historically constant as long as the measurement network has not changed. A detailed discussion of the application of these methodologies is presented by Linsley et al. (1975) and Barfield et al. (1981).

Mean areal precipitation can be evaluated using kriging techniques. Kriging is actually a collection of methods with which to analyze spatial data. It was originally derived for geostatistical analyses and prediction. In general, kriging uses linear regression techniques to minimize the error associated with the estimate of a new point. The estimate is made from a prior covariance model developed from the entire network of data points. In effect, kriging statistically evaluates data from an entire set of spatial data, such as a network of precipitation gages, to make estimates of interspatial data. The output can then be used to develop an isohyetal map similar to that described above. The difference between the two techniques is that the standard isohyetal method uses linear interpolation between two precipitation gages to estimate values between two points. Kriging uses statistical methods to estimate values between two points, taking into account data from other nearby gages. Karnieli and Gurion (1990) described the use of kriging to map areal precipitation and applied it to historical precipitation data for the State of Arizona. Kriging is the most intensive technique to evaluate areal precipitation and specific software is required. For most mining scenarios, however, it would provide better estimates of precipitation inputs, especially in areas with complex topography and in areas where precipitation is spatially more variable. Use of this technique would help to minimize errors associated with rainfall-runoff measurements and to develop more accurate probabilistic relationships over time.

As previously indicated, historical rainfall data are used to develop probabilistic relationships for rainfall and/or runoff events. These relationships describe the frequency or probability of occurrence (i.e., return periods) of rainfall or runoff events. Some common methods for developing these relationships are the Log-Pearson Type III distribution, the Extreme Value Type I Distribution, and the Gumbel Distribution. The methods for developing these relationships are described in various hydrologic manuals and will not be described here (see U.S. Bureau of Reclamation, 1977; Linsley et al., 1975; Barfield et al., 1981). The hydrologist should consider the ultimate use of the data when choosing the methods to determine mean areal precipitation. The specific method used is not as critical to simply characterize the average conditions of a site, such as for a NEPA analysis, as when being applied to hydrologic design, such as for sizing a storage pond or runoff control structure.

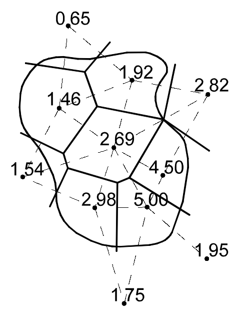
Van Zyl et al. (1988) described an application of the Weibull (1939) formula that utilizes available historical snow pack data to develop probabilistic relationships for snow melt. They indicated that local snow data often are not available for a particular basin of interest and that historical snow course data obtained by the Natural Resource Conservation Service (formerly, the Soil Conservation Service [SCS]) must be used. Figure A-3 shows an example of a probability/return period relationship developed for a snow pack. These types of relationships are similar to those developed for precipitation and runoff events. Linsley et al. (1975) indicated that the best methods to estimate runoff from snow pack are based on simple air temperature, rather than more complicated analytical models that incorporate wind speed, relative humidity, solar radiant flux, and other variables. They suggested methods using a degree-day or degree-hour factor and the average probability of occurrence with elevation. These data typically are available for specific regions of interest. McManamon et al. (1993) described a GIS method for combining snow-water equivalent measurements with other watershed physical parameters to provide better estimates of runoff from snow pack. The design engineer should note, however, that the prediction of runoff from snow-pack analyses is complicated by other hydrological factors such as ground water storage, antecedent soil-moisture deficiency, and the amount of precipitation that occurs during runoff periods (Linsley et al., 1975).



Arithmetic mean:

$$\frac{1.46 + 1.92 + 2.69 + 4.50 + 2.98 + 500}{6} = 3.09 \text{ in.}$$

(a)



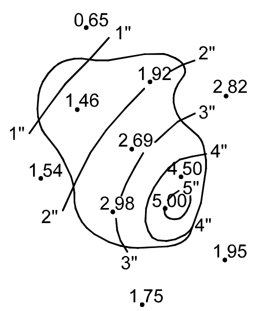
Thiessen method:

Observed precip. (in.)	Area* (sq. mi.)	Percent total area	Weighted precipitation (in.) (col.1 x col.3)
0.65	7	1	0.01
1.46	120	19	0.28
1.92	109	18	0.35
2.69	120	19	0.51
1.54	20	3	0.05
2.98	92	15	0.45
5.00	82	13	0.65
4.50	76	12	0.54
	626	100	2.84

Average = 2.84 in.

* Area of corresponding polygon within basin boundary

(b)



Isohyetal method:

Isohyet (in.)	Area* enclosed (sq. mi.)	Net area (sq. mi.)	Avg. precip. (in.)	Precipitation volume (col.3 x col.4)
5	13	13	5.3	69
4	90	77	4.6	354
3	206	116	3.5	406
2	402	196	2.5	490
1	595	193	1.5	290
<1	626	31	0.8	25
				1634

Average = 1634 ÷ 626 = 2.61

* Within basin boundary

(c)

Figure A-2. Areal averaging of precipitation by (a) Arithmetic Mean, (b) Thiessen Method, and (c) Isohyetal Method (Linsley et al., 1975).

Probabilistic relationships, such as those of Figure A-3 or those published by NOAA, provide maximum precipitation depths or intensities for certain durations and frequencies of occurrence. These data can provide peak-flow or runoff estimates for use in designing hydrologic facilities and structures. In addition to peak flow data, modern design criteria often requires more detailed information regarding the runoff hydrograph. Developing runoff hydrographs typically requires temporal information for storm events (i.e., time versus precipitation intensity relationships) (Barfield et al., 1981).

A plot of the distribution of rainfall intensity versus time is called an hyetograph. Methods to develop design hyetographs (also termed design storms) use theoretical or average time distributions that are based on actual storm events (see summaries in Chow et al., 1988 and Koutsoyiannis, 1994). The time distribution of rainfall intensity associated with a storm greatly affects the quantity and time distribution of runoff. Design storms are created to study or predict theoretical storm runoff for the design of structures, drainage, or containment ponds. The methods commonly used to create design hyetographs can be divided into three categories as described below (Chow et al., 1988; Koutsoyiannis, 1994).

The first category uses pre-selected time distributions such as triangle, bimodal, or uniform distributions. The most commonly used of these methods is that outlined by the Natural Resource Conservation Service (NRCS [formerly SCS]) and is described by SCS (1972). This method uses two theoretical time distributions known as Type I, and Type II distributions. The Type I distribution is recommended for use by NRCS for general application in Alaska and Hawaii; however, an additional distribution has been added by the NRCS known as the Type I-A. The Type I-A distribution produces less severe peak runoff rates than the Type I distribution and is more suited to simulate storm patterns associated with the coastal regions in the northwest United States. For this reason, the Type I-A distribution is recommended for use in Washington and Oregon and should also be considered for use in southeast Alaska. The climate of southeast Alaska differs substantially from that of inland Alaska and is more closely related to that of British Columbia, Washington, and Oregon. The Type II distribution is applicable to the remainder of the United States. A major problem with using these methods is that two or three average distributions are not adequate for all types of storms or for all areas where they are recommended for use. Another major problem is that the runoff hydrographs produced from these methods do not have any real measure of the probability or frequency of occurrence. Thirdly, these distributions base all design events on a 24-hour distribution. Despite these problems, average time distributions, particularly the NRCS distributions, are commonly used for design studies because of their simplicity.

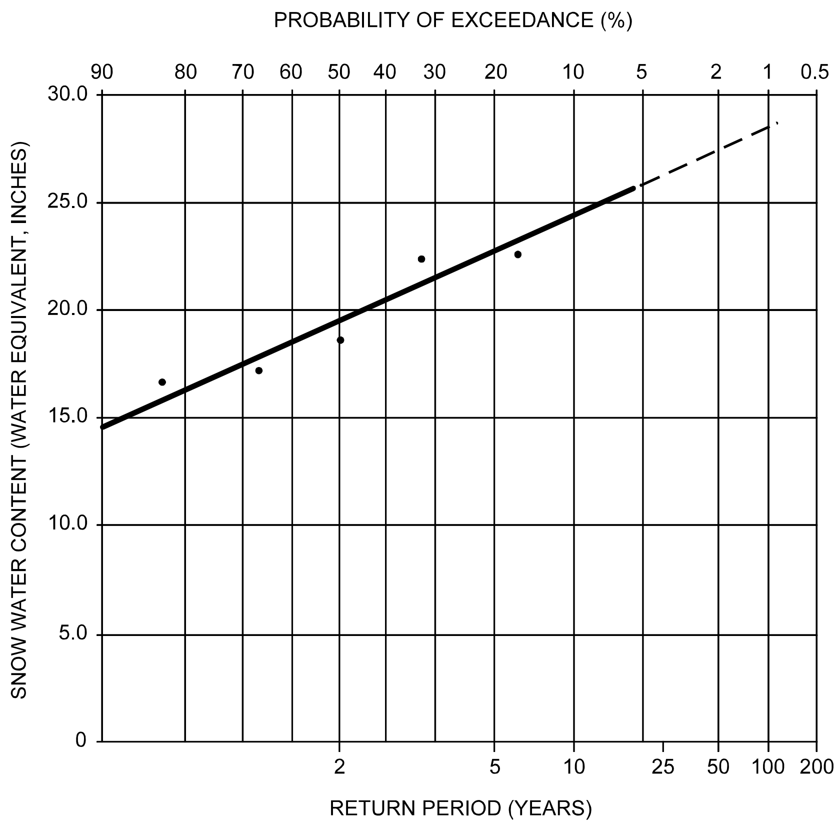


Figure A-3. Typical snowpack frequency curve (Barfield et al., 1981).

The second category of methods is based on regionalized average distributions and the probabilistic occurrence for that time-intensity distribution. An example of this type of distribution is described by Huff (1967). These methods are based on better probabilistic/statistical approaches than those described above. However, Koutsoyiannis (1994) indicated that the exact determination of the probability of the resulting runoff hydrograph is still ambiguous for use in design.

The third category of design storms is based on the intensity-duration-frequency (IDF) curves of the Probable Maximum Precipitation (PMP) for the region of interest. These methods do not rely on average or probabilistic time-intensity distributions within rainfall events. Instead, hyetographs are designed to apply maximum depths (i.e., worst case scenarios) of rainfall based only on the frequency of occurrence for that depth and for a particular storm duration. Unfortunately, like the methods discussed in the first category, the probability or frequency of occurrence of the resulting runoff hydrographs are ambiguous and undefined.

Regardless of the specific method used to calculate runoff, the hydrographs produced by the IDF design storms are conservative, which makes them the preferred choice for design purposes. This is because they use PMP to create peak flows without considering the physical aspects of rainfall, infiltration, and runoff. Although these methods may result in conservative designs, they can bet cost effective because they may be more environmentally protective and because of their relative ease of use.

Koutsoyiannis (1994) described a fourth method, stochastic disaggregation, for creating design storms for the purposes of hydrological design. This method applies stochastic modeling techniques (i.e., a Markovian structure) to commonly used design storm methods or to other methods for determining runoff and flood routing. Stochastic disaggregation computes a probability distribution function of the outflow peak. This is a statistically more robust method for using design storms to provide information for hydrological design, regardless of the methods used to develop runoff hydrographs and route flows. Stochastic methods, such as those described by Koutsoyiannis (1994), are less likely to produce overly conservative designs, but they remain realistic in their physical and statistical analyses of precipitation inputs. Several stochastic models that use the methods outlined by Koutsoyiannis (1994) are available for personal computers. These programs typically run in conjunction with spreadsheets.

4.2 Losses from Precipitation

Infiltration, evapotranspiration, and surface storage are considered losses or "abstractions" from precipitation. A review of general procedures and information regarding precipitation losses is provided below, but a more detailed discussion of the methods used to measure each of these parameters is beyond the scope of this appendix. The reader is referred to Barfield et al. (1981) for a more complete discussion of these parameters as they are applied to mining.

Infiltration is the major source of precipitation loss. The physical processes controlling infiltration are complex and governed by a variety of interrelated factors. Particle-size distribution of the soil, porosity, antecedent moisture content, surface roughness, macroporosity, freeze-thaw cycles, and fluid properties all affect infiltration and each responds uniquely to storm intensity and duration. Field methods that are used to measure infiltration include double ring infiltrometers and rainfall simulators.

Several empirical methods are available to estimate infiltration. The most common of these are models by Green and Ampt (1911), Horton (1940), and Holtan (1961), and variations of these models. The original Green and Ampt model is commonly used by many computer hydrological models when adequate data are available to describe soil hydrological variables and antecedent moisture conditions. Barfield et al. (1981) indicated that for mining applications, the application of these methods is limited by the difficulty in measuring the physical parameters necessary for input. Accurate application also is confounded by the nonuniformity of soils, both spatially and with depth, and the high variability of all conditions across any watershed. It is important, therefore, that a hydrologist apply good professional judgment with well-founded assumptions when using these methods to estimate loss rates from precipitation. Wright-McLaughlin Engineers (1969) suggested that specific field tests were preferable and highly useful when making these estimates or applying professional judgment.

4.3 Surface Runoff

In the conceptual hydrodynamic model, excess precipitation is routed as overland flow to established channels and channel flow is routed to a basin outlet or a location of interest where a hydrological structure will be designed. Different methods can be used to develop and analyze the runoff hydrograph from data about precipitation excess and to route the flow down a channel or through a structure. In some cases, only the analysis of overland flow is required to design structures to protect or control runon of excess precipitation at a mine site. Methods commonly used to route flows through channels, detainment basins, or other hydrologic control structures are summarized in Section 4.4.

The method described by the SCS (1972) is the most common technique for estimating the volume of excess precipitation (i.e., runoff) after losses to infiltration and surface storage. The method involves estimating soil-types within a watershed and applying an appropriate runoff curve number to calculate the volume of excess precipitation for that soil and vegetation cover type. This method was developed for agricultural uses, and Van Zyl et al. (1988) suggested that it usually is not accurate enough for most design purposes at mine sites, primarily because the development and classification of runoff curve numbers by the SCS are imprecise. Curve numbers are approximate values that do not adequately distinguish the hydrologic conditions that occur on different range and forest sites and across different land uses for these sites.

A more appropriate technique for developing and analyzing runoff at mine sites utilizes the unit hydrograph approach. A unit hydrograph is a hydrograph of runoff resulting from a unit of rainfall excess that is distributed uniformly over a watershed or sub-basin in a specified duration of time (Barfield et al., 1981). Unit hydrographs are used to represent the runoff characteristics for particular basins. They are identified by the duration of precipitation excess that was used to generate them; for example, a 1-hour or a 20-minute unit hydrograph. The duration of excess precipitation, calculated from actual precipitation events or from design storms, is applied to a unit hydrograph to produce a runoff hydrograph representing a storm of that duration. For example, 2 hours of precipitation excess could be applied to a 2-hour unit hydrograph to produce an actual runoff hydrograph. This runoff volume can be used as input to route flows down a channel and through an outlet or for direct input to the design of a structure. Detailed procedures for developing unit or dimensionless hydrographs are presented in a variety of texts (Chow, 1964; Linsley et al., 1975; U.S. Bureau of Reclamation, 1977). The volume of runoff (i.e. precipitation excess) derived from an actual or design hyetograph is multiplied by the ordinates of the 1-inch unit hydrograph to produce a runoff hydrograph for a particular storm. Figure A-4 graphically demonstrates how a 1-inch unit hydrograph for duration D is used to produce a runoff hydrograph from 0.75 inches of precipitation excess of duration D. Figure A-5 demonstrates how a 1-inch unit hydrograph of duration D is used to develop a 0.7 inch runoff hydrograph by summing three components of excess precipitation from a complex storm with each component of duration D (Barfield et al., 1981). In this case individual runoff hydrographs are produced for each component of the storm using the 1-inch unit hydrograph. The hydrographs produced are lagged according to the duration of the components of the hyetograph as shown on the x-axis of Figure A-5. The individual runoff hydrographs produced are then summed to produce a 0.7 inch runoff hydrograph.

Common methods to develop and use unit hydrographs are described by Snyder (1938), Clark (1945), and SCS (1972). Unit hydrographs or average hydrographs can also be developed from actual stream flow runoff records for basins or sub-basins. The SCS (1972) method is perhaps the most commonly applied method to develop unit hydrographs and produce runoff hydrographs. The SCS (1972) publication recommended using the SCS Type I, Type I-A or Type II curves for creating design storms and using the curve number method to determine precipitation excess. Most mine site designs will require use of more rigorous techniques for determining precipitation excess than those proposed by SCS (1972).

Another technique to determine runoff from basins or sub-basins is the Kinematic Wave Method. This method applies the kinematic wave interpretation of the equations for motion (Linsley et al., 1975) to provide estimates of runoff from basins. A summary of the theory and the general application of this method for determining runoff is provided by the U.S. Army Corps of Engineers (1987) in outlining the operation of the HEC-1 computer software package. If applied correctly, the method can provide more accurate estimates of runoff than many of the unit hydrograph procedures described above, depending on the data available for the site. The method, however, requires detailed site knowledge and the use of several assumptions and good professional judgment in its application.

As previously indicated, only peak runoff rates for a given frequency of occurrence are used to design many smaller hydrologic facilities, such as conveyance features, road culverts, or diversion ditches around a mine operation. The hydrograph methods listed above can be used to obtain peak runoff rates, but other methods are often employed to provide quick, simple estimates of these values.

A common method to estimate peak runoff rates is the Rational Method. This method uses a formula to estimate peak runoff from a basin or watershed:

$$Q = C\,i\,A \tag{A-1}$$

where Q is the peak runoff rate, C is a dimensionless coefficient, i is the rainfall intensity, and A is the drainage area of the basin. A comprehensive description of the method is given by the Water Pollution Control Federation (1969). The coefficient C is termed the runoff coefficient and is designed to represent factors such as interception, infiltration, surface detention, and antecedent soil moisture conditions. Use of a single coefficient to represent all of these dynamic and interrelated processes produces a result that can only be used as an approximation. Importantly, the method makes several inappropriate assumptions that do not apply to large basins or watersheds, including: (1) rainfall occurs uniformly over a drainage area, (2) the peak rate of runoff can be determined by averaging rainfall intensity over a time period equal to the time of concentration (t_c), where t_c is the time required for precipitation excess from the most remote point of the watershed to contribute to runoff at the measured point, and (3) the frequency of runoff is the same as the frequency of the rainfall used in the equation (i.e., no consideration is made for storage considerations or flow routing through a watershed) (Barfield et al., 1981). A detailed discussion of the potential problems and assumptions made by using this method has been outlined by McPherson (1969).

Other methods commonly used to estimate peak runoff are the SCS TR-20 (SCS, 1972) and SCS TR-55 methods (SCS, 1975). Like the Rational Method, these techniques are commonly used because of their simplicity. The SCS TR-55 method was primarily derived for use in urban situations and for the design of small detention basins. A major assumption of the method is that only runoff curve numbers are used to calculate excess precipitation. In effect, the watershed or sub-basin is represented by a uniform land use, soil type, and cover, which generally will not be true for most watersheds or sub-basins.

The Rational Method and the SCS methods generally lack the level of accuracy required to design most structures and compute a water balance at mine sites. This is because they employ a number of assumptions that are not well suited to large watersheds with variable conditions. However, these methods are commonly used because they are simple to apply and both Barfield et al. (1981) and Van Zyl et al. (1988) suggest that they are suitable for the design of small road culverts or non-critical catchments at mines. Van Zyl et al. (1988) suggested that the Rational Method can be used to design catchments of less than 5 to 10 acres.

It is important that the design engineer and the hydrologist exercise good professional judgment when choosing a method for determining runoff as discussed above. Techniques should be sufficiently robust to match the particular design criteria. It is particularly important that critical structures not be designed using runoff input estimates made by extrapolating an approximation, such as that produced by the Rational Method, to areas or situations where it is not appropriate. Robust methods that employ a site specific unit hydrograph or the Kinematic Wave Method will produce more accurate hydrological designs, but will be more time-

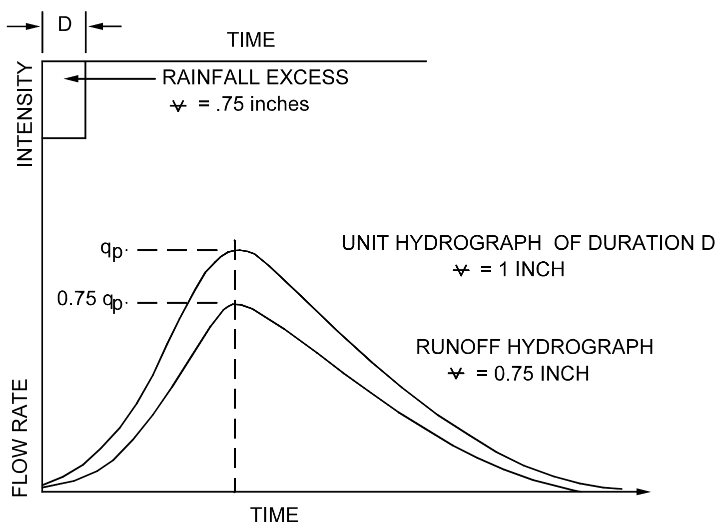


Figure A-4. Runoff Hydrograph Ordinates (y values) from rainfall Excess of Duration D Proportional to Ordinates of D-minute Unit Hydrograph (after Barfield et al.,1981).

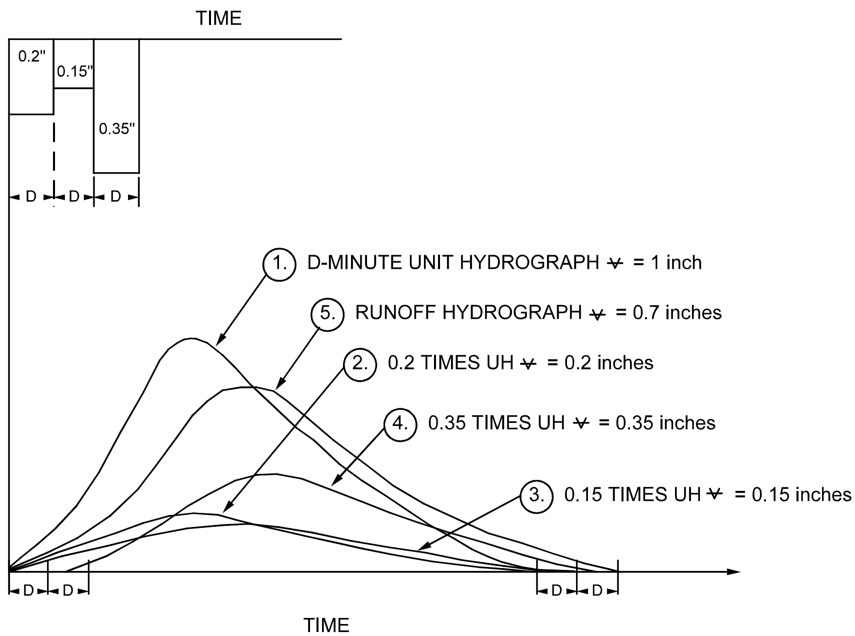


Figure A-5. Runoff hydrograph from a complex storm is obtained by summing the ordinates (y-values) of individual hydrographs from D-minute blocks of rainfall excess (Barfield et al., 1981). The hydrograph from each component of the complex storm of D duration is lagged by duration D, as shown on the x axis.

consuming to use. Nevertheless, many of the more robust methods have data requirements that often cannot be fulfilled because the available data are statistically inadequate. This may force a hydrologist to use their professional judgment to estimate input parameters or to use data that are not statistically adequate for their designs. Design and planning documents should describe the uncertainties associated with any assumptions or calculations, including those used to provide conservatism to the design. In general, EPA emphasizes that the method selected should be base don project objectives, and is prescribing no particular method in this document.

4.4 Stream Flow Routing

Designing hydrological structures or conducting water balance studies often requires an evaluation of the hydrologic inputs to the upper reaches or sub-basins of a watershed. As these flows are conveyed to the mine site, either in natural or constructed channels, their flow hydrographs are modified by travel time, channel storage, and the effects of influent and effluent reaches. Several methods are available to evaluate or study how flood flows are routed through a reservoir, a series of ponds, or an outflow structure. These techniques also can be used to design constructed channels.

Methods commonly used to route flows in channels are the Muskingum Method, a variant called the Muskingum-Cunge Method, the Modified Puls Method, and the Kinematic Wave Method. A detailed review of the general theory of flood routing and how each method solves or approximates the governing equation for continuity is beyond the scope of this appendix. The reader is referred to texts by Barfield et al.(1981) and Linsley et al.(1975) for more detailed discussions of how these methods are applied to mining. A summary of the theory and general application of these methods is also provided by the U.S. Army Corps of Engineers (1987) in their description of the HEC-1 computer software package.

The Kinematic Wave Method is a more robust technique that solves the continuity equation and, if applied correctly with appropriate data, can provide more accurate analyses of flood routing. As previously mentioned, this method requires the use of several assumptions and good professional judgment in its application.

4.5 Ground Water

Because most mine sites are located in regions with complex hydrogeologic conditions, a thorough understanding of the site hydrogeology is required to adequately characterize and evaluate potential impacts. Aquifer pump tests and drawdown tests of wells need to be conducted under steady-state or transient conditions to determine aquifer characteristics. If possible, it is important that these tests be performed at the pumping rates that would be used by a mining operation and for durations adequate to determine regional impacts from drawdown and potential changes in flow direction. These tests require prior installation of an appropriate network of observation wells. Transmissivities, storage coefficients and vertical and horizontal hydraulic conductivities can be calculated from properly designed pump tests. These measurements are necessary to determine the volume and rate of ground water discharge expected during mining operations and to evaluate environmental impacts. Tests should be performed for all aquifers at a mine site to ensure adequate characterization of the relationships between hydrostratigraphic units. Characterization studies should define the relationships between ground water and surface water, including identifying springs and seeps. Significant sources or sinks to the surface water system also need to be identified.

Hydrogeological characterizations should include geologic descriptions of the site and the region. Descriptions of rock types, intensity and depth of weathering, and the abundance and orientation of faults, fractures, and joints provide a basis for impact analysis and monitoring. Although difficult to evaluate, the hydrological effects of fractures, joints, and faults are especially important to distinguish. Water moves more easily through faults, fractures and dissolution zones, collectively termed secondary permeability, than through rock matrices. Secondary permeability can present significant problems for mining facility designs because it can result in a greater amount of ground water discharge than originally predicted. For example, faults that juxtapose rocks with greatly different hydrogeological properties can cause abrupt changes in flow characteristics that need to be incorporated into facility designs.

Computer modeling of surface and ground water flows is described in Section 6.0. The use of computer models has increased the accuracy of hydrogeological analyses and impact predictions and speeded solution of the complex mathematical relations through use of numerical solution methods. However, computer modeling has not changed the fundamental analytical equations used to characterize aquifers and determine ground water quantities. Traditional analytical calculations are briefly discussed below. The application of ground water modeling programs and analysis are discussed in Section 6.2.

A common method to analyze ground water in relation to a mine relies on a simple analytical solution in which the mine pit is approximated as a well. This method uses the constant-head Jacob-Lowman (1952) equation to calculate flow rates. Although not as sophisticated as a numerical (modeling) solution, this method gives a good approximation of the rate of water inflow to a proposed mine. It generally yields a conservative overestimate of the pumping rates required to dewater a mine (Hanna et al., 1994). A second method uses the technique of interfering wells, where each drift face of the proposed mine is considered to be a well. The cumulative production of the simulated wells is used to estimate the total influx into the mine and the extent of drawdown.

5.0 DEVELOPING A SITE WATER BALANCE

An accurate understanding of the site water balance is necessary to successfully manage storm runoff, stream flows, and point and non-point source pollutant discharges from a mine site. The water balance for typical mining operations will address process system and natural system waters (Van Zyl et al., 1988). Process system waters, which include make-up water, chemical reagent water, operational start-up water, water stored in waste piles, water retained in tailings, and mine waters (miscellaneous inflows), have reasonably constant and predictable flows over time. Natural system waters include rainfall, snowmelt, evaporation, and seeps and springs, which have variable and less predictable values (see Section 4.0). An overall site water balance superimposes these two systems to account for all waters at the site.

A mine site water balance must recognize that water may be stored in various facilities during mine operations. For example, in a heap leach operation, water is stored in the process ponds, the heap leach, and the ore itself. Water is lost from the system water through evaporation; facilities such as spray systems and process ponds may result in significant evaporative losses. Natural precipitation that falls on facilities such as heap leach pads or process ponds increases the total amount of water in the system as do any liquid chemical additives that are used in the processing of ore. During winter shutdown, or other temporary or permanent shutdowns, water collected in the facilities, including the ore itself, will drain and must be stored in the process ponds. In heap leach operations, the ore must be rinsed with water or chemical solutions to neutralize the environmental impacts of chemical reagents remaining in the ore (Van Zyl et al., 1988). For a tailings basin/milling type operation, inflows include tailings water, runoff, and other types of waters such as mine water that are often co-managed with tailings. Losses include water retained in tailings, seepage (to ground water beneath the tailings dam), pond evaporation, and recirculation waters.

A key aspect of the water balance at a site is the long-term variability of precipitation amount, intensity, and duration. Precipitation events can significantly change the estimated surface water and ground water volumes used in the water balance assessment. In turn, this can change the determination of whether a system will have a net gain or loss of water. For a mine with a gaining system, such as those in wetter climates, some type of a water disposal system may be required to achieve a balance. Typical disposal systems include evaporation ponds, surface outfalls, and ground water recharge systems. A mining operation with an overall losing system, as in dry climates, usually requires the input make-up water over time. A site with an overall losing system may still have a net gaining system for short times, such as during periods of high precipitation or snowmelt. Water disposal systems need to be designed to manage the water balance during these periods.

Process ponds should be sized to contain all water that would be in circulation during facility operations and during periods of temporary shutdown or rinsing and closure. A water balance is required to determine the sizes of these ponds (Van Zyl et al., 1988). In addition to holding the required volumes of process solutions, ponds must be able to accommodate additional water that flows into the system during extreme precipitation events.

Brown (1997) describes methods to determine a site water balance using both deterministic and probabilistic approaches. Deterministic water balances, similar to that described in Section 5.1, use set input values (e.g., average annual precipitation) to compute inflow and outflow. To provide insight into the range of conditions that could be expected to occur, deterministic water balances should be computed for average, wet, and dry conditions. In contrast, the input values used in probabilistic approaches are sampled from probability distributions (e.g., annual precipitation probability). Computer spreadsheets are used to iteratively calculate inflow and outflow probabilities. According to Brown (1997), probabilistic approaches result in better facility designs because they can indicate which parameters have the most effect on model results and may reveal potential design weaknesses.

5.1 Average Water Balance

The concept of an average water balance can be stated with the following mathematical formula:

$$S = I - O \tag{A-2}$$

where S is the total storage requirement, and I and O are the sums of all inflows and outflows, respectively (Broughton and Tape, 1988). Using a cyanide heap leach operation as an example, the components of the average water balance are outlined as follows (Van Zyl et al., 1988):

Water Balance Period (T) - This is the period over which the average water balance components will be evaluated. The period must be long enough to include a complete leach rinse-cycle. On expanding ore pads, this period would equal the actual leach-rinse time. For a permanent pad, which may have several segments of ore that are either being leached, rinsed, or removed, the period would have to include a number of these cycles.

Precipitation on the Ore and Pad (P) - This is evaluated by multiplying the long-term average precipitation over period T by the total area contained within the berms around the leach pad.

Evaporation from the Ore and Pad (E) - Evaporation for the period T can be evaluated using either a factor multiplied by the Class A pan evaporation and the irrigated area at a particular time horizon, or using spray-loss graphs. Only the period during which actual leaching or rinsing occurs should be used when determining the pan evaporation.

Rinse Water (R) - Laboratory tests are usually required to determine the amount of rinsing water and reagents that must be applied to adequately clean the spent ore before disposal. Rinse-water volume may be as high as seven or eight pore volume displacements.

Soil Storage (S) - Soil moisture conditions vary in the heap during the ore placement, leaching, rinsing, and draindown periods. Each change in ore moisture results in water being taken up and stored in the pile or being drained from the pile into the ponds. Some of the water stored in the heap leach pile will not drain. Various moisture contents in a heap leach pile must be taken into consideration, including natural moisture content, agglomerated moisture content, field capacity or specific retention, and moisture content of the heap leach pile during leaching.

Net Evaporation Loss from Pregnant and Barren Ponds (EP) - This is calculated as the area of the ponds multiplied by the gross lake evaporation, minus the average precipitation over period T. In some cases, the evaporation rate may be modified by the water chemistry.

Normal Operating Water Stored in Pregnant and Barren Ponds (SP) - The ponds need to contain sufficient water to facilitate operation of the pump systems, as well as daily and weekly fluctuations in operating the system.

Water Stored in the Process Facility (SPR) - This volume is equal to the capacity of vessels contained in the process facility. It is generally very small and is included here for thoroughness.

Reagent Addition (RA) - This equals the amount of water added with the reagents used throughout the operating period T.

Bleed Water (BL) - This is the amount of barren bleed required to prevent the buildup of concentrations of certain constituents to values that are sufficiently high to interfere with mineral extraction.

After the above parameters are determined, the overall average water balance of the system, termed the balancing flow (BF), can be calculated as follows:

$$BF = P - E + R - EP - BL + RA - S \qquad \text{(A-3)}$$

Negative values of BF indicate that the system will require additional water, on average, equal to the amount of BF. Positive values indicate that water storage in the system will build up and excess water must be disposed.

5.2 Evaluating Pond Capacity

The water storage facilities at any site must be sized to contain the amount of water that would be in the system during a low probability, wet hydrological event (i.e. the worst-case scenario). Pond sizes should take into consideration the conditions that are likely to prevail during winter and total system shutdown, as appropriate. The conservativeness of the hydrologic event used in pond design depends on regulatory requirements, economic considerations such as the cost of additional pond capacity, the value of processed ore, and especially the environmental consequences caused by exceeding storage capacity.

During operations, process pond capacity should be evaluated monthly to measure fluctuations caused by changing precipitation and evaporation conditions. Performing monthly and quarterly evaluations permits close inspection of the operational aspects that may affect water storage requirements. Moreover, the monthly evaluation gives an indication of the critical or maximum storage capacity needed during any month.

The storage capacity of process ponds at a site typically is based on the worst-case climatic condition (i.e., a low-probability, high-flow event). In drier climates where, on average, the system operates with a large negative water balance, the critical duration of the design storm event usually is relatively short, varying from 1 to 60 days. During these events, the water system will show a net precipitation gain, thereby allowing the system to exceed storage capacity. In wetter climates, the critical duration is longer and may last over an entire season or over several wet years. Once again, it is prudent to consider a range of durations and choose the worst-case scenario (Van Zyl et al., 1988).

The critical duration design criterion is extremely important and should always be considered, even though such evaluations may be beyond the mandate of the regulatory requirements. If the critical duration evaluation is not used, the result may be unnecessarily conservative or dangerously overly optimistic pond sizing. The following two scenarios are examples from Van Zyl et al. (1988):

Overly Conservative Design - Assume the regulatory requirement prescribes a 6-hour probable maximum precipitation event (PMP) as the critical event. Water balance calculations indicate that the critical duration is 15 days. Analysis shows that the return period of the design event exceeds 1,000 years, which is considered overly conservative. Designing for this event means that there would be less than a 0.1 percent chance of overtopping a pond during any 1 year.

Liberal Design - Assume that the regulatory requirement prescribes a 24-hour, 100-year event as the critical design event. Furthermore, assume that the operation is located in a moderately wet climate and that the critical duration is actually 60 days. Analysis shows that the actual return period of the design event is less than 25 years. This means the chances that the pond will overtop exceed 4 percent each year. During a 20-year leach operation life, the probability of overtopping will exceed 80 percent. By most standards, this design would be deemed unacceptable.

In cases where critical duration analysis produces overly conservative or overly liberal designs, applicants should provide to regulatory agencies calculations disclosing the probability of overtopping for different critical durations as a part of their impact analysis. Further iterative design calculations may be warranted.

6.0 SURFACE WATER AND GROUND WATER MODELING

Mathematical models can be solved analytically or numerically. Either type of solution may involve the use of a computer. Analytical solutions are usually simple in concept and assume a homogeneous, porous media. Numerical solutions are usually more appropriate for complex, heterogeneous conditions. In general, models become more complex as fewer simplifying assumptions are used to describe a system or approximate a set of governing equations.

Anderson and Woessner (1992) suggest answering the following questions to determine the type and level of modeling effort needed:

- Is the model to be constructed for prediction or system interpretation, or is it a generic modeling exercise?
- What should be learned from the model? What questions do you want the model to answer?
- Is a modeling effort the best way to obtain the information required?

- Can an analytical model, rather than a more complex and labor intensive numerical model, be used to obtain a solution?

Answers to these questions will help the mining hydrologist to determine the methods to use to conduct a water balance study or design hydrological structures at a mine site. In addition, they will help to determine whether a solution should be analytical or numerical, steady state or transient, or, especially for ground water solutions, whether a modeling effort should be conducted in one-, two-, or three-dimensions (Anderson and Woessner, 1992).

Applicants will recognize that many ground water flow models assume porous media flow and may not replicate conditions at mines where rocks are intensely fractured. Modeling fracture flow may require applicants to collect additional data on the number, width, and interconnection of fractures (Anderson and Woessner, 1992). As described in detail in Anderson and Woessner (1992), fractured systems can be modeled by invoking conceptual models of equivalent porous medium, discrete fractures, or dual porosity. Each of these conceptual models uses assumptions that oversimplify flow through the fractured system. Consequently, applicants should exercise caution when interpreting the results of models developed in this manner.

6.1 Developing a Conceptual Site Model

A conceptual site model can be used to address the questions and evaluate the parameters discussed in Section 6.0. This model is a depiction, descriptive, pictorial, graphical, or otherwise, of the surface and subsurface hydrological systems, how they interact, and how they are related. The conceptual model should be developed concurrently with site characterization studies to determine important geologic formations, hydrostratigraphic units, and surface water interactions. A carefully constructed conceptual model will reveal important interrelationships that need to be evaluated, studied, or modeled. In addition, it will provide a basis for developing plans to monitor site conditions, analyze impacts, and construct numerical ground and surface water models. The conceptual model is usually simplified to consider only significant surface, subsurface, and interactive components because a complete reconstruction of actual field conditions is not feasible (Anderson and Woesner, 1992). It should be sufficiently complex to accurately depict system behavior and meet study objectives, but simple enough to allow timely and meaningful development of modeling or other analytical solutions.

The conceptual model provides a tool for identifying the questions to analyze using a mathematical model. Comparing the boundaries, dimensions, and input parameters of a particular mathematical model against the conceptual model, permits a user to evaluate the ability of the mathematical model to meet assessment needs. This type of comparison may indicate that specific components of the surface or subsurface hydrologic system cannot be simulated easily using a mathematical model. In this case, the conceptual model can be used to identify additional site characterization needs or model codes that are needed to accurately model specific components.

Conceptual model development begins by defining the area of interest and the boundary conditions of that area. Boundary conditions may include definitions of flow or hydraulic conditions across the boundary. The main steps in developing a conceptual model are to: (1)

define hydrostratigraphic units (these may or may not correspond to specific geologic units, depending on the degree of complexity required by the project objectives); (2) develop a general water budget that identifies sinks and sources to the system; and (3) define the type of flow systems to be studied or modeled.

6.2 Analytical Software for Surface Water Modeling

Most computer programs available to analyze surface water hydrology, perform watershed studies, and design hydrological structures are considered "analytical" software. Many of these programs use the algorithms discussed in Section 4.0 for analyzing precipitation, runoff, flow routing, and structure design. These programs allow a user to apply different algorithms to a particular problem and then compare the solutions. The output from one analysis, such as a watershed precipitation or snowmelt analysis, can be easily utilized by other routines to analyze runoff and route flows through a structure. One problem that can be associated with the use of empirical models (whether applied using a computer or by hand calculation) is that they are easy to misapply. As discussed in Section 4.0, it is important that the mining hydrologist understand the assumptions and approximations used by different methods and in what situations different methods are appropriate.

The U.S. Geological Survey has published a compendium on the use of surface water models (Burton, 1993). A complete review of this publication is beyond the scope of this report; however, the publication outlines recent research and application of surface water modeling techniques and the use of interactive spatial data systems, such as the use of satellite imagery and Geographical Information Systems.

Most analytical software used for hydrological analyses and structure design is available through the private sector. Some surface water hydrological, water quality, and groundwater software programs and models are available through the United States Geological Survey (USGS). Many of these programs and their manuals can be accessed and downloaded to a computer from the USGS via the internet (as of February 1999: water.usgs.gov/software). Brief descriptions of some of the more commonly used programs are provided below with particular emphasis on those that typically are used in mine settings.

HEC-1 Flood Hydrograph Package

HEC-1 (U.S. Army Corps of Engineers, 1987) is perhaps the most commonly used software for conducting watershed analyses and performing surface hydrological analyses for use in structure design and water balance studies. The program was originally developed in 1967 by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC). The program has been modified and improved throughout the years and a visual (graphical) version has recently been released.

HEC-1 generates hydrographs from rainfall and/or snowmelt, adds or diverts them, then routes the flow through stream reaches, reservoirs, and detention ponds. It models multiple stream and reservoir networks, and has dam failure simulation capabilities. The program can simulate level-pool routing for reservoirs and detention ponds. Figure A-6 outlines the techniques incorporated into HEC-1, many of which are discussed in Section 4.0.

TR-20 Project Formulation Hydrology

TR-20 (Soil Conservation Service, 1973) performs hydrograph generation, additions, or diversions, reach routing, or multiple pond network analyses. TR-20 uses the SCS methods to generate runoff hydrographs based on precipitation amounts specified for any storm duration. Hydrographs are computed using standard SCS Type I , IA, or II rainfall distributions, or other design hyetographs specified by the user.

HMR-52 Probable Maximum Storm

HMR-52 (Hansen et al., 1982) computes basin-average precipitation for Probable Maximum Storms and finds the spatially averaged Probable Maximum Precipitation (PMP) for a watershed. The PMP can be used directly with HEC-1 to compute runoff hydrographs for the Probable Maximum Flood (PMF) as the basis for dam spillway and failure analyses.

HECWRC Flood Flow Frequency

HECWRC performs a statistical analysis of historical stream flow data and plots the resulting flow-frequency curve. The program places both the observed and computed probability curves on the same plot. HECWRC uses the Log-Pearson Type III distribution as discussed in Section 4.0 to compute the return frequency curve.

HEC-RAS Water Surface Profiles

HEC-RAS (U.S. Army Corps of Engineers, 1991) software employs methods commonly used in open channel hydraulics and in the design and analysis of hydrologic structures. HEC-RAS computes water surface profiles for steady or gradually varied flow in natural or man-made channels. It handles subcritical and supercritical flows and can analyze the performance of culverts, weirs, and floodplain structures. HEC-RAS is used for evaluating flood hazard zones and designing man-made channels or channel improvements.

6.3 Numerical Modeling of Surface Water

A variety of software is available that combines analytical solutions with numerical modeling techniques to create watershed models. In general, these models employ finite-difference or finite-element techniques to route hydrographs and pollutants through surface-water systems. These models are particularly useful for evaluating the fate and transport of point and non-point sources of pollution through a watershed. Studies of this type could be used by mining

Overview of HEC-1 Computer Program
U.S. Army Corps of Engineers

Precipitation Analysis
- User Enters Time Intensity Distributions
- Any Distribution
- Any Duration
- Capable of Handling Multiple Stations

Infiltration Analysis
- SCS Curve Number
- Holtan Loss Rate
- Green and Ampt
- Initial and Uniform Loss Rate
- Exponential Loss Rate

Runoff Hydrograph Analysis
- SCS Unit Hydrograph
- Clark Unit Hydrograph
- Snyder Unit Hydrograph
- Kinematic Wave Method
- User Supplied Unit Hydrograph

Flow Routing
- Muskingum
- Muskingum-Cunge
- Modified Puls
- Working R & D
- Kinematic Wave

Other Features
- Reservoir Routing
- Dam Break Approximations
- Watershed Calibration
- Flood Damage Analysis
- Pumping Plants
- Diversions

Figure A-6. Summary of methodologies available in HEC-1.

operations to evaluate and model potential operational effects and releases in conjunction with the NPDES permit process. Two of the more commonly used models are described below.

Hydrologic Simulation Program FORTRAN (HSPF)

HSPF (Bicknell et al., 1997) is a set of computer codes that simulates the hydrologic and associated water quality processes on pervious and impervious land surfaces, in the soil profile, and in streams and well-mixed impoundments. The operational connection between the land surface and the instream simulation modules is accomplished through a network block of elements. Time series of runoff, sediment, and pollutant loadings generated on the land surface are passed to the receiving stream for subsequent transport and transformation simulation. Water quality and quantity can be evaluated along different segments or at outflow points within a watershed.

Water Erosion Prediction Project Hydrology Model (WEPP)

WEPP (Foster and Lane, 1987) is designed to use soil physical properties and meteorological and vegetation data to simulate surface runoff, soil evaporation, plant transpiration, unsaturated flow, and surface and subsurface drainage. The model uses the Green and Ampt infiltration equation to estimate the rate and volume of excess storm precipitation. Excess precipitation is routed downslope to estimate the overland flow hydrograph using the kinematic wave method. In WEPP, surface runoff is used to calculate rill erosion and runoff sediment transport capacity. The infiltration equation is linked with the evapotranspiration, drainage, and percolation components to maintain a continuous daily water balance for a watershed.

6.4 Analytical and Numerical Modeling of Ground Water

Ground water models are used in water balance studies at mine sites to evaluate and quantify ground water inflow to pits, channels, or other large structures associated with the mine. One-dimensional, vertical models may be used to evaluate situations where pond liners or other containment structures may have failed and knowledge of contaminant transport to natural ground water systems is required.

Most ground water modeling software is available through government agencies or the private sector. A thorough description of ground water modeling and the assumptions associated with its proper application is beyond the scope of this report. Instead, the reader is referred to the text by Anderson and Woessner (1992) for a detailed discussion of modeling techniques and applications and to a report produced by EPA in cooperation with the Department of Energy (DOE) and the Nuclear Regulatory Commission (NRC) that provides technical guidance regarding the development of modeling objectives, the development of site conceptual models, and the choice of models for use in particular problems (EPA, 1994). A brief description of ground water modeling and its application to mining is provided below. A description of some of the more common ground water modeling programs is also provided, with particular emphasis on those that are commonly used in mine settings.

Van der Heijde (1990a) defined a ground water model as the mathematical description of the processes active in a ground water system. Models vary in sophistication, with analytical solutions being the least complex and numerical methods, such as finite-difference or finite-element methods, being the most complex. A comparison of finite-difference and finite-element numerical methods is detailed by Pinder and Gray (1977). Both schemes are widely used to simulate transient flow in ground water aquifers (Freeze and Cherry, 1979).

Ground water models can be used to simulate heterogeneous systems in which a variety of coupled processes describe the hydrology, chemical transport, geochemistry, and biochemistry of near surface and deep aquifer systems. Ground water models may also incorporate the mathematical description of fluid flow and solute transport systems for both the saturated and unsaturated zones and take into consideration the complex nature of hydrogeological systems.

The predictive capabilities of ground water models depend on the quality of input data. The accuracy and efficiency of the simulation depend on the applicability of the assumptions and simplifications used in the model, the accurate use of process information, the accuracy of site characterization data, and the subjective decisions made by the modeler. Where precise aquifer and contaminant characteristics have been reasonably well established, ground water models may provide a viable, if not the only, method to adequately predict inflow to a mine pit, evaluate dewatering operations, conduct contaminant fate and transport studies, locate areas of potential environmental risk, identify pollution sources, and assess mining operational variables.

Ground water models can be classified into two broad categories. The first includes flow models that describe the hydraulic behavior of single or multiple fluids or fluid phases in porous or fractured media. The second category includes contaminant/chemical fate-and-transport models that analyze the movement, transformation, and degradation of chemicals in the subsurface. A detailed discussion of model classifications is presented by van der Heijde et al. (1985; 1988).

The modeling process consists of defining the problem, creating and calibrating the model, and conducting an analysis for a particular mining scenario or problem. Analysis of the water management problem in question is used to formulate modeling objectives and create simulation scenarios. Key elements of the problem definition step are conceptualizing the ground water system and analyzing and interpreting the existing data. Conceptualizing the ground water system includes: (1) identifying the hydraulic, thermal, chemical, and hydrogeologic characteristics of the system; (2) determining active factors such as pumping rates, artificial recharge, injection, or other anthropogenic factors, and passive factors, such as natural recharge, evaporation, and seep discharge; and (3) analyzing the level of uncertainty in the system (Kisiel and Duckstein, 1976).

The model calibration phase begins with the design of a computational grid that provides the basis for discretization of spatial parameters (van der Heijde, 1990a). Model calibration is accomplished by running iterative simulations, starting with field parameters and system stresses, followed by improving initial estimates based on the differences noted by comparing computed with observed values. As input parameters are continually refined, the model becomes more precise representation of the physical system.

After the model is calibrated to field conditions, it can be used to make predictive estimates. In this phase, different engineering designs, system alterations, or failure scenarios can be evaluated. Van der Heijde (1990a) suggests that uncertainty analyses should be conducted in conjunction with predictive modeling to assess the reliability of the simulation results.

During any modeling application, a lack of data can impede the efficiency of the simulation. Insufficient data can result from inadequate spatial data resolution, inadequate temporal sampling of time-dependent variables, and measurement errors. Van der Heijde (1990b) presents specific guidance on setting up quality assurance (QA) programs for ground water modeling studies. The major elements which should be incorporated into a QA program for modeling include:

- Formulate QA objectives and required quality level in terms of validity, uncertainty, accuracy, completeness, and comparability;

- Develop operational procedures and standards for performing adequate modeling studies; and

- Establish QA milestones for internal and external auditing and review procedures.

The QA plan should address collecting data, formulating the model, conducting sensitivity analyses, and pre-establishing guidelines for model calibration criteria. Ground water modeling for use in hydrologic design or water balance studies should incorporate a QA plan that addresses specific modeling objectives and the above parameters, depending on the risk associated with the specific design or study.

Commonly used programs for developing ground water models are briefly described below. These models were chosen to demonstrate the capabilities of some of the software available in the public domain.

AT123D

AT123D (Yeh, undated) uses analytical solutions for transient one-, two-, or three-dimensional transport in a homogeneous, anisotropic aquifer with uniform, stationary regional flow. The program allows for retardation and first-order decay when evaluating contaminant transport problems and permits simulation of a variety of source configurations, including point source, line source, and areal source inputs. It further allows the use of several boundary conditions to define flow parameters; longitudinal, horizontal and vertical transverse dispersion values can be input independently. The model calculates concentration distributions in space and time.

MODFLOW

MODFLOW (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996) is perhaps the most commonly used software for creating ground water models and conducting predictive studies. MODFLOW is a numerical model that uses a finite-difference solution to solve the governing equations for ground water flow. It can be used to create two-dimensional areal or vertical models as well as quasi-three-dimensional or full three-dimensional models. Because of its numerical approach, it can be used to model transient flow or steady-state flow under anisotropic and layered aquifer conditions. Layers can be simulated as confined, unconfined, or convertible between the two conditions. The model can also handle layers that "pinch out". The model allows for analysis of external influences such as wells, areal recharge, drains, evapotranspiration, and interaction with surface water bodies such as streams. This software has been accepted for use by many regulatory programs.

FEMWATER/FEMWASTE

FEMWATER (Yeh, 1987) is a numerical model that uses a finite-element solution to solve the governing equations for ground water flow. It can be used to create two-dimensional areal or vertical models as well as full three-dimensional models in both saturated and unsaturated media. Because of its numerical approach, it can be used to model transient flow or steady-state flow under anisotropic and layered aquifer conditions. FEMWASTE is a two-dimensional transient model for the transport of dissolved constituents through porous media. The transport mechanisms include: convection, hydrodynamic dispersion, chemical sorption, and first-order decay. The waste transport model is compatible with the water flow model (FEMWATER) for predicting convective Darcy velocities in porous media that are partially saturated.

7.0 DATA REPRESENTATIVENESS

It is critically important to adequately understand the unique hydrology of a particular mine site. Mine sites may be situated in areas where precipitation rates vary significantly over a small area (e.g., due to orographic effects) or in remote areas for which meteorological records are lacking. In mountainous terrains, snowmelt and rain-on-snow events may produce large flow volumes that are difficult to quantify. These uncertainties make it difficult to characterize the entire hydrologic system.

Because the quality of field data available for mine sites may vary substantially, it is critical to know the advantages and limitations of the different methods that may be used to characterize site hydrology. As discussed in Section 4.3, the standard methods for predicting runoff must be used cautiously in mine site planning. The unique geographical and meteorological settings often encountered at mine sites mandate careful consideration of the assumptions used and require model results to be correlated with actual field data and conditions.

The nature of mining inevitably impacts the hydrology of a site, in terms of both water quantity and quality. Often, baseline hydrologic conditions are not well characterized because historical data either are unavailable or inadequate, or because the data have not been adequately evaluated. Preventing potential environmental impacts requires that a mine site's water system, both the natural and facility systems, be adequately evaluated. Evaluations of and conclusions concerning environmental impacts to site hydrology and water quality should be at least as precise and accurate as those of other economically important aspects of the project. For example, the studies, conclusions, and disclosure of potential hydrological and water quality impacts should be at least as accurate as those concerning the certainty and extent of the economic ore deposit.

The selection of appropriate statistical analysis techniques and the accuracy of their predictions are linked to data representativeness. Those statistical procedures whose assumptions best fit the population characteristics should be identified as the most appropriate data analysis procedures for use in baseline characterization and for design (Ward and McBride, 1986). In initial efforts to design a basic characterization or monitoring system, it is necessary to statistically analyze existing hydrological data and determine those characteristics that will influence the selection of data analysis procedures. If there are no existing data, data from a watershed presumed to be hydrologically similar should be obtained to provide initial estimates.

7.1 Statistical Concepts and Hydrological Variables

Basic descriptive statistical parameters for hydrological data include the mean, variance, skewness, and coefficient of variation. Statistical methods use hypotheses and tests to determine distributions, differences in parameters between objects, the significance of those differences, and confidence in the estimated values.

For many hydrological variables and environmental contaminants, the basic statistical assumptions of independent, normally distributed data are not realistic because environmental data commonly are correlated and non-normally distributed, with variance that may change over time (Gilbert, 1987). For hydrological and water quality data in particular, there are three commonly assumed parameters which may not apply to hydrological studies (Ward and Loftis, 1986): (1) independence of observations, including the absence of seasonality or serial dependence; (2) homogeneity of variance over the period of record; and (3) form of the probability distribution, (e.g., normal or non-normal). For these reasons, the statistical characterization of hydrological data for calculating mine water balances should include time series plots and testing for normality.

The many statistical techniques that can be used to characterize hydrological processes are presented in the references cited and will not be discussed herein. However, the following paragraphs present examples of two commonly used statistical methods for predicting components of a mine site water balance. Statistical techniques used for flood frequency analysis are presented in Section 4.0.

Linear regression is used to define the relationship between two variables whereas multiple regression is used to explain how one variable varies with changes in several variables. Analysis of Variance (ANOVA) can be used to determine the most or least significant variable. For example, single factor linear regression can determine the relationship of runoff volume to rainfall volume while multiple regression can determine the effect of multiple watershed characteristics (e.g., basin size or shape, stream length, stream density) on runoff peak discharges. Regression also can be used to analyze trends, provide information about flow and water quality differences, measure variance, and extend hydrological records from a gaged basin to an ungaged basin or stream.

Factor analysis can be used to evaluate complex relationships between a large number of variables and determine their separate and interactive effects. An example of factor analysis in hydrology would be to determine significant factors of importance in predicting watershed runoff, such as determining effects of basin size, shape, soil type, aspect, vegetation type, or other geomorphological factors.

7.2 Development of a Quality Assurance Program with Data Quality Objectives

The difference between the true value of a variable and the measured or calculated value is a measure of data quality. All hydrological data are subject to random errors, systematic errors including inconsistency and bias, and non-homogeneity. Random errors always are present in data. Inconsistency is the difference between observed values and true values while non-homogeneity reflects a changed condition that has taken place between sampling events. Predicting stream flows based on past properties of hydrologic variables requires that the conclusions be derived from data that are free of significant inconsistency and non-homogeneity, and with tolerable random errors (Yevjevich, 1972).

The amount of uncertainty that can be tolerated depends on the intended use of the data. The level of uncertainty that is acceptable is a critical part of the monitoring design (i.e., what, where, and how often to sample) and, therefore, must be incorporated into the sampling program. Statistical design criteria should be defined within any monitoring program. These criteria set limits on the confidence in the data by specifying the acceptable uncertainty in the estimated variables.

Gilbert (1987) identifies four categories of data validation procedures that should be performed:

(1) Routine checks made during the processing of data. Examples include looking for errors in identification codes (those indicating time, location of sampler, method of sampling, etc.), in computer processing procedures, or in data transmission.

(2) Tests for the internal consistency of a data set. These include plotting data for visual examination by an experienced analyst and testing for outliers.

(3) Comparing the current data set with historical data to check for consistency over time. Examples are visually comparing data sets against gross upper limits obtained from historical data sets, or testing for historical consistency using the control chart test.

(4) Tests to check for consistency with parallel data sets, i.e., data sets thought to be from the same population (i.e., from the same time period or similar stream). Three tests for consistency are the sign test, the Wilcoxon signed-ranks test, and the Wilcoxon rank sum test. These tests are discussed by Gilbert (1987).

Data reliability can be assessed using ANOVA to evaluate analytical, sampling (at a site), and regional (between sites) variability. If replicate samples have been collected, then an analysis of variance can determine whether there is a statistically significant difference between sources of variation. Basic assumptions for ANOVA tests include random samples, normal distributions and equal variances. ANOVA methods can help to focus additional sampling and aid data interpretation.

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APPENDIX B

RECEIVING WATERS

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1.0 GOALS AND PURPOSE OF THE APPENDIX

The primary goal of this appendix is to outline the rationale and methods to characterize water quality in and around a proposed mine site. It 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 E, *Wastewater Management,* Appendix F, *Solid Waste Management,* and Appendix H, *Erosion and Sedimentation.* Background materials in this appendix review how mining activities can impact water quality, describe how water quality standards are developed, outline general processes related to contaminant dispersal, and summarize important aspects of a watershed-based evaluation. The background materials are followed by a section that describes practical aspects of developing a program to monitor water quality. A section on data analysis provides general information for modeling water quality data. The appendix concludes by reviewing the important aspects of monitoring and quality assurance as needed for NEPA (EIS) and NPDES purposes.

Surface and ground waters that receive treated and untreated discharges from mine sites are referred to as "receiving waters". Point source discharges to receiving waters are regulated under Section 402 of the Clean Water Act, which requires the preparation of National Pollutant Discharge Elimination System (NPDES) permits. A key aspect of the NPDES permitting process is protecting the quality and designated uses of receiving waters. To predict the potential impacts of mining operations on receiving water quality, it is important to have adequate discharge and baseline receiving water data. Because data needs are varied and many, it is important to assess the scope of specific water quality data needs and their uses prior to beginning data collection to ensure that data will serve all intended purposes and that they will be collected in an efficient manner. Receiving water quality data at mines may be used for a variety of other purposes including:

- Establishing baseline conditions to support calculations of NPDES permit limits,
- Providing justifications for site-specific criteria,
- Developing dissolved to total recoverable translators,
- Developing the basis for effluent trading,
- Documenting the quality of the affected environment for NEPA analysis,
- Determining cumulative impacts under NEPA,
- Predicting environmental consequences of the proposed action and alternatives under NEPA,
- Assisting in conducting watershed analyses,
- Supporting remedial activity in impaired watersheds, and
- Monitoring long-term trends.

This guidance is focused on characterizing water quality at proposed mines. Although the term "receiving water" is used throughout, the methods and techniques described can be applied to any surface or ground water and are not restricted to waters that will receive direct discharges of mine effluent. As part of this analysis applicants may be required to understand the interactions between surface and ground waters and characterize other physical and biological aspects of the aquatic environment. The concepts and guidance presented herein also are appropriate for surface water and ground water quality monitoring at other stages of a mine's life cycle, including operation, closure, and post-closure. In these settings, water quality data can be used for compliance monitoring, trend monitoring, monitoring the effectiveness of Best Management Practices (BMPs), and establishing and verifying any permitted mixing zones.

In 1997, EPA released the "Hardrock Mining Framework", a document that outlined the Agency's approach to dealing with environmental concerns at hardrock mining sites. This document acknowledged that recent national initiatives were directed toward ensuring that point sources of pollution were addressed on a watershed basis. In addition, the Framework recognized that the watershed approach could be an administrative means to reduce pollutant loadings on a cost-effective basis. Consequently, this appendix stresses the use of the watershed approach to determine receiving water quality.

2.0 REGULATORY AND TECHNICAL BACKGROUND FOR DESIGNING A WATER QUALITY ASSESSMENT PROGRAM

This section briefly discusses technical and regulatory factors that are important to consider when designing a program to assess water quality. It begins by describing the types of water quality impacts that can occur as a result of mining activities, then briefly summarizes the regulatory development of water quality standards, describes processes that affect contaminant dispersal, and discusses the watershed approach to water quality assessment. Applicants proposing new or expanded mining projects should be certain to fully characterize the existing quality of surface and ground water resources at their site, so that an EA or EIS will be able to fully describe the types of impacts that the mine may create.

2.1 Mining Impacts on Water Quality

For the purposes of considering impacts to water quality, the diverse activities associated with hardrock mining can be divided into four main areas. *Disturbance* activities include the development of mine pits, shafts, and adits and surface disruptions associated with mine development and facility construction (e.g., grading, road construction, impoundment construction, foundation preparation, soil stripping, and pipeline and powerline construction). *Processing* activities include the construction and operation of crushing and milling facilities; flotation concentrators; smelters and refineries; heap and dump leach facilities; vat and tank leach plants; water treatment facilities; and carbon stripping, zinc precipitation, and solvent extraction/electrowinning plants. *Waste disposal* activities include the construction and operation of waste rock dumps, overburden piles, tailings impoundments, and slag piles and other process waste. *Support* activities include those actions required for day-to-day operation of the mine such as equipment maintenance, fuel storage, wastewater treatment, and laboratory analysis. EPA has prepared a series of Technical Resource Documents that summarize the extraction and beneficiation of lead-zinc, gold, copper, iron, uranium, gold placer, and phosphate and molybdenite ores. They can be obtained from the EPA Office of Solid Waste webpage (http://www.epa.gov/epaoswer/other/mining.htm).

2.1.1 Disturbance Activities

Disturbance activities increase the potential for surface or ground water impact by exposing mineralized rock, disturbing native soils and vegetation, altering slope angles, and modifying watershed and aquifer characteristics. Mine pits, adits, shafts, and open cuts that expose mineralized rock have the potential to produce increased loadings of metals, dissolved solids, suspended solids, and acidity to surface waters. The construction of roads, utility lines, and facility foundations and stripping activities associated with the development of mine pits and the construction of mine processing, disposal, and water management facilities increase the potential for sediment contamination. These activities alter natural watershed characteristics by increasing runoff, decreasing soil cohesion and infiltration, and increasing susceptibility to erosion. Potential mining impacts associated with erosion and sedimentation are described in more detail in Appendix H, *Erosion and Sedimentation.*

The types of constituents that can be released during or following disturbance activities depend on the nature of the mineralization and the mining operation. Mining disturbances may increase the concentrations of suspended particles and metals (e.g., Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg, Ni, Se, Ag, Zn), major cations (e.g., ammonia nitrogen, Ca, Mg, K, Na), and anions (e.g., nitrate, sulfate, chloride, carbonate) that form a large portion of the total dissolved solids in surface waters. Constituent concentrations can be increased through dissolution or retransport of naturally occurring compounds or by the dissolution of reagents, such as blasting residues (Table B-1), that are used during disturbance activities. Importantly, surface and underground disturbances can result in the production of acid drainage. This phenomenon, referred to as acid mine drainage or acid rock drainage, results when iron sulfide minerals (pyrite and marcasite), which commonly occur in mineralized zones, are exposed to the oxidizing environment of the atmosphere. The acidity produced from exposed pit walls and underground workings can impact surface water quality for many years after mining ceases by lowering pH and increasing the amount of metals leached from exposed surfaces and maintained in solution.

Disturbance activities release contaminants to surface and ground waters primarily through precipitation runoff, releases of mine water, or disruption of aquifers and their confining layers.

2.1.2 Processing Activities

Processing activities increase the potential for surface water impact by creating facilities in which metals are concentrated to values significantly above those in the ore, dissolving metals into solution, grinding metal-rich ore into fine particle sizes, and storing and using large quantities of reagents that can potentially degrade surface water quality. Depending on the type of milling and concentrating process employed, a mine may construct ore stockpiles to assure consistent feed to a mill. Pad and dump leaching facilities have associated impoundments to store barren and pregnant leach solutions, pipelines to transfer solutions between storage ponds and leach pads, and leachate and seepage collection facilities.

Contamination from processing facilities can occur in many forms that depend on the type of ore being processed, the type of on-site processing, and the specific mine design. 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. Table B-1 gives examples of the types of processing reagents that may be used by mining operations; it should be recognized that this table does not provide a comprehensive listing.

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.

2.1.3 Waste Disposal Activities

Waste disposal activities increase the potential for surface water impact by creating permanent features in which waste materials are stored. Waste materials can serve as sources of leachable metals, acidity, cyanide or other toxic constituents, and fine-grained sediment for many years after mining ceases. Examples of these facilities include waste rock dumps, impoundments, and spent ore piles. Descriptions of the types of waste disposal facilities used at mines sites are given in Appendix F, *Solid Waste Management.*

Waste disposal facilities can impact receiving waters through the release of sediment, metals, and other contaminants. In part, the types of contaminants available to the environment depend on the character of the waste materials (e.g., grain size and mineralogy), the means by which these materials were processed (e.g., cyanide or acid leach), and the types of closure procedures that were employed (e.g., rinsing, neutralization, capping and revegetation). Fine-grained materials such as tailings piles are a significant source of erodible sediment that potentially can be mobilized and redeposited in stream beds by surface runoff. Over the long term, waste rock dumps, tailings impoundments, and spent ore piles that contain sulfide-bearing material can contribute acidity to receiving waters through the oxidation of pyrite and marcasite as described in Appendix F, *Solid Waste Management.* Acid leachates produced from these materials facilitate the dissolution of the metals listed in Section 2.1.1, *Disturbance Activities.* Closed cyanide and acid heap leach units may contain residual cyanide and cyanide by-products, or acidity that can be released to receiving waters if the heaps are not properly rinsed and neutralized (Simovic et al., 1985).

Contaminants can be released to surface waters in a variety of ways that include physical failure (e.g., breach or sloughing of a tailings impoundments), seepage (e.g., below an impoundment dam), saturation and overflow of lined facilities (i.e., the “bathtub” effect), and erosion by wind and water (e.g., gully formation during storm events). Contaminant pathways can be direct (release directly to surface waters) or indirect. Examples of indirect contaminant

Table B-1. Example Reagents Used at Metal Mines

Disruption Activities		
Blasting Agent	Ammonium nitrate & fuel oil (ANFO)	
Processing Reagents		
Flotation Reagents	Alkaline sulfides Sodium cyanide Sodium ferrocyanide Aliphatic alcohol Phenol Ethyl and amyl xanthates Alkyl dithiophosphate Methyl isobutyl carbinol Aerofloats Copper sulfate Zinc sulfate Sodium sulfide Kerosene	Phosphorous pentasulfide Sulfuric acid Sodium hydroxide Pine oil Polyglycol ether Sodium isopropyl xanthate Sodium diethyl phosphorodithioate Thiocarbamate Pine oil Dichromate Zinc hydrosulfate Sodium bisulfate
Solvent Extraction - Electrowinning Reagents	Sulfuric acid Oxime compounds Amphoteric fluoroalkylamide derivative	Hydrocarbon distillates Cobalt sulfate solution Diethylene glycol butyl ether
Miscellaneous Concentrator Reagents	Anionic polyacrylamide Polyacrylate	Polyphosphate Polymeric and organophosphorous compounds
Leaching Reagents	Sulfuric acid	Sodium cyanide
Leach Processing Reagents	Sodium hydroxide Hydrochloric acid Nitric acid	Lead nitrate Zinc Sodium sulfide
Leach Neutralizing Reagents	Hydrogen peroxide Chlorine Sodium hypochlorite	Lime Sulfur dioxide Copper
Support Activities		
Petroleum Products	Gasoline Diesel fuel Gear oil, motor oil, hydraulic oil Lubricating grease and oil	Antifreeze Paraffinic, napthenic, and aromatic hydrocarbons (solvent) Propane
Wastewater Treatment Reagents	Ion Exchange Regenerants: Hydrochloric acid Sulfuric acid Sodium chloride Descalants: Calcium sulfate Calcium carbonate Silicon dioxide Sodium hexametaphosphate	Chemical Precipitation Reagents: Lime Alum Sodium hydroxide Calcium hydroxide Hydrogen sulfide Calcium sulfide

Sources: Coeur Alaska, Inc., 1997; U.S. EPA, 1994a, 1994b, 1994c, 1998a; Knorre and Griffiths, 1985; Montgomery Watson, 1996; Scott, 1985; Viessman and Hammer, 1993.

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.

2.1.4 Support Activities

Support activities can increase the potential for receiving water impacts through facilities that use and store chemicals and generate waste materials. Support activities can release contaminants to surface waters through a variety of means that include spills and leaks from fuel handling and storage facilities, seepage from solid waste landfills, and seepage and runoff from equipment maintenance facilities. Contaminant pathways may be direct or indirect. Examples of indirect contaminant pathways include seepage to soil or bedrock from above-ground fuel storage tanks and runoff from soils contaminated with solvents or degreasing agents.

2.2 Water Quality Standards

An important aspect of mine review for EPA is evaluating whether a project will adversely affect water quality. One measure of this analysis is the potential to cause exceedances of water quality standards. This type of analysis involves characterizing potential discharges to streams and determining the impacts they would cause to water quality. Prior to evaluating the potential for water quality impacts, the water quality standards that apply to the receiving water must be determined. Water quality standards are provisions of State or Federal law which consist of three components: (1) designated beneficial uses for all Waters of the U.S., (2) water quality criteria (which may be numeric or narrative) for the waters based upon their uses, and (3) antidegradation policies. State water quality standards and implementing provisions are approved by EPA and are codified in State regulations. It is essential for a mine to obtain the most up-to-date state water quality standards and regulations since they often change on a periodic basis. Many of these regulations are now available on-line. More information regarding water quality standards is provided in EPA's Water Quality Standards Handbook (U.S. EPA, 1994d).

Under the Clean Water Act, each State must classify all of the waters within its boundaries by their intended use [see §303(c)(2)]. Once designated beneficial uses have been determined, the State must establish numeric and narrative water quality standards to ensure the attainment and/or maintenance of the use. Designated beneficial use classifications include the use and value of water for public water supplies; protection and propagation of fish, shellfish, and wildlife; recreation in and on the water body; and agricultural, industrial and navigational purposes (see 40 CFR §131.10 for more detail on the designation of uses). For a specific water body, a mine can determine the applicable standards based on the designated use classifications. Where multiple use classifications apply to a water body (e.g., recreational and aquatic life uses), the most sensitive use designations generally apply. Water bodies, especially minor tributaries, may not be identified in State regulations along with their designated beneficial uses. In these cases, States may assign to tributaries the same designated uses as the larger water body that they flow into. Alternatively, they may have a general set of classifications that apply to all unspecified water bodies.

EPA recently published an updated listing of nationally recommended water quality criteria for 157 pollutants (U.S. EPA, 1998b). States may either adopt these criteria or develop alternative criteria that protect the designated uses of their waters. In such cases, the Clean Water Act requires States to use sound scientific rationale to develop their water quality criteria. Criteria may be expressed as constituent concentrations, levels, or narrative statements that represent a quality of water that supports a designated use. Criteria may be developed for acute and chronic toxicity to aquatic organisms, agricultural and industrial uses, and human health effect protection. Criteria, which are developed for both fresh waters and saline waters, may be designated in the form of dissolved, total recoverable, and/or total constituent concentrations. Acute criteria are based on one-hour average concentrations that cannot be exceeded more than once every three years on average, whereas chronic criteria are based on four-day average concentrations that cannot be exceeded more than once every three years on average. While some States use the same water quality standard values for all streams assigned an individual designated use, others depend on stream-specific conditions. For example, some metals are more toxic under low hardness conditions and the applicable standards depend on the hardness of the receiving water. Other standards (e.g., turbidity and temperature) may be based on deviation from natural conditions. For carcinogenic constituents, applicants should check with State authorities to determine the human health risk factors that apply. The need for representative baseline data for water quality parameters, especially as they relate to changes in flow, is obvious and should be considered in developing baseline and operational monitoring programs.

Many states have specific procedures to establish "mixing zones," which allow for the natural dilution of discharges by stream flow, taking into consideration background levels of individual pollutants and contributions from other dischargers. A mixing zone is a limited area or volume of water where initial dilution of a discharge takes place and where numeric water quality criteria can be exceeded but acutely toxic conditions are prevented (U.S. EPA, 1994d). Mixing zones typically are granted based on low-flow conditions (e.g., the 7Q10 flow in a stream). Since mines often discharge to streams where 7Q10 conditions approach zero, many do not qualify for mixing zones and water quality standards must be met at points of discharge. Operators wishing to use mixing zones must submit an application following procedures outlined in the State water quality standards. Such applications require applicants to work closely with the permitting authority.

States have a wide range of antidegradation requirements that prohibit discharges from degrading existing water quality except under specific conditions. These policies are designed to protect existing instream uses and water quality and to maintain and protect waters of exceptional quality that represent an outstanding National resource. In cases where water quality would be diminished, States are required to assure that water quality would remain adequate to fully protect existing designated uses.

Most State water quality regulations include provisions for developing site- or stream-specific standards and reclassifying (i.e., changing the designated uses of) water bodies. However, there is almost always a significant burden on the applicant to demonstrate the need for such changes. Operators are encouraged to work closely with States and EPA in determining whether site-specific standards/reclassifications are possible for a site and the supporting information that would be required. EPA must approve all changes to State water quality standards, including site-specific standards and reclassifications.

2.3 Processes that Affect Contaminant Dispersal

The processes that affect contaminant dispersal depend in part on site-specific factors such as climate, geology, surface and ground water hydrology, and water chemistry. These factors control runoff, infiltration, weathering and erosion, and the dissolution and attenuation of metals. One goal of watershed-based analysis is to identify the processes that have a primary controlling influence on water quality throughout the watershed.

2.3.1 Climate

Climatic factors determine seasonal flow in a watershed and affect seasonal infiltration and ground water recharge (see Section 3.3). Changes in infiltration and runoff can impact water quality by affecting the extent to which metals are diluted during downstream flow, the degree to which sediment and metal-bearing particles are eroded and transported downstream, and the impact that may be caused as oxidation products are periodically flushed from waste rock dumps and tailings piles. These effects need to be quantified so that natural and mining-induced contributions to water quality can be distinguished.

2.3.2 Geology

Surficial geology in mineralized areas should be expected to vary at the watershed scale. Variations can be manifested as changes in rock type, depth and character of soils, degree and character of alteration, nature of mineralization, and extent of fracturing. Surface waters flowing over and through different rock and soil types may have different constituent concentrations, particularly with regard to major ions, pH, and alkalinity (e.g., Stumm and Morgan, 1996). For example, where limestone or dolomite are present in a watershed, surface waters may contain significant bicarbonate alkalinity and high concentrations of dissolved Ca and Mg. However, in a different portion of the same watershed that is underlain by granite, waters may have much lower bicarbonate, Ca, and Mg concentrations.

In most mine areas, both the intensity of mineralization and the types of metallic minerals present are likely to change with location in a watershed. Variations in the style of rock alteration (e.g., phyllic vs. propylitic) can cause portions of a watershed to produce surface and ground waters with different water quality characteristics (Smith et al., 1994; Mast et al., 1998). Mountainous terrains may expose the transition from primary hydrothermal sulfide minerals to secondary oxide and carbonate minerals. The different solubilities and acid generating capabilities of sulfide and oxide minerals may produce waters with significantly different pH and metals and sulfate concentrations (e.g., Stumm and Morgan, 1996; Langmuir, 1997). Variations in the intensity and style of fracturing, which should be expected in watersheds that host structurally controlled mineral deposits, can lead to changes in infiltration, ground water flow, and ground water discharge within a watershed.

2.3.3 Surface Water Hydrology and Hydrogeology

A detailed discussion of characterization and measurement of surface water hydrology and hydrogeology is presented in Appendix A, *Hydrology.* Hydrological and hydrogeological processes and their accurate characterization are inherently related to the characterization and identification of potential impacts to important resources such as receiving water quality, aquatic life, vegetation, and wetlands. Watershed hydrology and hydrogeology need to be well understood prior to finalizing a program to characterize receiving water quality. Important watershed characteristics that should be evaluated include peak storm flow, infiltration-runoff relations, sediment load, surface water-ground water exchange, water table elevation, ground water recharge and discharge, aquifer confinement, and the extent of dewatering activities.

2.3.4 Aqueous Chemistry

The extent to which receiving waters disperse contaminants through the environment depends partly on water chemistry and soil character (Hutchinson and Ellison, 1991). Under equilibrium conditions, surface and ground waters will acquire constituent concentrations that depend on local physical and chemical conditions, the rate at which secondary phases precipitate from solution, and the tendency for dissolved constituents to sorb onto particle surfaces (Schnoor, 1996). Figure B-1 shows a conceptual physicochemical model of metal transport in a surface water system illustrating the complex interactions affecting concentration. In general, waters with comparatively low pH can retain higher concentrations of metals in solution than neutral waters (Salomons, 1995). Consequently, downstream changes in pH, redox potential, or other chemical parameters (e.g., in mixing zones) can lead to dissolution or precipitation of metal-bearing phases or their adsorption or desorption from bottom sediments or from colloidal precipitates (Oscarson, 1980; Moore et al., 1988; Langmuir, 1997).

The precipitation of colloidal particles is known to be an important process that should be evaluated when assessing water quality (Church et al., 1997; Schemel et al., 1998). Colloids are solid particles with diameters smaller than 1 micron that remain suspended in water due to Brownian motion (particles move as a consequence ionic attraction and molecular collision). Colloidal deposition can occur when particles aggregate into larger masses that can no longer be suspended by molecular forces. Aggregated particles that have settled to the bed of a stream can be resuspended during high flow, causing water quality to decline (Boult et al., 1994). Importantly, most colloidal particles will pass through a 0.45 micron filter and will report as "dissolved" constituents in water quality analyses. Colloidal particles, particularly iron oxyhydroxides, readily sorb dissolved metal ions from the water column (e.g., Chapman et al., 1983; Langmuir, 1997). Although the formation of oxyhydroxide minerals may improve water quality by facilitating sorbtion of other dissolved metal ions, deposition of colloidal particles may degrade aquatic habitat quality by coating substrate materials.

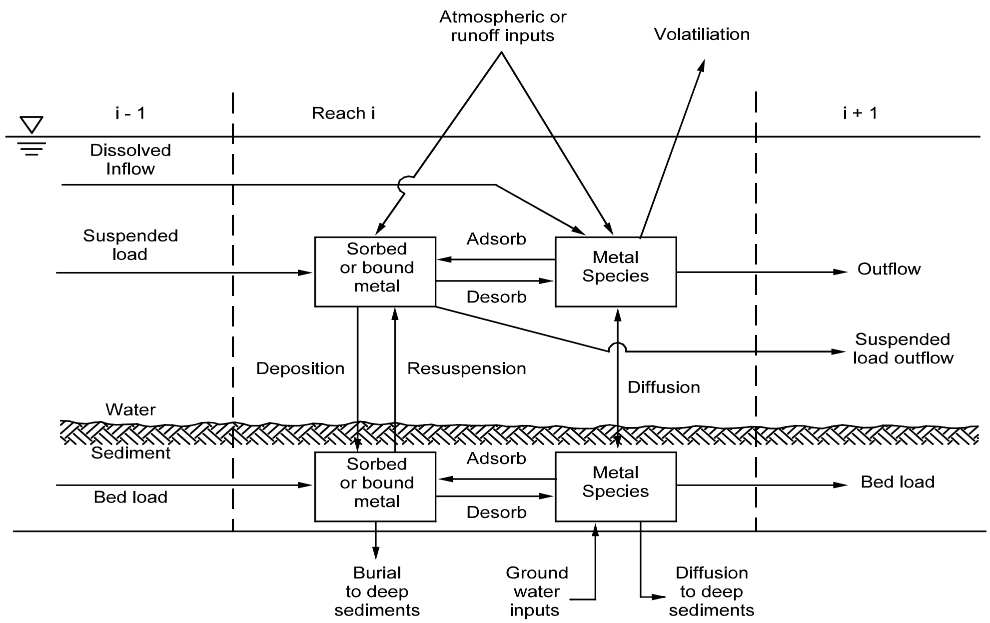

Figure B-1. Conceptual physicochemical model of metal transport in a river from Schnoor (1996).

The stability of colloidal precipitates is a function of chemical parameters such as pH and redox potential. Consequently, chemical changes occurring in a receiving water, such as in a mixing zone, can cause colloidal particles to precipitate or to redissolve and release their adsorbed metal constituents to solution (Church et al., 1997). For example, acidic, metal-bearing water draining an area of quartz-sericite alteration that flows into a stream with significant buffering capacity that is draining an area of propylitic alteration can cause iron- and aluminum hydroxide minerals to precipitate (*cf.,* Chapman et al., 1983; Boult et al., 1994). Even under natural conditions, water quality in a receiving stream above a mixing zone may have metals concentrations, alkalinity, pH and redox potential that are different from water below a mixing zone (Walton-Day, 1998).

2.4 Using the Watershed-Based Approach

Mine facilities potentially can impact aquatic ecosystems for considerable distances downstream by dispersing contaminants through receiving waters (Salomans, 1995). To anticipate the environmental impact that future mining operations may have and to determine the impact that past and present operations have had on aquatic ecosystems requires an understanding at the watershed level (Hughes, 1985). The utility of the watershed approach recently was recognized in an initiative to remediate abandoned mine lands led by the U.S. Geological Survey (Buxton et al., 1997) and in EPA's Hardrock Mining Framework (EPA, 1997a).

Water quality may vary within a watershed in response to differences in factors such as surficial geology, hydrogeology, infiltration-runoff relationships, seasonal variation, vegetation, land use, and anthropogenic disturbance. As a result, water quality in the downstream portion of a watershed is a mix of the components contributed from each upstream tributary. The watershed-based approach seeks to identify how changes occurring in one or several upstream tributaries impact downstream water quality. It is important to note that the term "watershed" does not necessarily refer to an enormous expanse beyond the reach of the operation. In general, the "watershed" of concern is the upstream portion of a drainage basin that contributes surface and shallow ground water flows to the project area and the downstream portion(s) whose water quality or quantity may be affected by mining-related activities. Under the generally accepted clarification system established by the U.S. Geological Survey, cataloging units appear to be the most appropriate size of "watershed" that may need to be evaluated for the majority of mining projects (see USGS Information Sheet Hydrologic Units, February 1999).

2.4.1 Determining Pre-Mining Background Water Quality

Prior to developing a program to characterize baseline conditions, it is important to recognize the physical variables that may influence water quality in potentially affected watersheds. Among the most important of these are the presence of mineralized exposures, the history and nature of existing disturbances that have caused impacts to water quality, and changes in watershed hydrology. "Natural background" is a term used to describe the water quality of a watershed that has not been disturbed by the actions of man (U.S. EPA, 1997b). In contrast, "anthropogenic background" is a term used to describe the water quality existing in all or a portion of a watershed that has been disturbed by human actions. The term "baseline" is used to describe the water quality measured at a given point prior to future disturbance and from which departures can be measured. Baseline values may include components of both natural and anthropogenic background.

2.4.1.1 Natural Background in Mineralized Areas

Natural background levels of metals can be high and pH can be low in streams draining watersheds with exposed mineralized rock (Runnells et al., 1992, Bowers and Nicholson, 1996; Mast et al., 1998; Runnells et al., 1998). These characteristics generally are attributed to the weathering and erosion of metal-bearing ores at the earth's surface (Runnells et al., 1992; Bowers and Nicholson, 1996). In some cases, weathering locally produces streams that are discolored with precipitating metal phases such as ferric hydroxide and zinc carbonate (Runnells et al., 1992). Runnells et al. (1992) compared metals values in stream waters draining areas with exposed metallic mineral deposits to worldwide averages determined for streams draining nonmineralized areas. They found that streams in mineralized areas can have natural pH values of less than 3 and metals values that are 3 to 4 orders of magnitude higher than streams draining nonmineralized areas.

Determining natural background values in a watershed requires knowledge of the geological relationships throughout the watershed, including the distribution, intensity and character of mineralization and alteration, water quality as it relates to natural variations in stream flow, precipitation-runoff relationships, downstream changes in water quality, interactions between surface and ground waters, and the forms in which metals occur in surface and ground waters. For example, variations in the distributions and abundances of metallic minerals will influence the concentrations of metals in surface waters. This is especially true of partially oxidized hydrothermal deposits in which natural weathering processes have converted primary sulfide minerals to variably soluble secondary oxide, hydroxide, or carbonate minerals. Moreover, watersheds in which mineralization occurs in a structurally complex geologic setting may have tributary streams with distinctive water quality characteristics that may be due to the exposure of different rock types in different portions of the watershed. Metals are transported in streams either as dissolved constituents or as suspended particles. The predominance of one form or the other partly reflects the solubility and erodibility of the metal-bearing minerals and the surface water chemistry (e.g., redox state, pH, speciation, adsorptive properties, and degree of saturation). Consequently, changes in stream discharge may have different effects on the concentrations of dissolved and suspended constituents. Typically, increased flow dilutes the concentrations of dissolved metals but increases the concentrations of suspended metals by entraining metal-bearing particles.

The recently documented Red Dog Mine area, located in northwestern Alaska, provides an example of surface waters with naturally high concentrations of metals. The main ore deposit, located in the Red Dog Creek watershed, is a massive lead and zinc sulfide orebody exposed in the upper portions of the Middle Fork of Red Dog Creek sub-basin. Studies conducted prior to mining found that a large portion of the watershed comprising the North Fork tributary was unaffected by the mineral deposit. However, these studies also found that water quality was degraded in the portion of the watershed downstream of the ore deposit as a result of weathering and erosion of the exposed mineralized rock. Seasonal effects on water quality were apparent. Studies by Dames & Moore (1983) showed that dilution decreased the natural concentrations of cadmium and zinc, which were present primarily as dissolved constituents, as flow increased from snowmelt and precipitation runoff. In contrast, the concentrations of aluminum and lead, which were present primarily as particulates, increased with increasing stream flow because metal-bearing particles were mobilized and carried in suspension by high flows. A clear understanding of the natural background conditions at the proposed mine site proved critical in the preparation of the EIS and NPDES permit for the Red Dog project.

The Red Dog site provides an example of extremely elevated natural background metals concentrations. In most locations, the effects of mineralization on natural background are expected to be much more subtle. Nevertheless, even small departures are important to recognize for the EIS and NPDES permitting processes.

2.4.1.2 Effects of Historic Mining and Other Anthropogenic Disturbances

In many mining areas, historic mining disturbances greatly complicate efforts to determine background geochemical values (Church et al., 1998; Mast et al., 1998). Historic mining activities or other anthropogenic disturbances can alter natural background constituent concentrations in a watershed by disturbing soils and slopes, altering runoff and stream characteristics, and creating mine pits, adits, waste rock dumps, tailings piles, spent leach pads, and other facilities that are sources of metals and other pollutants. These activities lead to increased sediment loads (e.g., by removing vegetation); seeps, runoff, and surface discharges (e.g., from an adit) with elevated levels of acidity and/or metals; and downstream transport and deposition of leachable materials (e.g., tailings solids).

In watersheds with numerous historic facilities, it may be difficult to find surface or ground water sites that have not been affected. A program designed to acquire samples from undisturbed sites may provide data that apply only to the local area or sub-basin from which the samples were collected and not to the entire watershed (Mast et al., 1998). In fact, historic mining disturbances may be so extensive in some areas that it is nearly impossible to fully characterize background values. Runnells et al. (1998) review methods that can be used to determine background at extensively disturbed sites. The most desirable of these is to use historical water quality data. Unfortunately, such data are rarely available or sufficiently complete that they provide an accurate assessment of pre-mining values. Consequently, three indirect methods have been developed to provide some measure of understanding of natural background conditions. One method extrapolates data from an analog site in a nearby undisturbed watershed (Hughes, 1985; Runnells et al., 1992; Bowers and Nicholson, 1996). Such sites must have geological and hydrological characteristics that are similar to those of the watershed of interest. Although analog sites can provide useful data, it is usually difficult to find an exact hydrologic and hydrogeological match (Runnells et al., 1998). A second method uses equilibrium geochemical models to predict the maximum constituent concentrations that can occur in water that is in equilibrium with rock and metallic ore minerals (Runnells et al., 1992; Nordstrom et al., 1996). Geochemical models require that users establish boundary conditions and make other assumptions (e.g., regarding pH, redox state, etc.) that cannot be easily tested or verified (Runnells et al., 1998). A third method uses a statistical approach to identify the natural background component in water from disturbed areas (Runnells et al., 1998). For example, probability graphs (Stanley, 1987) have been used to identify natural background values in anthropogenically impacted ground waters at the Bingham Canyon Mine in Utah (Runnells et al., 1998). Although statistical methods are capable of identifying multiple concentration populations, the process can become very complicated for areas where surface waters are impacted by numerous mining features. Some of these challenges are described by Moore and Luoma (1990) for the Clark Fork River drainage in Montana.

Church et al. (1998) describe an innovative, indirect approach for determining the extent to which historic mining activities may have affected baseline metals concentrations in a watershed. Their method is to collect and analyze sediment cores from stream deposits formed prior to the onset of mining activities and to compare these values to those obtained from recently formed deposits. In addition to metals and other constituents, sediments can be analyzed for signs of biotic life. This approach provides data only about stream sediment compositions and does not provide direct information on water quality.

In addition to mining, there can be a wide range of other existing disturbances in a watershed that affect water quality. Understanding the effects of all disturbances is essential to producing an adequate characterization of baseline conditions. Depending on the specific setting, this may necessitate collecting samples of runoff and seepage, pore waters, and solids. In some cases, water quality may be controlled by a set of interactive processes that need to be recognized in order to predict future water quality changes. For example, Paschke and Harrison (1995) describe an area of historic mining in Colorado in which metal transport in a stream is affected by ground water interaction and seasonal recharge of a natural wetland. Without such information, it may be impossible to predict and measure the incremental effects of new operations.

3.0 DESIGNING A WATER QUALITY MONITORING PROGRAM

Several factors must be considered when designing and establishing programs to sample and characterize baseline water quality conditions and to conduct long-term water quality monitoring. These factors include: (1) the location of the proposed or existing mine site and its support and waste disposal facilities in relation to the watershed, natural drainages, aquifers, and ground water flow; (2) the location of proposed or existing discharges and expected areas of infiltration; (3) the type of mineral to be mined and the mineralogy of associated waste rock and ore; (4) the type of process chemicals and hazardous materials that will be associated with the operation; (5) the designated uses of all surface waters in the watershed; and (6) the utilization of ground water in potentially impacted aquifers. A complete water quality data set will expedite establishing water-quality-based effluent limits and total maximum daily load allocations, which may be required by a National Pollutant Discharge Elimination System (NPDES) permit (EPA, 1996a).

In general, monitoring programs should achieve the following objectives:

- Define spatial differences in water quality parameters and constituents throughout the watershed.
- Define temporal differences in water quality that result from general changes in seasonal flow.
- Define differences in water quality that can occur during major climatic events, such as low probability storms or droughts.
- Define the effects of mining operations and associated accidental or permitted discharges on water quality.
- Define and monitor the effectiveness of applied Best Management Practices and mitigation measures used by the operation to protect water quality.

3.1 Sampling Locations

A surface water sampling program should define the number and locations of monitoring stations on a watershed basis. Monitoring stations should be established on all major tributaries in a watershed to quantitatively measure spatial changes in water quality that result from variations in geology, soils, mineralization, and land cover and from historic mining operations and other land use disturbances. Existing water quality should be well characterized in potential mixing zones and at downstream points of compliance. Consequently, monitoring stations should be established above and below a proposed or existing mine site and immediately below the confluences of all major tributaries. These locations will provide the types of data needed to define the contributions of different flows to downstream water quality and the water quality changes that occur as two flows mix together. To the greatest practical extent, monitoring stations should be located on straight, hydraulically stable stream reaches that are free of pools and large depositional areas. This will minimize the possibility that samples may vary over time due to streambank erosion, sediment aggradation, and channel (thalweg) migration.

Surface water monitoring stations also should be established above and below permitted discharge points and all hydrologic control structures, such as stream diversions, storm water detention/retention facilities, tailings disposal facilities, or process ponds. These stations are usually required for compliance monitoring. It is important to note that ambient and compliance monitoring programs should be established with common objectives, measured constituents, sampling frequency, laboratory procedures, and detection limits.

Ground water quality monitoring locations should be established in each potentially affected aquifer after considering the lithology and permeability of the aquifer; how, in what direction, and at what speed water flows through it; and whether exchanges occur with surface or other ground waters. Special considerations may be required for shallow aquifers that exhibit seasonal flow in response to spring snowmelt or winter freeze. In general, ground water monitoring requires that data be collected from wells that are located both up-gradient and down-gradient of potential contaminant sources. Existing water quality should be well established in areas that could be impacted by seepage from mine facilities. Numerous publications are available that describe the design and construction of monitoring wells and provide guidance on programs to monitor ground water (e.g., Nielson, 1991; U.S. EPA, 1993a; 1993b).

Lakes, estuaries, bays, and other tidal areas have unique chemical, physical, and biological characteristics that need to be identified prior to establishing sampling locations. For lakes, this likely will require applicants to complete limnological studies that characterize seasonal biological processes and identify physical phenomena such temperature stratification, evaporation, degree of mixing, sediment-water chemical exchange, chemical stratification (particularly dissolved oxygen), retention time, and ground water inflow (e.g., Thomann and Mueller, 1987; U.S. EPA, 1990). Additional factors such as tidal currents and temperature, salinity, and density gradients are important in estuaries, bays and other near-shore waters (e.g., Thomann and Mueller, 1987; U.S. EPA, 1992). These types of data are fundamental for establishing sites that will provide representative samples and they form a basis for interpreting the results of water quality analyses.

3.1.1 Mixing Zones

Proposed mixing zones, as defined in Section 2.2, should be characterized as part of the monitoring program. Importantly, mines may be located in areas with highly variable flow conditions that can cause the effects and extent of mixing to change significantly with time. In this regard, water quality immediately above a proposed outfall and mixing zone should be assessed at the time of highest risk. For many dissolved constituents, this typically occurs under conditions of low flow. In contrast, highest risk for constituents carried as suspended particles occurs under conditions of high flow. Developing an accurate understanding of high risk conditions requires that data be collected for as long as possible to adequately characterize seasonal and annual variations in runoff and stream flow that occur in all environments. Applicants requesting mixing zones in lakes, estuaries, bays, or other tidal areas may need to conduct limnological or oceanographic studies that characterize the physical and chemical nature of these environments.

Most States allow mixing zones as a matter of policy, but limit the spatial dimensions of permissible zones. Each is reviewed on a case-by-case basis. State regulations regarding the dimensions permitted for flowing waters (rivers and streams) may differ from those for still-water bodies (lakes, estuaries, coastal waters). Applicants should check with State personnel early in the NEPA and CWA processes to determine the types of data that will be required for a mixing zone application. More information on mixing zones is available in U.S. EPA (1991).

3.2 Sampling Considerations

The data that are used to assess the quality of surface and ground waters form the foundation upon which all interpretations of potential impacts rest. Consequently, it is vital that these data accurately portray water quality. For ambient waters, it may be necessary to use special sample collection and analysis techniques to measure very low concentrations of trace constituents.

3.2.1 Sampling Methods

A variety of techniques can be used to collect samples of flowing or still surface waters and ground water from the vadose and saturated zones. Depending on their intended use, samples may be taken as grab samples, depth integrated samples, composite samples, or continuous samples. Descriptions of sampling techniques and evaluations of the utility of each are not presented herein. Instead, the reader should consult one of the many sources dedicated to these topics such as Hamilton (1978), Canter (1985), Nielson (1991), U.S. EPA (1990; 1992; 1993a; 1993b), or U.S. Geological Survey (1998).

Many EPA analytical methods require that samples be filtered in the field through a 0.45 µm filter. Depending on the constituents that will be analyzed, samples are then treated to prevent precipitation of metal compounds, volatilization of organic constituents, or the production of hydrogen cyanide. These methods are outlined in U.S. EPA (1983; 1986) and briefly described in Appendix C, *Characterization of Ore, Waste Rock, and Tailings*.

Importantly, the quality of trace metal data, especially for metals concentrations below 1 part per billion, can be compromised by contamination that occurs during sample collection, preparation, storage, and analysis. EPA has developed Method 1669 specifically for collecting samples of ambient waters that will be analyzed for trace metals (U.S. EPA, 1996i). The method outlines procedures for collecting, filtering, and preserving samples and field blanks that will be analyzed using low-detection-limit techniques (see Appendix C, *Characterization of Ore, Waste Rock, and Tailings*).

3.2.2 Selecting Parameters

The specific water quality parameters that should be measured by a given operation depend on the site geology, soils, climate, and vegetation; the mineralogy of the mined ore and waste rock materials; process methods and chemicals used in the operation; and the designated uses of and the water quality criteria that apply to the receiving waters. These factors must also be considered when selecting sampling protocols and laboratory analysis procedures. The suite of metals analyzed should be based on knowledge gained from baseline sampling and site geologic studies, including the mineralogy of the ore and waste rock. Table B-2 lists constituents typically measured at metal mining operations.

The adsorptive behavior of metals in water varies as a function of pH and redox potential, and soils have different cation and anion exchange capacities. Due to changes in soil characteristics across a watershed, metals attenuation by soils and sediments will also vary. For these reasons, a mining operation may need to analyze samples for both total recoverable and dissolved metals. These data will help to delineate the chemical behavior of specific metals in the environment and they can be used to define spatial variations in metal loads within the watershed. These data are required to adequately assess impacts to receiving waters that could be associated with an accidental discharge of pollutants.

Table B-2. Water Quality Parameters Typically Measured at Proposed Metal Mining Sites

TCLP Metals		Other Metals	
Arsenic Barium Cadmium Chromium	Lead Mercury Selenium Silver	Aluminum Antimony Beryllium Cobalt Copper	Iron Manganese Molybdenum Nickel Thallium Zinc
Major Cations		**Major Anions**	
Boron Calcium Magnesium	Potassium Sodium	Ammonia Nitrogen Bicarbonate Carbonate Chloride Fluoride	Hydroxide Nitrite Nitrogen Nitrate Nitrogen Orthophosphate Sulfate
Other Constituents		**Other Parameters**	
Acidity Dissolved Oxygen Total Alkalinity	Free Cyanide Total Cyanide WAD Cyanide	Conductivity Eh pH Temperature SAR	Total Dissolved Solids Total Hardness Total Suspended Solids Turbidity

3.3 Sampling Schedule and Frequency

Sampling of all monitoring stations should occur at a frequency that permits accurate definition of the changes to water quality that occur seasonally and in response to short-lived changes in flow. Several years of sampling data typically are required to accurately define monthly, seasonal, and annual variations. In general, a sampling schedule should be designed to ensure that water quality data are collected from the range of flows that occur. This will provide a representative set of data that can be used to support NEPA and CWA requirements. Typically programs will need to utilize a combination of periodic and opportunistic sampling. Periodic samples are collected on a regular schedule, for example, monthly. Opportunistic samples, which should be collected throughout the year, are used to define water quality that occurs during extremes in the seasonal hydrograph or during short-lived events. For example, opportunistic sampling should be conducted during high runoff events to determine those parameters that are diluted by high flow (typically dissolved constituents) and those that occur at increased concentrations (typically suspended constituents). Opportunistic sampling also can help to define differences in water quality that occur between high and low stream flow conditions and to define water quality on ephemeral and intermittent streams. During high runoff events, opportunistic sampling can be used to establish a baseline from which to evaluate the effectiveness of water control structures and BMPs designed to minimize impacts from erosion and sedimentation.

For some locations, applicants may find it useful to link sampling schedules to stream flow as defined by seasonal hydrographs. This approach could prove especially beneficial in watersheds that host a variety of climatic zones due to topographic factors or proximity to coastal waters and in watersheds with severe climates. For example, orographic effects, which cause precipitation to increase with elevation in a watershed, are especially important to consider in coastal and mountainous areas, such as southeast Alaska. Alternatively, mines that are located in mountainous terrain or in northern climates may experience winter periods with extremely low stream flows or freeze-over, followed by periods with excessive runoff during the spring thaw. Mines located in arid or semi-arid areas may experience summer periods with low flow and short periods of intense rainfall that locally produce large discharges. These effects can impact water quality and contaminant dispersal as described in Section 2.3.1.

3.4 Assessing the Health and Diversity of Biota

In addition to characterizing the chemical and physical quality of surface and ground waters, applicants will need to provide an analysis of the health and diversity of biota in receiving waters. These analyses are described in more detail in Appendix G, *Aquatic Resources.* For proposed mining operations, existing streams may be severely impacted by historic activities. Hughes (1985) presents a methodology for determining the health and quality of aquatic life in streams in which this has occurred. His technique relies on identifying control streams in nearby unimpacted watersheds that have similar watershed characteristics to the impacted stream. Control streams are used as analogs from which the potential biotic and habitat conditions of the impacted stream are estimated.

4.0 DATA ANALYSIS

Preparation of Environmental Impact Statements and NPDES permits will require an analysis of water quality and potential impacts that could result from the proposed project. This section describes the types of data analyses that may be required under NEPA and the CWA.

4.1 Contributions of Tributaries and Ground Water to Surface Flow

Applicants may be required to conduct an analysis that constrains the contributions of tributary drainages and ground waters to surface flow. The objective of this type of analysis is to identify whether changes in water quality are related to inflows, particularly in sensitive areas such as proposed mixing zones. Ground water contributions to gaining systems may be especially difficult to assess since the influent sources may not be amenable to direct sampling (i.e., ground water seeps into the stream beneath flowing water). The analysis can be further complicated in historic mining areas located in mountainous terrain where contaminated seepage flows through shallow soils in response to seasonal climatic changes or short-lived storm events. In cases such as these, the use of dye or salt tracers may provide a clearer understanding of ground water contributions to stream discharge (e.g., Kimball, 1997). Accurate discharge measurements are important for computing metal loadings (Section 4.3).

4.2 Translators for Dissolved to Total Recoverable Constituent Concentrations

Applicants and regulatory personnel may encounter the need to express water quality data in both dissolved and total recoverable (dissolved plus particulate) forms for NPDES permits and Total Maximum Daily Load (TMDL) allocations. NPDES regulations typically require permits to list metals limits in total recoverable form (there are exceptions, so applicants should check with State and Federal agency personnel). On the other hand, EPA may be required to perform TMDL calculations in which metals are expressed in dissolved form to ascertain that water quality standards are being met. Accepted methods for translating between dissolved and total recoverable forms are described in U.S. EPA (1996j).

4.3 Computing Metal Loadings

Constituent concentrations, which are subject to dilution in downstream surface water flows, provide limited information about the behavior of metals in streams. EPA (1996a) suggests that this shortcoming can be overcome by considering metals loads, in which the instantaneous load equals concentration multiplied by discharge:

$$L = C * Q$$

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

$$L_D = L_U + L_T$$

(EPA, 1996a). 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 metals loads.

4.4 Other Characterization and Data Analysis Issues

This section briefly describes issues that applicants should be aware of when preparing summaries of water quality data and when analyzing and interpreting historical water quality.

4.4.1 Below Detection Limit Values

Water quality data sets characteristically contain analyses in which some constituent concentrations are reported at values below the method detection limit (MDL). Non-detected values complicate statistical presentations of summary data and can result in statistically unsupported biases being incorporated into summary data presentations. The latter occurs whenever mean and standard deviation values are computed using assumed values (e.g., zero or one-half MDL) for analyses reported as below the detection limit. Further statistical challenges are presented by water quality data sets that include multiple detection limit values.

Computational methods have been developed to deal with data sets containing below detection limit (BDL) values (Gilliom and Helsel, 1986; Helsel and Cohn, 1988; Helsel, 1990; Travis and Land, 1990). In general, these approaches assume that constituent values have a normal or log-normal distribution. Based on this assumption, portions of the distribution reported with BDL values can be reconstructed using either regression order statistics (Gilliom and Helsel, 1986), probability plotting methods (Helsel and Cohn, 1988; Travis and Land, 1990), or maximum likelihood estimations (Cohen, 1959). Extrapolated values are then used to compute mean and standard deviation values for the constituent populations (Helsel and Cohn, 1988; Helsel, 1990). Appendix B of Helsel and Cohn (1988) describes a probability plotting method to extrapolate data sets that include multiple detection limits. The method has gained widespread acceptance for analyzing data with BDL values (e.g., Runnells et al., 1998).

The success with which a substitution method accurately determines the true statistical parameters of a population depends on how closely the data fit an assumed distribution (Helsel, 1990). Bias and imprecision can be introduced whenever data depart from the assumed distribution or when data are transformed (e.g., when means and standard deviations are computed for log-transformed data and then converted back to original units) (Helsel, 1990). Helsel and Cohn (1988) and Helsel (1990) compared root mean square errors of the statistical parameters computed using six methods, including simple substitution for BDL values (e.g., one-half MDL). They concluded that a robust probability plotting method, in which a distribution fit to data above the reporting limit is used to extrapolate values below the MDL, provides the best assessment of population mean and standard deviation. Helsel and coworkers also concluded that percentile values are best estimated using maximum likelihood estimation procedures.

Software to compute summary statistical parameters for data that include BDL values using Helsel’s method is available on the worldwide web at http://www.diac.com/~dhelsel/.

Simple substitution for non-detected values continues to be widely used and EPA accepts summary data that are prepared in this manner. Most commonly, values of one-half the detection limit are used for non-detected values. However, in cases where numerous parameters are reported as below the detection limit, or where a constituent routinely is not detected, EPA prefers that applicants use techniques that provide the lowest available detection limits.

4.4.2 Using Existing and Historical Data Sets

Water quality data may exist in published and unpublished sources for some mining sites. In many cases, these data can provide valuable insight into water quality prior to, and subsequent to historical land disturbance activities, including historical mining operations. The Agency uses the term "secondary data" to describe data obtained from other sources. Before using such data, the data user needs to determine the reliability or quality of the data. It is often difficult to determine the quality of secondary data because original laboratory reports are not included in published documents and the analyses were conducted prior to the acceptance of standard laboratory protocols (see Appendix C, *Characterization of Ore, Waste Rock, and Tailings*). Interpretations of receiving water quality that are based entirely or partly on existing data should be made cautiously when one or more of the following parameters is unknown: exact sample location, sample collection method, surface or ground water flow, sample preservation, sample handling (chain-of-custody), analytical method, analytical detection limit, and lab accuracy and precision.

It is important for applicants to recognize that secondary data may not have been collected pursuant to a Quality Assurance Project Plan (QAPP), which often leads to problems with its use. In general, applicants should assume that the use of historical or existing data sets, in the absence of a QAPP or other supporting QA/QC documentation, is unlikely to be adequate to support permitting and decision-making on a mining proposal. More detail on quality assurance issues is provided in Section 5.0 of this appendix.

4.5 Geochemical Modeling

The extent to which receiving waters disperse contaminants through the environment depends partly on water chemistry and soil character (Hutchinson and Ellison, 1991). Under equilibrium conditions, surface and ground waters will acquire constituent concentrations that depend on local physical and chemical conditions, the rate at which secondary phases precipitate from solution, and the tendency for dissolved constituents to sorb onto particle surfaces (Schnoor, 1996). Figure B-1 shows a conceptual physicochemical model of metal transport in a surface water system illustrating the complex interactions affecting concentration. In general, waters with comparatively low pH can retain higher concentrations of metals in solution than neutral waters (Salomons, 1995). Consequently, downstream changes in pH, redox potential, or other chemical parameters (e.g., in mixing zones) can lead to dissolution or precipitation of metal-bearing phases or their adsorption or desorption from bottom sediments or from colloidal precipitates (Oscarson, 1980; Moore et al., 1988; Langmuir, 1997). Dissolved metals concentrations also may change through adsorption onto or desorption from the surfaces of soil particles, especially clays (Hutchinson and Ellison, 1991; Salomons, 1995). The adsorptive behavior of metals in water commonly varies nonlinearly as a function of pH due to pH control of precipitation and complexation reactions (Salomons, 1995). Soils have different cation and anion exchange capacities (which measure of the amount of adsorption that can occur) that are a function of the amount and type of clay and organic content (Hutchinson and Ellison, 1991). Due to changes in soil character across a watershed, metals attenuation by soils also is likely to vary.

Geochemical models can be used to determine the stability of phases in aqueous solutions under equilibrium conditions, identify whether metals are likely to be adsorbed onto or desorbed from co-existing solid phases, and calculate the equilibrium composition of natural waters. These programs are particularly useful for understanding how changes in pH can affect metals contents, determining whether metals are likely to precipitate, be adsorbed, or remain as dissolved constituents, and predicting water quality in mixing zones. Brief descriptions of two of the more commonly used models are provided below.

MINTEQA2/PRODEFA2

MINTEQA2 (Allison et al., 1991) is an equilibrium geochemical speciation model for dilute aqueous systems. It can be used to compute the mass distributions between dissolved, adsorbed, and solid phases under a variety of conditions. The software includes an interactive program (PRODEFA2) to create input files. MINTEQA2 can be obtained from EPA's Center for Exposure Assessment Modeling, ftp://ftp.epa.gov/epa_ceam/wwwhtml/minteq.htm.

PHREEQC

PHREEQC (Parkhurst and Appelo, 1999) is designed to perform a variety of aqueous geochemical calculations based on an ion-association aqueous model. The software can be used for calculations of speciation, saturation index, reaction path, and advective transport and to conduct inverse modeling. PHREEQC is available from the EPA Robert S Kerr Environmental Research Lab, Center for Subsurface Modeling Support..

4.6 Fate and Transport Modeling

Numerical chemical fate and transport models are useful for analyzing spatial changes in water quality parameters in receiving waters. In general, fate and transport models employ finite-difference or finite-element techniques to route hydrographs and pollutants through surface water or ground water systems. These simulations couple equilibrium chemical speciation models with physical transport equations to calculate downstream or down-gradient changes in constituent concentrations. These models are especially useful for evaluating the fate and transport of pollutants from point and non-point sources through a watershed. For mining operations, such studies can be used to evaluate and model potential operational releases in conjunction with a NPDES permit application. Brief descriptions of some of the more commonly used models are provided below.

Enhanced Stream Water Quality Model with Uncertainty Analysis (QUAL2EU)

QUAL2EU is a chemical fate and transport model for conventional pollutants in branching streams and well-mixed lakes. The program, which is intended to be used as a water quality planning tool, can be operated in either the steady state or dynamic mode. The software is available on the world wide web through EPA's Center for Exposure Assessment Modeling (ftp://ftp.epa.gov/epa_ceam/wwwhtml/softwdos.htm).

One-dimensional Transport with Inflow and Storage (OTIS)

OTIS is an equilibrium transport model developed by the U.S. Geological Survey that has been applied to small streams in Colorado that have been contaminated by mine drainage (Runkel et al., 1996). The program allows users to subtract the effects of one or more input sources from downstream water quality.

Hydrologic Simulation Program FORTRAN (HSPF)

HSPF simulates hydrologic and water quality processes on pervious and impervious land surfaces, in the soil profile, and in streams and well-mixed impoundments. The operational connection between the land surface and the instream simulation modules is accomplished through a network block of elements. Time series of runoff, sediment, and pollutant loadings generated on the land surface are passed to the receiving stream for subsequent transport and transformation simulation. Water quality and quantity can be evaluated at different segments or outflow points within a watershed. Given appropriate input data and constraints, the model can account for degradation (i.e., decay) or retardation of pollutants. HSPF is available on the world wide web through EPA's Center for Exposure Assessment Modeling, ftp://ftp.epa.gov/epa_ceam/wwwhtml/softwdos.htm.

Finite Element Model Water (FEMWATER)/Finite Element Model Waste (FEMWASTE)

FEMWATER is a numerical ground water model that uses a finite-element solution to solve the governing equations for ground water flow. It can be used to create two-dimensional areal or vertical models as well as three-dimensional models in both saturated and unsaturated media. Because of its numerical approach, it can be used to model transient flow or steady-state flow under anisotropic and layered aquifer conditions. FEMWASTE is a two-dimensional transient model for the transport of dissolved constituents through porous media. Modeled transport mechanisms include convection, hydrodynamic dispersion, chemical sorption, and first-order decay. The waste transport model is compatible with the water flow model (FEMWATER) for predicting convective Darcy velocities in partially saturated porous media. Outputs from ground water fate and transport modeling can be used to develop pollutant input parameters for point or non-point sources to surface water fate and transport models such as QUAL2EU or HSPF. FEMWATER is available on the world wide web through EPA's Center for Exposure Assessment Modeling (ftp://ftp.epa.gov/epa_ceam/wwwhtml/softwdos.htm).

4.7 Other Analysis Techniques

Plots of water quality data can reveal potentially significant changes in constituent concentrations and mass loading that occur downstream through a watershed (spatial trend) or that occur with seasonal changes in discharge at a given point within a watershed (temporal trend). Mass loading profiles (constituent load vs. distance downstream) are particularly useful for identifying reaches of a stream in which metals are being removed by chemical reaction or reaches affected by contaminant inflow (for example, ground water impact in a gaining stream) (Walton-Day, 1998). Mass loading profiles are being used by scientists at the U.S. Geological

Survey to identify and rank contaminant sources and to guide efforts to remediate abandoned mine lands in the Arkansas drainage in Colorado (Kimball, 1997). Plots of constituent concentration vs. discharge or total suspended solids (TSS) for a given sampling point can distinguish elements that are transported as dissolved constituents from those present primarily as suspended particles.

Although not a widely used technology, water quality data are amenable to analysis using a geographic information system (GIS). GIS technology is being incorporated into the U.S. Geological Survey's National Water Quality Assessment Program where it is used to manage large water quality databases and produce graphical data presentations (Qi, 1995; Qi and Sieverling, 1997). At the watershed scale, a GIS can facilitate analysis of spatial variations in water quality and the relationships of water quality to rock, soil, and mine waste compositions.

5.0 GUIDANCE FOR PREPARATION OF A QUALITY ASSURANCE PROJECT PLAN (QAPP)

This section describes the need for and preparation of a Quality Assurance Project Plan (QAPP) for monitoring receiving waters. The section provides an overview of the planning process that is used to develop a QAPP and describes the major components of a QAPP. EPA QA/G-5 Guidance on Quality Assurance Project Plans (EPA/600/R-98/018, February 1998) provides guidance on developing Quality Assurance Project Plans (QAPPs) that will meet EPA expectations and requirements. This document provides a linkage between the Data Quality Objective (DQO) process and the QAPP. It contains tips, advice, and case studies to help users develop improved QAPPs.

5.1 Overview of the Process for Developing a Monitoring Plan

The Agency QA Division recommends the use of a systematic planning process when developing a monitoring program. One such systematic process is the Data Quality Objective Process (U.S. EPA, 1994e). MacDonald et al. (1991) and Dissmeyer (1994) also provide examples of systematic planning approaches that may be applicable to mining projects. Figure B-2, taken from Dissmeyer (1994), is an example of the process used to develop a program to monitor receiving water quality. The two steps most critical to developing a sound plan are to identify specific monitoring goals and objectives and to determine whether the plan, when implemented, meets those objectives. For example, one objective of a surface water monitoring plan might be to define temporal differences in water quality that result from general changes in seasonal flow (see Section 3.0).

Monitoring plans will vary depending on the particular monitoring situation. In general, they include goals and objectives; sampling locations and schedules; a list of water quality parameters that will be monitored and their required detection limits; a brief description of stream morphology at surface water sampling points; sample collection, handling, and analysis procedures; sample transport and chain-of-custody procedures; quality assurance/quality control protocols; and data analysis and reporting procedures.

The time period from mine planning and permitting to reclamation and post-operational monitoring typically is measured in decades. During this time, environmental conditions, mine operations, monitoring requirements, and sampling and analysis protocols are likely to change. Therefore, establishing comprehensive quality assurance and quality control (QA/QC) protocols will help to minimize the impacts of these changes by ensuring that a consistent and accurate approach is used to collect and analyze receiving water data. Implementing these protocols through a written plan will help to ensure that the collected data can be used to evaluate both the short- and long-term quality of receiving waters.

Although there are numerous approaches for ensuring long-term data quality assurance and control, the most common (and often required) approach is the development of a either a Sampling and Analysis (SAP) plan, Quality Assurance Project Plan (QAPP), or both. The SAP and QAPP can be combined into one document, the purpose of which is to establish sound and defensible sampling and analysis protocols that can be used to generate unbiased data with known and traceable accuracy and precision. For the purposes of this appendix, the combined QA/QC document is referred to as the QAPP. The QAPP should be prepared in a manner that promotes acceptance and use by field and laboratory personnel. It should serve as a resource tool and reference manual for all sampling and analytical procedures. The QAPP should be modified when changes occur that significantly alter the applicability or effectiveness of the document.

5.2 Components of a QAPP

The primary elements of an acceptable QAPP include comprehensive discussions regarding Project Management, Measurement and Data Acquisition, Assessment and Oversight, and Data Validation and Usability. Each of these are described in the ensuing subsections. A complete explanation of and prescribed format for all required elements is presented in U.S. EPA (1998c; 1998d). Both documents are available on the world wide web (http://www.epa.gov/r10earth/offices/oea/qaindex.htm). Although monitoring programs initially are developed to support decision-making and permitting of proposed mining projects, the formal monitoring programs that are documented in a QAPP can be later used or amended to support other objectives during various stages of a mine life cycle, including operation, closure and post-closure. For example, NPDES permits generally include specific requirements for the preparation of QAPPs to guide collection of water quality data during mine operation. Typically NPDES permits specify that QAPPs adhere to the two guidance documents cited above.

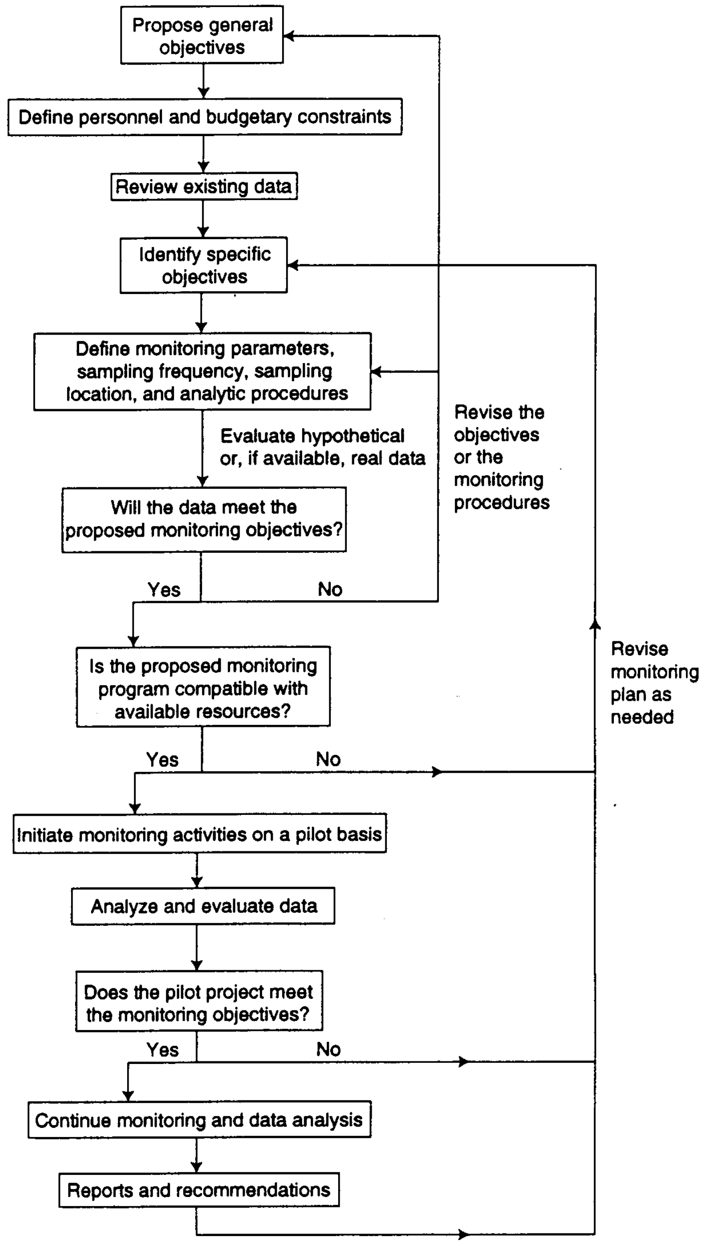

Figure B-2. Example flow-chart for developing a monitoring project (from Dissmeyer, 1994).

5.2.1 Project Management

The project management portion of the QAPP includes an introduction and sections that describe the project schedule, training and certification, expected data quality, and data quality objectives.

Introduction

The introduction should be informative and provide the foundation for solid QA/QC procedures. The section should address plan approval, modification, distribution, and project organization. The introduction should establish procedures for plan modification and identify by name the individuals responsible for project management, overall project quality assurance, field work, and laboratory quality assurance. This should be followed by a detailed presentation of project background information and a brief problem statement. Maps and/or figures should be provided where appropriate.

Project Schedule

An overall project schedule should be developed that highlights key project dates, if applicable. The schedule should be developed in an easily readable format and all project-associated staff should be aware of its presence, content, and key dates.

Training and Certification

The QAPP should address staff sampling and safety training and should include a listing of certifications held by the laboratory. If a commercial laboratory is contracted, it should hold the relevant certifications for the planned analyses from the state where the project is located.

Expected Data Quality

Data quality refers to the level of uncertainty associated with a particular data value (i.e., how sure are you that the value of the data point is what the analysis has determined it to be?). Data quality is affected by all elements of the sampling event, from the sampling design through the laboratory analysis and reporting. Early in the QAPP development process, the acceptable and appropriate levels of uncertainty must be determined through the use of a systematic planning process. Such decisions will depend on the contaminant of concern, the effect it has on human and environmental health, and the levels at which concerns arise.

Decisions regarding acceptable levels of uncertainty should consider the following questions:

- What chemical(s) are expected to be found at the site?
- Approximately what level of contamination is expected (high = >10 ppm; medium = 10 ppm to 10 ppb; low = <10 ppb)?

- What is the action level or level of concern for the contaminant for human health? For the environment?
- Based on the answers to questions 1 through 3, which analytical methods are appropriate to achieve needed detection limits?
- How was the sampling design developed (e.g., area vs. number of samples; frequency of sampling; random or biased sampling)?
- How many of the samples will be field quality control samples (i.e., field duplicates, field blanks, equipment blanks, trip blanks, field spikes or split samples)?
- How many samples will be laboratory quality control samples?

Data Quality Objectives and Data Quality Indicators

After a decision has been made regarding the expected data quality, the QAPP should address data quality objectives and measurement criteria. Data Quality Objectives (DQOs) are quantitative and qualitative objectives that define usable data for meeting the requirements of the project. Data Quality Indicators (DQIs) are specifications for the quality of data needed for the project, such as sample measurement precision, accuracy, representativeness, comparability, and completeness. DQOs and DQIs define the quality of the services required from the laboratory and are used in any quality assurance reviews of the field and laboratory data. Review of the quality control data against the DQOs and DQIs determines if the data are fully usable, considered estimates, or rejected as unusable.

Precision is the degree of mutual agreement between or among independent measurements of a similar property (standard deviation [SD] or relative percent difference [RPD]). This indicator relates to the analysis of duplicate laboratory or field samples.

Accuracy is the degree of agreement of a measurement with a known or true value. To determine accuracy, a laboratory or field calibration value is compared to the known or true concentration. The laboratory, by developing a database of instrument runs using performance samples, should be able provide information regarding this objective.

Completeness compares the data actually obtained to the amount that was expected to have been obtained. Due to a variety of circumstances, analyses may not be completed for all samples. The percentage of completed analyses required will depend on the sampling design and data use. Expectations of completeness should be higher when fewer samples are taken per event or site.

Representativeness expresses the degree to which data accurately and precisely represent a characteristic of an environmental condition or a population. It relates both to the area of interest and to the method of taking the individual sample. The idea of representativeness should be incorporated into discussions of sampling design.

Comparability expresses the confidence with which one data set can be compared to another. The use of standard, published methods allows straightforward comparisons of data collected during multiple sampling events.

Data quality indicators for field and laboratory measurements should be stated in measurement performance criteria. Field measurements should be made with calibrated instruments; laboratory measurements should be specified by individual method criteria or by laboratory control limits.

5.2.2 Measurement and Data Acquisition

The measurement and data acquisition section describes in detail how, where, and when data will be collected and analyzed and provides supporting quality control information related to sample handling; equipment calibration, testing, and repair; analytical methods and quality control requirements; and data management. This section is particularly applicable to all field personnel insofar as it establishes required procedures for sample collection and field measurements. Where possible, information should be presented in tables or other easily understandable formats and should clearly identify prescribed sample locations; maps are strongly encouraged. Tables should be created that list the sample site by assigned identifier (e.g., station 102), common name (e.g., Dry Creek below mill), intended purpose (e.g., assess effectiveness of treatment), and sample types (e.g., pH, flow, turbidity, etc.). The QAPP should provide the reason for including specific sample sites and, where necessary, detailed descriptions of the sample location. Sampling and measurement schedules should be included; tables are recommended in cases where multiple parameters are sampled on varied schedules.

Critical and Non-Critical Samples

In some instances, certain samples may be determined to be less critical than others (e.g., informational samples versus compliance samples). The collection of critical samples may be required at all times, while sampling for non-critical samples may be postponed or excluded based on weather or safety considerations. Criteria for such should be clearly identified.

Sample Collection

Field sampling and measurement procedures should be completely described at a level that would permit a new employee to read and implement these activities without jeopardizing the quality of data. The QAPP should specify methods for collecting different types of samples, using field equipment, and preparing, preserving, and handling samples. In addition, it should present information regarding approved sample containers, preservation methods, holding times, and analytical methods. Proper chain of custody procedures and an example of the form to be used should be provided. The citation and attachment of Standard Operating Procedures to the QA plan can reduce the amount of writing that must be done to properly document the details for a project. For guidance on the preparation of Standard Operating Procedures, refer to U.S. EPA (1995). Field staff should be thoroughly trained on all elements of field sampling and measurement and one or more trial events should be conducted prior to initiating unsupervised sampling.

Analytical Methods and Quality Control Requirements

The QAPP should specify laboratory analytical methods and quality control procedures. A preferred approach is to include a table that presents the analytical methods, method detection limits (MDLs), reporting limits or minimum levels, laboratory precision (in relative percent difference (RPD)) and accuracy (in % recovery), sample holding times, sample container type, sample preservation method, and completeness requirements. The table provides a reference for field teams and allows for easy review of the data deliverables package provided by the laboratory. EPA has established preferred analytical methods for surface water, ground water, soils, sediment, and other media (EPA, 1983; 1986; 1996b-i); other methods are described in APHA et al. (1992) and ASTM (1996) (see Appendix C, *Characterization of Ore, Waste Rock, and Tailings*). Method detection limits are specified in the individual method, while reporting limits or minimum levels are based either upon desired data accuracy and/or regulatory requirements (e.g., NPDES permit limits). Although precision and accuracy guidelines typically vary depending on the specific analysis and/or sample media, <10 to <30% RPD and 85 to 115 % recovery are commonly applied values for water samples.

In addition, the QAPP should specify sample preparation methods and sampling handling procedures as described in the laboratory's QA/QC manual or plan. The lab QA/QC plan or manual should be included with the QAPP as an appendix and pertinent information should be extracted and included in the text of the QAPP.

Field Quality Control

Quality control checks of field sampling procedures and laboratory analyses should be used to assess and document data quality, and to identify discrepancies in the measurement process. Field blanks, equipment decontamination blanks, field duplicates (or replicates), trip blanks, and standard reference samples can be used to assess sample representativeness, sample collection and handling procedures, field equipment decontamination procedures, and laboratory precision and accuracy. Field blank samples, which are used to evaluate whether contaminants have been introduced into the samples by the sampling process, are created by pouring deionized water through a field filter into a sampling container at the sampling point; the field blanks are analyzed for metals and other constituents. In some cases, trip blanks may be needed to evaluate whether shipping and handling procedures introduce contaminants into the samples, or if cross-contamination (e.g., migration of volatile organic compounds) has occurred between the collected samples. Duplicate samples, which are collected simultaneously with a standard sample from the same source under identical conditions and placed into separate sample containers, should be used to assess laboratory performance. One or more duplicate samples should be collected and analyzed for every 20 samples (5%) or once per sampling event, whichever is more frequent. The duplicates should be labeled in a way that does not reveal their status to the laboratory.

Laboratory Quality Control

Laboratories routinely monitor the precision and accuracy of their results through analysis of laboratory quality control samples (EPA Region 10 provides a document for laboratories entitled "Guidance on Preparation of Laboratory Quality Assurance Plans," available on the world wide web at http://www.epa.gov/r10earth/offices/oea/qaindex.htm). The QAPP should provide a reference to the specific QC protocols used by the labs that will conduct analyses. The typical frequency specified for laboratory QC samples (e.g., matrix spikes, matrix spike duplicates, method blanks, lab control samples) is one of each QC sample that is appropriate for the method per batch of samples. A batch of samples is defined as 20 or fewer samples that are received by a laboratory within a 14 day period for the specific project. If deemed necessary for the project, a higher frequency of QC samples can be designated.

Corrective Action

If nonconformance with any QAPP element is identified, corrective action should be taken to remedy, minimize, or eliminate the nonconformance. Sampling and measurement system failures include an inability to collect a sample, sample collection errors, field measurement errors, and laboratory errors. The QAPP should prescribe remedies for each of these possible system failures.

Calibration

Field equipment should be calibrated regularly and records should be kept in a field calibration log. The QAPP should include a list of all equipment requiring calibration (e.g., pH meters, DO meters, etc.) and appropriate calibration procedures.

Data Management

Data management requirements should be established for field and laboratory data. They should include acceptable field documentation procedures, laboratory data deliverables, data validation techniques and requirements, data entry, electronic data management, and records retention. The QAPP should present a list of the steps that will be taken to ensure that data are transferred accurately from collection to analysis to reporting. Discussions should focus on the measures that will be taken to review the data collection processes, including field notes or field data sheets; to obtain and review complete laboratory reports; and to review the data entry system, including its use in reports.

Chain-Of-Custody

Chain-of-custody records are used to document sample collection and shipment to laboratories for analysis. All sample shipments for analyses must be accompanied by a chain-of-custody record. Form(s) should be completed and sent with the samples for each laboratory and each shipment (i.e., each day).

5.2.3 Assessment and Oversight

The QAPP should adequately describe all monitoring program assessment and oversight. Oversight evaluates how well the specifications contained within the QAPP are being implemented and the types of information needed to continuously improve the monitoring program. It also verifies that the quality assurance guidelines for sampling and analysis are being met. The QAPP should identify the individual(s) responsible for ensuring that sampling and QA activities are being implemented as described in the QAPP. The primary elements of an acceptable assessment and oversight program include audits of field data and sample acquisition, laboratory audits, and audits of data management.

Audits of Field Data and Sample Acquisition

Data quality audits assess the effectiveness and documentation of the field and laboratory data collection processes. In particular, these audits evaluate whether the DQOs established for the project are being met. Additionally, they determine whether the QAPP is still applicable to the current project. The frequency of these audits, which may range from daily to annually, depends on the scope and complexity of the monitoring program. The audit should be performed by someone who is not associated with the day-to-day implementation of the monitoring plan.

Laboratory Audits

A review of the laboratory facility, its equipment, personnel, organization, and management, evaluates the reliability of the data produced by the laboratory. The laboratory, as a system, is verified against the documentation provided in their QA manual and standard operating procedures.

Data Management Audits

Data management reviews evaluate whether the standard procedures in the QAPP are being followed and if the integrity of the data is being maintained. Audits should be conducted at least every other year, but may be conducted more frequently if needed.

5.2.4 Data Validation and Usability

This section of the QAPP states the criteria for deciding whether a data element has met its quality specifications as described above. Data validation is the process by which data are compared with DQOs to determine which data points are accepted, rejected, or qualified. The data validation and usability determination evaluates sampling design, sample collection procedures, sample handling, analytical procedures, quality control, calibration, and data reduction and processing.

Validation and Verification Methods

Upon receipt from the laboratory, data should be compared with the specified DQOs and analytical methods. Corrective actions should be selected to prevent or reduce the likelihood of future nonconformances and, to the greatest extent practical, address the causes of nonconformance. Prescribed corrective actions should already exist in the QAPP and these should be implemented first. Future audits should ensure that similar errors do not recur.

Reconciliation with DQOs and DQIs

The QAPP should clearly identify the actions that will be taken to reconcile any deviations from the DQOs and DQIs. Resolution should be made by identifying the elements of the sampling and data collection process that are in question and addressing the situation that caused the qualification.

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APPENDIX C

CHARACTERIZATION OF ORE, WASTE ROCK, AND TAILINGS

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C-3. Minimum number of samples as a function of rock mass recommended by the BC AMD Task Force C-37

1.0 GOALS AND PURPOSE OF THE APPENDIX

EPA expects that applicants will conduct a sufficient number and variety of environmental tests on a representative suite of samples in order to support projections of wastewater and solid waste management practices and effluent quality. This appendix describes the methods used to characterize the solid wastes from mining activities and the rationale for their implementation. The materials in this appendix complement those in Appendix B, *Receiving Waters* and Appendix F, *Solid Waste Management.*

Determining the physical and chemical character of solid waste materials is a prerequisite to delineating the area that would be affected by waste disposal; recognizing the physical, chemical, and biological impacts of waste disposal; and developing appropriate mitigation measures. Environmental test samples should be collected as part of a comprehensive program designed to examine the range of conditions that occur or could occur. For areas in which mining has concluded or is on-going, tested materials should be produced by normal mine operations. For areas in which mining is proposed or production methods are expected to change, tested materials should include batch and pilot-plant waste products. Physical and chemical characterization studies should be conducted in a manner that provides conservative estimates of the potential environmental impacts.

An environmental sampling program should be related to the mine plan and should be designed to represent the different lithologic units that have been or will be encountered, excavated, processed, disposed of, or exposed (for example in pit walls). It should establish the chemical and physical variability of each geologic unit encountered at the mine site, including borrow materials. It can have the benefit of reducing or eliminating the potential future costs associated with mismanagement of disposed materials. For proposed or expanding mining activities, ore sample testing should be representative of the range of materials that will be mined and wastes that will be generated. Although simple in concept, developing and implementing a reliable environmental sampling program may be a complex endeavor.

This appendix presents the methods used to determine the physical and chemical characteristics of waste materials, describes the environmental tests used to assess contaminant mobility, outlines the conceptual models used to analyze contaminant fate and transport, and discusses the elements of quality assurance and quality control engendered in an environmental testing program.

2.0 ANALYSIS OF PHYSICAL CHARACTERISTICS

2.1 Extent of Analysis

The proposed mine plan should be used to determine the types and volumes of materials that will be excavated or otherwise disturbed and the management of those materials. This information, some of which can be presented in the form of maps and cross-sections, provides the basis for determining the types of characterization studies that will be needed. For example, if waste rock materials will be used in road construction, then the potential effects on water quality will need to be ascertained. If the gangue rock at the site consists of several lithologic types that will be mined in sequence, then the resulting waste rock dump could contain vertical or lateral changes in rock type that might impact water quality models and geotechnical stability. Because many material or waste dumps cover significant areas, characterization studies of substrate materials can determine whether lateral changes in physical properties are present that could impact dump stabilities and contaminant transport models. Although the physical and chemical characterization of solid materials can be an intricate process, a well-planned and executed program can provide the benefits of improved project design and environmental impact mitigation.

2.2 Physical Parameters

The physical characteristics of waste materials govern their hydrologic properties and physical stability. Important parameters that affect porosity and permeability include particle size, particle-size distribution, particle-size grading, stratification, and mineral composition. Important parameters that affect stability include stratification, mineral composition, cohesion, compaction, moisture retention, shrink-swell potential, Atterberg limits, and bulk density. For existing waste rock dumps and tailings piles, physical characteristics testing should determine whether the disposed material contains vertical or lateral changes in physical properties sufficient to affect the flow of leachate or the stability of the pile. Such variations could arise from changes in mining, processing, and disposal methods; variations in the geology of the ore or gangue materials as mining progressed; or the effects of subaerial weathering, alteration, and secondary mineral growth after the materials were emplaced.

Particle-size characteristics (median diameter, sorting, size distribution) are determined through mechanical analyses (sieve analysis). Those of fine-gained materials (smaller than 50 microns) are determined using methods based on particle settling velocities (e.g., pipette analysis) or optical techniques (e.g., Coulter counters). The American Society for Testing and Materials provides methods for determining particle-size characteristics (ASTM, 1996); additional methodologies can be found in Sobek et al. (1978).

Particle-size grading (i.e., changes in particle size normal to a bedding surface) typifies many waste rock dumps constructed by end-dumping. Grain-dispersive forces that occur as materials avalanche down the working face of a waste rock dump can create deposits that become coarser upward and outward (e.g., Blatt et al., 1980). Changes in particle-size grading potentially can form preferred pathways for the flow of water through waste rock piles.

Stratification can be created within waste rock and spent ore dumps and tailings piles by construction practices. In addition to affecting fluid flow, bedding surfaces can serve as planes of weakness along which slope failure can occur. The presence of stratification can be noted from visual observation of existing waste materials or drill cores obtained from these materials.

Methods to measure *cohesion, compaction, moisture retention, shrink-swell potential, Atterberg limits, and bulk density* have been developed by the American Society for Testing and Materials (ASTM, 1996). These parameters are particularly important for assessing the stability of waste rock and spent ore dumps, tailings piles, and pit benches. For existing waste materials, vertical or lateral changes in the amount and type of clay minerals can cause many of these parameters to change throughout a deposit. Consequently, existing waste deposits should be sampled in several locations and at several depths to determine the range of values that occur. For those tests that cannot be conducted on materials *in situ*, appropriate ASTM procedures should be followed to ensure sample integrity. The stability of waste rock dumps and tailings piles is discussed in more detail in Appendix F.

2.3 Mineralogical Composition

Mineralogical composition and mineral textures can be determined using a petrographic (polarizing light) microscope equipped with both transmitted and reflected light. Samples can be viewed in thin-section, as grain mounts, or as discrete grains. Mineral percentages can be estimated through counts of a statistically significant number of points or grains. Thin-sections are particularly useful for recognizing mineral reaction (alteration) textures and products that may influence the interpretation of geochemical test results as described in the next section. Moreover, they permit identification of reaction products that may form as a consequence of mineral processing (by examining samples "before" and "after" processing). Petrographic techniques, including oil immersion, are well-established and widely accepted (Kerr, 1977; Sobek et al., 1978; Gribble and Hall, 1993; Craig and Vaughn, 1994).

X-ray diffraction (XRD) is used to identify minerals that are difficult to resolve with a petrographic microscope and to characterize crystal structures. The method measures the diffraction of an incident beam of X-rays during its passage through a crystal structure caused by atoms or atomic layers in the crystal (e.g., Hutchison, 1974; Bish and Post, 1989). The technique is a quick and easy means to determine the compositions of clay minerals that are associated with many ore deposits (e.g., Sobek et al., 1978). Analyzing clay minerals, which have different sorptive properties, can provide useful data that can be used in the design of waste rock and tailings piles, drainage covers, compacted liners, and remediation plans.

Scanning electron microscopy (SEM) can be used to image reaction products and grain coatings that cannot be resolved with an optical (petrographic) microscope. For example, it can be used to gather data on secondary mineral growths in the pore spaces of waste materials. This knowledge can be used to refine models of fate and transport by clarifying the potential for contaminant sorption onto the surfaces of clays or other minerals. In addition, the technique can be used to gather quantitative or semi-quantitative chemical data on the major constituents of minerals at scales that vary from a few microns to a few millimeters. The SEM scans a tightly focused beam of high-energy electrons across the surface of a prepared sample. The beam dislodges secondary electrons from the atoms in the sample, which are then collected, counted and formed into an image of the specimen surface (e.g., Goldstein et al., 1981). Because the energies with which secondary electrons are emitted are unique to each element, secondary electrons also provide compositional data through energy dispersive microanalysis.

Electron microprobe (EMP) analysis is used to determine the compositions of mineral grains in a sample. The EMP focuses a beam of high-energy electrons onto a fixed spot on a sample surface (typically 1 to 2 microns in diameter). The beam dislodges secondary electrons that emit radiation in wavelengths and energies characteristic of particular elements. Similar to SEM analysis, EMPs can be operated in an energy dispersive analysis mode. However, these machines typically are operated using wavelength dispersive detectors, which provide lower detection limits and more accurate analyses. Because it utilizes a tightly focused incident beam of high energy, EMP microanalysis is poorly suited for determinations of light elements(atomic number less than 10) and volatile elements.

3.0 ANALYSIS OF CHEMICAL COMPOSITION

Acceptable techniques for determining the concentrations of inorganic and organic constituents in solid and liquid wastes are given in 40 CFR, Part 136.3. Analytical methods are detailed in publications by the U.S. EPA (1983; 1986a), American Public Health Association (APHA et al., 1992), American Society for Testing and Materials (ASTM, 1996), and the U.S. Geological Survey (Fishman and Friedman, 1989). Considerations regarding the number and types of samples that should be tested are described in Section 6.0.

3.1 Analysis of Solids

The chemical composition of solid materials such as waste rock, tailings, or spent ore can be determined using a variety of techniques. Most analytical techniques require solubilization of the solid material into a liquid form prior to analysis. An exception is *X-ray fluorescence (XRF),* which is a common technique used to determine the major and minor chemical constituents of rocks and minerals (Norrish and Chappell, 1967; Bertin, 1970; Johnson and Maxwell, 1981). The technique analyzes sample materials in solid form (either as compacted powders or powders that have been fused into glass) by bombarding the sample with X-rays of known wavelength and energy. Excitation by the primary X-rays induces emissions of secondary photons (fluoresence) with energies and wavelengths characteristic of individual elements. The number of photons emitted (intensity) at a given wavelength or energy is proportional to the abundance of a given element. X-ray fluorescence is capable of determining the abundance of many elements that occur in concentrations of a few parts per million. It is an inferior technique for light elements, volatile elements, and many elements occurring at concentrations of less than 10 ppm.

Solid samples commonly are solubilized using strong-acid dissolution. Methods to digest solid materials in nitric acid are common and widely accepted (ASTM D5198 [ASTM, 1996]; EPA Method 3051 [U.S. EPA,1986a]). The subsequent liquids can be analyzed by several methods that most commonly include atomic absorption spectrometry, inductively coupled plasma spectrometry, and colorimetry.

In *atomic absorption (AA) spectrometry,* samples are vaporized at high temperatures and the concentrations of selected elements are determined by measuring the absorption of light at wavelengths characteristic of that element (Harris, 1987; Patniak, 1997). The technique is highly sensitive, comparatively simple, and permits determination of a variety of metals to levels of parts per million or less. In the direct aspiration method, sample solutions are injected into a flame, where they are dissociated and made amenable to absorption. The more sensitive graphite furnace technique uses an electrically heated furnace to vaporize the sample solution. The graphite furnace technique affords lower detection limits, but is more sensitive to matrix interference effects; it works best on relatively "clean" samples (U.S. EPA, 1986a). A primary disadvantage of the AA technique is that it is time-consuming, because each element must be analyzed separately (i.e., a sample must be analyzed repeatedly). Accepted atomic absorption techniques using both methods are given in U.S. EPA (1983; EPA 200 series methods) and U.S. EPA (1986a; EPA 7000 series). Methods for determining trace metal concentrations at levels of a few tens to hundreds of parts per trillion were recently developed by U.S. EPA (1996d, f). The absorption of elements that occur at low concentrations can be masked by interference from elements at higher concentrations. Consequently, chemical separation is used to isolate these elements and permit their analysis without interference. The cold-vapor technique (EPA Methods 245.1 and 245.2, U.S. EPA [1983]; EPA Method 7470A, U.S. EPA [1986a]; EPA Method 1631 for low detection limits, U.S. EPA [1996a]) is used to reduce and isolate mercury for analysis. The gas hydride method is used to reduce and isolate selenium (EPA Method 7741A; U.S. EPA [1986a]) and arsenic (EPA Method 7061A; U.S. EPA [1986a]; EPA Method 1632 for low detection levels; U.S. EPA [1996b]) for analysis. A co-precipitation method (EPA Method 218.5, U.S. EPA [1983]; EPA Method 7195, U.S. EPA [1986a]) is used to remove trivalent chromium from solution, permitting measurement of hexavalent chromium in the remaining solution by AA.

In *inductively coupled plasma (ICP) spectrometry,* aqueous samples are ionized at extreme temperatures in an argon plasma. The ions are focused into a stream of material that is accelerated toward detectors that measure either the photon emissions at specific wavelengths (ICP-AES, atomic emission spectrometry) or the masses of specific isotopes (ICP-MS, mass spectrometry) (Robinson, 1990). Standard ICP techniques can detect elements in concentrations of a few parts per billion to parts per million, but recently developed guidelines permit detection of a few to a few hundred parts per trillion. The primary advantage of ICP analysis is that it permits rapid, simultaneous or sequential determination of multiple elements in a single analytical session (i.e., a sample need only be analyzed once). Disadvantages include interference from the plasma gases, background radiation from other elements, and interferences from large excesses of single elements (U.S. EPA, 1986a). Accepted standard ICP techniques using both methods are given in U.S. EPA (1986a; EPA Method 6010A for ICP-AES; EPA Method 6020 for ICP-MS).
"Ultraclean" ICP-MS techniques that permit low detection limits are given in U.S. EPA (1996e, 1996g).

Colorimetry is a type of spectrophotometric analysis that uses the absorption of visible radiation (Harris, 1987; Patniak, 1997) to determine concentration. The technique uses a spectrophotometer or filter photometer to determine the concentration of a constituent in a specially prepared aqueous solution by measuring the absorbance at a specific visible light wavelength. An accepted colorimetric technique for hexavalent chromium (EPA Method 7196A) is given in U.S. EPA (1986a). Colorimetric techniques also have been developed for nitrate-nitrogen, nitrate plus nitrite-nitrogen, ammonium nitrogen, and total cyanide.

3.2 Analysis of Liquids

Samples of waters and wastewaters typically are filtered in the field prior to analysis. Methods developed by EPA require filtration using a 0.45 µm filter. Care should be taken when reusing field filters to ensure that they do not become sources of contamination. Importantly, some colloidal particulates can pass through this filter and will report as dissolved constituents in water quality analyses. Because some of these constituents (e.g., iron oxyhydroxides) readily adsorb metals from solution, the presence of colloidal particles smaller than 0.45 µm can influence measurements of dissolved metals such as cadmium, copper, lead, and zinc.

Liquid samples may be analyzed as collected, but they typically are treated following collection to preserve their chemical constituents. In many cases, multiple splits of a given sample are preserved using a variety of techniques. Electrical conductivity and pH should be measured on untreated samples at the time of collection. In contrast, samples that must be delivered to a lab for analysis of their inorganic and organic constituents are preserved to preclude precipitation of metal compounds or the volatilization of organic compounds between the time of sample collection and analysis. Samples collected for total metals analysis should be acidified to pH <2.0 using nitric acid and stored at 4°C to permit dissolution of suspended constituents (EPA Method 200.0; U.S. EPA [1983]). In contrast, samples collected for cyanide analysis should be adjusted to pH >12.0 using sodium hydroxide and stored at 4°C to prevent the formation of hydrogen cyanide (EPA Method 335.3; U.S. EPA [1983]). Samples collected for analysis of their organic constituents should be preserved at 4°C and left untreated or treated with sodium thiosulfate (EPA 3500 and 5000 series methods; U.S. EPA [1986a]).

Many metals in ambient waters occur in concentrations of less than 1 part per billion, which are below the detection limits of most standard analytical techniques. To permit accurate determinations of background water quality, the U.S. EPA recently released draft Method 1669 (U.S. EPA, 1996h). This method provides guidance for collecting samples that will be analyzed by newly developed “ultraclean” ICP-MS, AA, and ion chromatographic techniques (U.S. EPA, 1996a-g). Using these sampling and analytical methods, trace metal constituents in ambient water can be determined at levels of a few to a few hundred parts per trillion.

Prior to analysis, organic constituents are separated using solvent extraction or purge-and-trap techniques. Nonvolatile and semi-volatile organic compounds are extracted using solvents such as methylene chloride and techniques that include liquid-liquid extraction, soxhlet extraction, or ultrasonic extraction (EPA 3500 series methods; U.S. EPA [1986a]). Volatile organic compounds are extracted by bubbling an inert gas (either N_2 or He) through the sample solution to liberate the volatile components which are trapped in a sorbent column (EPA 5000 series methods; U.S. EPA [1986a]).

The concentrations of metals and other inorganic cationic constituents in samples of surface water, ground water, waste rock leachate, or mine drainage are analyzed using the AA, ICP, and colorimetric methods described above. Other techniques used to analyze aqueous samples include titrimetry, gravimetry, ion-selective electrode analysis, ion chromatography, gas chromatography, liquid chromatography, and Fourier transform infrared spectroscopy.

Titrimetric analysis is used to measure the acidity and alkalinity of aqueous samples (Patniak, 1997). Acidity is measured by titrating a solution to a predetermined pH endpoint using sodium hydroxide (EPA Method 305.2; U.S. EPA [1983]). Alkalinity is determined by titrating a solution to a predetermined pH endpoint using a strong acid (EPA Method 310.1; U.S. EPA [1983]). In both cases, the amount of titrant is converted to milliequivalents of acidity or alkalinity per liter of solution.

In *gravimetric* analysis, the mass of a reaction product is used to determine the quantity of the original analyte (Harris, 1987). Although these techniques are among the most accurate in analytical chemistry, they are no longer widely used because they are time consuming. However, gravimetric analysis remains the most common method for determining total dissolved solids (TDS) and total suspended solids (TSS) in a sample. To determine these parameters, a sample is filtered through a standard glass fiber filter. The filter is dried and weighed, with the weight increase representing TSS concentration (EPA Method, 160.2; U.S. EPA [1983]). Total dissolved solids are measured by evaporating the filtrate and weighing the residual solids (EPA Method 160.1; U.S. EPA [1983]).

Ion-selective electrodes respond to a single ionic species in solution (Harris, 1987; Patniak, 1997). The electrodes measure the electrical potential difference across a membrane between a solute at constant chemical activity within the electrode and the activity of the solute in the solution of interest. Ion-selective electrodes can be used to measure the concentrations of fluorine, cyanide, and ammonia in water samples (Standard Method 4500 series; APHA et al. [1992]).

Chromatographic techniques, in which constituents of interest are separated from one another to permit their identification, include ion chromatography, gas chromatography, and high-performance liquid chromatography. *Ion chromatography* is used to measure the concentrations of common anionic constituents (EPA Method 300.0; U.S. EPA [1983]). The technique uses a series of columns filled with ion-exchange resins to separate the anions from solution and combine them with hydrogen to form acids (Harris, 1987; Patniak, 1997). The electrical conductivities of the different acids, which are variably strong electrolytes, are measured using a conductivity detector, from which anion concentrations can be determined. A method for determining low levels of hexavalent chromium by ion chromatography was recently developed by U.S. EPA (1996c). *Gas chromatography* is used to measure the concentrations of a wide variety of organic constituents. In this technique, a liquid sample is vaporized and carried by an inert gas through a column filled with a partitioning material (Harris, 1987; Patniak, 1997). Organic compounds are separated in the column by their variable affinities for the partitioning material, which causes the different compounds have discrete retention times prior to emerging from the column and flowing to a detector. Several detector types are employed including electrolytic conductivity detectors, electron capture detectors, and flame ionization detectors (EPA 8000 series methods; U.S. EPA [1986a]). More sensitive detection can be accomplished by using mass spectrometers (EPA 8200 series methods; U.S. EPA [1986a]). Constituents that cannot be differentiated by mass (i.e., isomers) can be distinguished using *Fourier transform infrared spectroscopy,* in which isomers are distinguished by their infrared absorption frequencies (EPA Method 8410; U.S. EPA [1986a]). *High-performance liquid chromatography* also is used to measure the concentrations of organic constituents. This technique uses columns filled with adsorbent material (typically microporous silica with a covalently bonded stationary phase) to separate the compounds of interest, which are then eluted from the column by solvents (Harris, 1987; Patniak, 1997; EPA 8300 series methods, U.S. EPA [1986a]). Liquid flow is accomplished under high pressure to increase efficiency of the system. Absorbance, refractive index, and polarographic monitors are used to detect solutes eluted from the column. Potential interferences occur in all chromatographic techniques when two or more solutes have similar retention times in the separation column or, for mass spectrometry, have similar masses.

4.0 ANALYSIS OF CONTAMINANT MOBILITY FROM SOLIDS

Rigorous geochemical testing programs can reveal whether the rocks exposed by the mining process or the wastes and materials produced by extractive operations are likely to release metals or other contaminants that could degrade the environment at or surrounding a mine site. Testing programs are aimed at determining the potential for acid generation and constituent release through weathering and leaching. Because these laboratory programs are conducted in a manner intended to speed natural processes, test results must be interpreted with caution. Particle size and mineralogy play pivotal roles that govern the long-term behavior of materials in the environment. Consequently, these variables should not be ignored by a testing program. Considerations regarding the number and types of samples that should be tested are described in Section 6.0.

4.1 Mineralogical Considerations

It is critical to understand the mineralogy of waste rock, tailings, and spent ore materials in order to establish a sound geochemical testing program. Because many ore deposits and their gangue materials are chemically and mineralogically zoned (also true of some waste rock dumps and tailings piles), selecting appropriate test materials requires knowledge of mineral composition, abundance and distribution. Recognizing spatial variations in mineral abundance is especially important for potentially reactive sulfides (e.g., pyrite), nonreactive but leachable sulfides (e.g., galena), acid- and nonacid-sulfates (e.g., jarosite and gypsum), readily soluble and comparatively insoluble carbonates (e.g., calcite and siderite), and other minerals that may affect test results (e.g., clays and feldspars). Smith et al. (1994) showed that alteration zoning can have a significant impact on the pH and metals content of drainage generated from a quartz-alunite epithermal deposit. Testing programs need to recognize the mineralogical changes that secondary alteration may have imparted to a given rock unit and characterize the range of environmental behavior that could occur as a result.

Mineralogical studies provide a framework for interpreting the results of the geochemical tests outlined below. For example, hydroxide coatings on calcite or sulfate coatings on pyrite may preclude these minerals from participating in acid neutralization or generation in existing waste rock dumps. Samples of this material that are crushed to fine particle sizes prior to acid-base accounting tests may exhibit net neutralization potentials significantly different from that of the *in situ* waste material. Having knowledge of mineral coatings would allow one to interpret the test results in a more sound scientific manner. Mineralogical studies also can provide information regarding the sorptive properties of host minerals (e.g., clays) which could allow a determination of whether they are likely to retard the movement of certain contaminants. Studies of mineral compositions could permit identification of the mineralogical sources of trace metals in leachates and provide a basis for designing effective disposal plans.

4.2 Physical Considerations

The ability of a material or solid waste to generate acidity or alkalinity, or to contribute metals or other constituents to the environment through leaching, depends partly on the particle-size characteristics of the waste material. Interpretation of test results is complicated if the particle size of the test materials differs significantly from the particle size of a waste material as it is or will be disposed of in the environment. Particle-size characteristics impact both reaction rate and reaction duration by affecting the reactive surface area, the distances between potentially reactive particles, and the porosity and permeability of the waste.

Test materials that are finely ground can impact the results of acid-base accounting tests (Robertson and Broughton, 1992; Lapakko et al., 1998). Crushing to small particle sizes increases the surface area of reactive sulfide and neutralizing minerals. In addition, fine crushing can increase the acid generating potential of a sample by releasing reactive sulfides that are enclosed in inert minerals (e.g., pyrite enclosed in quartz) and which would not be exposed to oxidation in coarser materials (Lapakko et al., 1998). The distance between reactive particles and neutralizing particles is greatly diminished in fine-grained materials, which may inhibit the formation of localized zones of low pH that are known to occur in coarse-grained waste rock piles (Robertson and Broughton, 1992).

The leaching characteristics of waste materials also are affected by changes in particle size. Smaller particle sizes increase the surface area of materials amenable to leaching. Moreover, smaller particle diameters and a smaller range of particle sizes (better grading) affects pore sizes and permeability, both of which influence the volume of extraction fluid held in the pore spaces of granular materials and the amount of time that it is retained by the material.

4.3 Acid Generation Potential

Materials that contain iron sulfide minerals such as pyrite, marcasite, or pyrrhotite can generate acid if exposed to moisture (for example, humid air) and an oxidant (either oxygen from the atmosphere or a chemical source such as ferric iron). In addition, some sulfate minerals, such as jarosite, can dissolve to form acidic solutions (e.g., Lapakko, 1991). Bacteria commonly accelerate the process of acid generation from sulfides by enhancing the rate of ferrous iron oxidation (e.g., Kleinman and Erickson, 1983) or the rate of reduced-sulfur oxidation (BC AMD Task Force, 1989). The rate at which acid is generated depends on the composition of the sulfide mineral (e.g., Lundgren and Silver, 1980), its crystal size and shape (surface area; Caruccio et al., 1977), the presence of reaction coatings that may form on the surfaces of sulfide minerals (Goldhaber, 1983; Nicholson et al., 1990; Sherlock et al., 1995), and the environmental conditions (for example, pH, humidity, oxygen fugacity, temperature) at the site of oxidation

(BC AMD Task Force, 1989). In general, acid generation involves a rather complex set of chemical reactions that change through time (BC AMD Task Force, 1989).

The potential for acid generation is offset by the ability of a material to neutralize acid. Acid neutralization is imparted by various minerals including calcium- and magnesium-bearing carbonates, oxides and hydroxides of calcium, magnesium, and aluminum, some silicate minerals, and some phosphates (Sherlock et al., 1995). In general, dissolution rates (and hence neutralization) are considerably faster for carbonate minerals than for other neutralizing minerals. Factors that influence mineral dissolution rates include pH, dissolved carbon dioxide content, temperature, mineral composition, crystal size and shape, redox conditions, and the concentration of "foreign" ions (e.g., trace metals) (Sherlock et al., 1995).

Static predictive tests are used to define the balance between potentially acid-generating minerals and potentially acid-neutralizing minerals in a sample (BC AMD Task Force, 1989). These tests, which are quick and comparatively inexpensive, cannot be used to predict the quality of effluent that may drain from waste materials in the future. However, they are useful for determining which geologic units have the potential to generate acidity and, in essence, serve as positive/negative indicators of the theoretical potential for acid generation (Robertson and Broughton, 1992). When coupled with mineralogical and petrological data from the test samples, certain static test procedures can provide some measure of neutralization rate (Mills, 1998a). Kinetic tests are used to define reaction rates through time under specific environmental conditions. These tests are significantly more expensive and may take months or years to complete.

In general, acid mine drainage testing programs utilize a two-step approach in which static tests of numerous samples are used to identify potentially acid-generating geologic units and to characterize the variability that occurs within them. Kinetic tests are then run on samples deemed representative of the range of compositions within potentially reactive units to determine whether acid drainage will occur. Although New Mexico (NMED, 1996) and Nevada (NV DEP, 1990; 1996) have specific guidelines mandating static and kinetic testing of mine wastes, the states of EPA Region 10 have not adopted a similar approach.

4.3.1 Static Tests

Static test methods, which were developed initially to determine the potential for acid generation from coal mine wastes, have been adapted for use in the metal mining industry. The variety of static test methods that are available are collectively referred to as acid-base accounting (ABA) analyses. Static test methodologies are described and evaluated in reports by Lapakko (1991; 1992), Lawrence and Wang (1996), and Mills (1998a; 1998b); digestion methods are compared and evaluated in Skousen et al. (1996). Table C-1 summarizes several of the more commonly used test methods.

4.3.1.1 Acid-Base Accounting Tests

Specific procedures for conducting acid-base accounting (ABA) tests are compiled in Mills (1998a; 1998b). Although a few tests produce a single value that can be used to indicate the likelihood for acid generation (Section 4.3.1.2), most static tests determine separate values for the acid generating potential (AP) and acid neutralizing potential (NP) of a sample. These values, expressed in units of tons of $CaCO_3$ equivalent per kiloton of material, are used together to indicate whether a sample has a stochiometric balance that favors net acidity or net alkalinity. In general, determinations of acid generating potential are relatively straightforward. This is not true of tests to measure neutralizing potential. The problem stems from the widely variable solubilities and reaction rates of minerals that have the potential to neutralize acidity (e.g., carbonates vs. silicates), the relative differences in aggressiveness of the various methods used to determine neutralization potential, and the different titration endpoints employed by each test (e.g., Mills, 1998a). Studies in which the neutralizing potential of a sample was determined using different methods concluded that the NP value is highly sensitive to test methodology (e.g., Lapakko, 1994). Consequently, it is important that any program established to test wastes and materials prior to or during operation use a single test method to ensure that the program produces data that are internally consistent.

4.3.1.1.1 Methods to Determine Acid Generating Potential

Acid generating potential is determined from the sulfur content of a sample (expressed in weight percent). This value is converted to acid generating potential (AP) by multiplying by a factor of 31.25 that is derived from the molar stoichiometry of the oxidation and neutralization reactions. The conversion factor assumes that all reported sulfur occurs as pyrite, that pyrite is completely oxidized to sulfate and ferric hydroxide, and that hydrogen ions produced in the oxidation reaction are neutralized by $CaCO_3$. Acid generating potential is reported in kilograms of $CaCO_3$ equivalent per metric ton of sample (also expressed in units of metric tons of $CaCO_3$ equivalent per kilotonne of material).

Samples typically contain sulfur in more than one form, not all of which are capable of generating acidity. The sulfur speciation tests of Sobek et al. (1978) are the most commonly used methods to determine sulfur content. Alternative methods include the hydrogen peroxide method (O'Shay et al., 1990) and reactive sulfur tests.

Sobek et al. (1978) describe procedures to determine the total sulfur, HCl-extractable sulfate sulfur, HNO_3-extractable sulfide sulfur, and organic sulfur contents of a sample. The tests require a sample crushed to particle sizes smaller than 60 mesh (0.25 mm), which is split into three parts that are analyzed for total sulfur using a Leco sulfur analyzer. One split is left untreated and provides a measure of the total sulfur content of the sample. A second split is leached with HCl and a third split is leached with HNO_3. Acid-extractable sulfate sulfur (e.g., gypsum and anhydrite) is computed from the difference between the total sulfur contents of the untreated and HCl-treated splits. Acid-soluble sulfide sulfur (e.g., pyrite) is computed from the difference between the total sulfur contents of the HCl-treated and HNO_3-treated splits. Nonextractable organic sulfur is computed as the total sulfur content of the HNO_3-treated split.

The test methods have disadvantages that include the potential removal of highly reactive sulfide by HCl and the potential nondetection of sulfide that is slow to oxidize under experimental conditions, but which may form acid in the environment (BC AMD Task Force, 1989).

It is important to recognize that sulfur speciation tests like those described above do not distinguish acid-insoluble sulfates, such as barite or jarosite, which will report as sulfide sulfur. As a result, samples containing significant quantities of these minerals will appear to have more sulfide sulfur than they actually do. Although acid-insoluble sulfates will not oxidize to produce acid, some of these minerals (e.g., jarosite, alunite, and melanterite) may dissolve, hydrolyze, and generate acidity (Carson et al., 1982; Mills; 1998a). Mills (1998a) states that whole-rock barium concentrations can be used to correct sulfide sulfur determinations when barite is present. However, barium also may be present in common alteration phases such as potassium feldspar and biotite (Deer et al., 1992). Consequently, caution must be used when applying a barium correction of this type. As pointed out by Mills (1998a), it is rarely acknowledged that each step in the sulfur speciation tests introduces analytical error; these errors are cumulative.

Table C-1. Summary of Commonly Used Static Test Methods

Static Test Method	***Reference***	***Comments***
Sobek	Sobek et al. (1978)	AP uses sulfur speciation and Leco analyzer. NP uses fizz test and heated HCl that dissolves carbonates and most silicate minerals; NaOH titration endpoint of 7.0. This is an aggressive test that provides “best case” values.
Modified Sobek NP	Lawrence and Wang (1997)	NP uses fizz test and HCl at ambient temperature that dissolves carbonates and reactive silicate minerals; NaOH titration endpoint of 8.3. Less aggressive test due to use of ambient temperature acid. Lapakko (1992) suggested that the alkaline titration endpoint may lead to overly optimistic estimates of NP.
Sobek NP Siderite Correction	Skousen et al. (1997)	NP uses fizz test and heated HCl; hydrogen peroxide added prior to titration to oxidize ferrous iron from dissolved siderite. Yields less alkaline NP than standard Sobek method when siderite is abundant.
BCRI Initial	Duncan and Bruynesteyn (1979)	AP uses total sulfur by Leco furnace or wet chemistry. NP uses H_2SO_4 added to pH 3.5 at ambient temperature that dissolves carbonates and possibly limonite and chlorite; gives “most likely case” values.
Lapakko NP	Lapakko (1994)	NP uses H_2SO_4 added to pH 6.0 at ambient temperature for up to 1 week that dissolves carbonates; gives “worst case” value.
Net Acid Generation (NAG)	Miller et al. (1997)	Crushed sample is boiled with hydrogen peroxide then titrated to pH 4.5 with NaOH. NAG value, expressed in units of kg H_2SO_4/tonne, provides indication of potential for net acidification.

Table C-1. Summary of Commonly Used Static Test Methods

Static Test Method	Reference	Comments
Carbonate Carbon	ASTM (1997)	Samples are either dissolved in acid or combusted and the amount of CO_2 gas evolved is measured and converted to $CaCO_3$ equivalent.
Paste pH	Sobek et al. (1978) Page et al. (1982)	Sample is mixed with water and pH measured by meter. pH value provides indication of potential for net acidification.
Summaries include information from Mills (1998a and 1998b).		

The hydrogen peroxide method (O'Shay et al., 1990) has been used to determine the pyrite content of coal mine wastes. In this test, a sample crushed to particle sizes smaller than 150 microns is soaked in HCl for two hours to remove carbonate minerals. The treated sample is mixed with hydrogen peroxide and pH is monitored at intervals of 1 to 2 minutes. Curves of pH versus time are compared to curves generated from synthesized standards. Potential acidity is determined using the conversion factor of 31.25.

Reactive sulfur tests treat sample splits with hydrogen peroxide to oxidize sulfide minerals to sulfates. The sulfate content of the peroxide leach solution is used to determine the amount of reactive sulfur, which is converted to potential acidity using the conversion factor of 31.25. Producing accurate results with this test method, which is not widely used, requires strict temperature control (Hinners and SAIC, 1993), because pyrite decomposition is exothermic.

4.3.1.1.2 Methods to Determine Acid Neutralizing Potential

A variety of procedures are used to determine the neutralizing potential of a sample (Table C-1). In general these methods involve reacting a sample with a known quantity of acid, determining the base equivalent amount of acid consumed by the sample, and converting measured quantities to neutralization potential (NP), which is expressed in units of tonnes of $CaCO_3$ equivalent per kilotonne of material (Mills, 1998a).

The Sobek and Modified Sobek methods, which are perhaps the most widely used procedures, both use a "fizz test" to determine the quantity of acid that will be used in the NP determination. In essence, the test consists of adding a small amount of acid to a small quantity of test sample and subjectively assigning a fizz rating of "no", "slight", "moderate", or "strong" to the resulting effervescence. Each of these ratings corresponds to a different quantity and/or normality of acid that is added to the sample (Sobek et al., 1978). Lawrence and Wang (1996) and Skousen et al. (1997) conducted studies to examine the effects of assigning different fizz ratings when determining Sobek NP values for a variety of samples. Their results showed that NP values could differ by amounts that varied from a few percent to a few hundred percent for one or two category changes in fizz rating.

Neutralization potential (NP) by the Sobek and Modified Sobek methods is determined by treating the sample with an excess of hydrochloric acid and then titrating with sodium hydroxide to determine the amount of unconsumed acid. In the original test procedure outlined by Sobek et al. (1978), the sample is reacted with hot acid and titrated to a pH of 7. In the Modified Sobek procedure outlined by Coastech Research (1989), the sample is agitated with acid at room temperature for 24 hours and titrated to a pH of 8.3 (cf., Lawrence and Wang, 1997). In both cases, the amount of titrated base is converted to a calcium carbonate equivalent in units of kilograms per metric ton of sample (also expressed in units of metric tons of $CaCO_3$ equivalent per kiloton of material).

The Sobek and Modified Sobek tests determine the maximum amount of neutralization potential available in a sample, but do not predict the rate of neutralization nor indicate the pH to which a sample can neutralize acidity. Lapakko (1992) showed that both tests provided a fairly reliable estimate of NP for samples composed of quartz, alkali feldspar, and mica, but overestimated NP in samples with abundant calcic feldspar, chlorite, clay, pyroxene and olivine. Similar conclusions were drawn by Skousen et al. (1996) who showed that NP estimates for a single sample could vary by an order of magnitude depending on sample mineralogy and digestion method. Other criticisms of the Sobek and Modified Sobek methods (see Lapakko, 1991; 1992 and Hinners and SAIC, 1993) include: 1) the small particle size used in the tests may produce unrealistically high values for NP, 2) hot acid which is mixed with water and heated to boiling in the Sobek method may increase analytical scatter, 3) hot acid may digest siderite (iron carbonate) and clay minerals that increase NP values but provide little alkalinity, 4) NP may be overestimated because pH is back-titrated to values of 7.0 or 8.3, not 6.0 which is a typical water quality standard, and 5) NP may be overestimated if metal hydroxides precipitate during the addition of the sodium hydroxide base.

The BCRI Initial test (Duncan and Bruynesteyn, 1979; Bruynesteyn and Hackl, 1984) and Lapakko NP test (Lapakko, 1994) both use sulfuric acid at ambient temperature to determine neutralizing potential; neither test requires a subjective fizz test rating. In both tests, the sample is suspended in water and acid is titrated into the suspension until a stable, pre-determined pH value is achieved. The BCRI Initial test uses a titration endpoint of 3.5, whereas the Lapakko NP procedure uses a titration endpoint of 6.0. The volume of titrated acid is used to compute a value for acid consumption, which is expressed in units of kilograms per tonne. Neither test is particularly aggressive in dissolving minerals in addition to the carbonates. Nevertheless, the higher titration endpoint of the Lapakko procedure makes it the most conservative (lowest NP estimate) of the static NP test procedures. Lapakko (1992) showed that the BCRI test overestimated NP for samples containing significant siderite (iron carbonate).

Carbonate analysis may be used in conjunction with neutralizing potential tests to determine the amount of neutralizing potential that is likely to react quickly with acid formed through sulfide oxidation. There are several methods to analyze carbonate carbon. In one method, a sample is digested in acid in a sealed chamber. Carbon dioxide (CO_2) gas evolved by reaction is absorbed into a solution and measured using coulometric titration (Crock et al., 1999). Alternatively, the sample can be combusted, with carbon analyzed using a Leco or similar furnace (e.g., ASTM E-1915-97). In both cases, the carbonate content of the sample is determined from the amount of CO_2 gas evolved, with the result converted to $CaCO_3$ equivalent. The titration test offers the advantage of determining the carbonate content of samples with a wide range of values but can suffer interference if samples contain significant quantities of sulfide minerals. Combustion tests with Leco analysis should not be used if samples contain significant pyrrhotite ($Fe_{1-x}S$), because this mineral will react to form sulfur dioxide gas that interferes with the Leco analyzer (BC AMD Task Force, 1989). Combustion tests also provide a measure of total carbon (including organic carbon) unless pretreatment steps are taken to remove this component.

The alkaline production potential test was developed for use by the coal mining industry. In this method, a sample crushed to minus 23 microns is mixed with HCl and allowed to react for two hours at room temperature. The mixture is then titrated to pH 5.0. Although this method reduces dissolution of less reactive carbonate minerals (e.g., siderite), it may not permit reaction of all of the buffering carbonates present in the sample (Coastech Research, 1989).

4.3.1.2 Static Tests that Produce a Single Indicator Value

Two test procedures have been developed that provide a means for quickly indicating whether a sample is likely to have a stoichiometric balance that favors acid production. The net acid generation (NAG) test (Miller et al., 1997) uses a peroxide solution to oxidize sulfide minerals to sulfates. The oxidation process produces acid which reacts with alkaline minerals in the sample. Upon complete reaction, the solution is titrated to pH 4.5 using NaOH. The volume of titrated NaOH is used to compute a NAG value, which is expressed in units of kg of H_2SO_4 per metric ton of material.

Paste pH is a simple and inexpensive method to indicate the presence of reactive carbonate or readily available acidity. In this test, powdered rock and water are mixed in a specific ratio to form a paste. The pH of the paste is determined using a pH meter and pH reference electrode assembly. The test offers no indication of the relative proportions of acidifying or neutralizing components in a sample (BC AMD Task Force, 1989).

4.3.1.3 Interpreting Static Test Results

Static test results provide a preliminary indication of whether a sample is likely to produce acidic drainage in the environment. These tests do not, however, provide any data regarding when acidification may occur or the rates at which acid generation and neutralization reactions will proceed. As such, they are useful only for screening samples for their potential behavior. It should be kept in mind that most static tests are conducted using crushed or pulverized samples that may have particle sizes significantly smaller than materials as they will be disposed of. This can significantly change the chemical availabilities of reactive minerals as described in Section 4.2. In addition to these factors, interpretations should incorporate knowledge of sample mineralogy.

Static test results are generally interpreted within an empirically developed framework. Interpretations are based on the net neutralization potential and the neutralizing potential. The net neutralizing potential (NNP) is defined as the difference between the acid neutralizing potential (NP) and acid generating potential (AP) of a sample. It is computed by subtracting the latter from the former (NP-AP) when both are expressed in units of kilograms of $CaCO_3$ equivalent per metric ton of material (or metric tons per kiloton). The neutralizing potential ratio (NPR) is the ratio of acid neutralizing potential to acid generating potential (NP/AP) and also is computed from static test results when both are expressed in units of kilograms of $CaCO_3$ equivalent per metric ton of material (or metric tons per kiloton).

Many static test interpretations use a value for acid generating potential computed from the total sulfur content of a sample because it provides the most conservative (highest AP value) measure of acidification potential. In contrast, sulfide sulfur values (or values of total sulfur minus sulfate sulfur) provide more realistic estimates of acid generating capability because these analyses do not report sulfur in forms that are not acid generating (e.g., gypsum). The Canadian metal mining industry has adopted the use of sulfide sulfur as its standard method to compute acid generating potential (Mills, 1998a). It should be recognized that the assumptions inherent in the derivation of the stoichiometric conversion factor lead to additional uncertainty, since the factor could be significantly greater or less than 31.25 (BC AMD Task Force, 1989; see Section 4.3.1.1.1). In fact, some workers advocate using a value of 62.5 (Brady et al., 1990).

The values given in Table C-2 provide general guidelines for interpreting static test results, but they should not be interpreted as definitive values. Instead, the values should be viewed in light of the sulfur content of the sample, the aggressiveness of the test method used to determine neutralizing potential, sample mineralogy and expected ambient conditions. Because exceptions to these guidelines can and do occur, kinetic tests should be conducted to confirm the static test results. As always, operators are encouraged to communicate with state and federal regulators regarding their preferred method to interpret these test results.

In both schemes shown in Table C-2, there are “gray” areas where static acid-base accounting tests point to uncertainty. Under the Robertson and Broughton scheme, the gray area exists where NNP is between -20 and +20 tonnes/kilotonne and NPR is between 1 and 3. In the scheme of Price et al., uncertainty is present where NPR is between 1 and 4. Samples falling into the uncertain areas should be tested kinetically (section 4.3.2) to determine their acid generating capability. Regardless of their acid generating character, representative samples from all geochemical groups should be tested for metals mobility using one of the leach tests described in section 4.4.

4.3.1.4 State Recommendations

The States comprising EPA Region 10 presently have not established formal regulatory guidelines for conducting static tests of mine wastes and materials. The State of Nevada (NV DEP, 1990) recommends use of the Sobek et al. (1978) method to determine neutralization potential and either the Sobek et al. (1978) or the peroxide method (presumably O’Shay et al.,

Table C-2. Suggested Guidelines for Static Test Interpretation

Guidelines from Robertson and Broughton (1992)

	Potentially Acid Generating	*Uncertain Behavior* *	*Potentially Acid Neutralizing*
NNP	< -20 tonnes/kilotonne	> -20 to < +20 tonnes/kilotonne	> + 20 tonnes/kilotonne
NPR	< 1	1 to 3	> 3

* Samples exhibiting uncertain behavior should be tested kinetically.

Guidelines from Price et al. (1997)

	Paste pH	*NPR*	*Potential for ARD*	*Comment*
Sulfide-S <0.3%	>5.5	---	None	No further ARD testing required provided there are no other metal leaching concerns. Exceptions: host rock with no basic minerals, sulfide minerals that are weakly acid soluble.
Sulfide-S >0.3%	<5.5	<1	Likely	Likely to be ARD generating.
		1 - 2	Possibly	Possibly ARD generating if NP is insufficiently reactive or is depleted at a rate faster than that of sulfides.
		2 - 4	Low	Not potentially ARD generating unless significant preferential exposure of sulfides occurs along fractures or extremely reactive sulfides are present together with insufficiently reactive NP.
		>4	None	No further ARD testing required unless materials are to be used as a source of alkalinity.

1990) to determine acid generating potential. Those samples in which NP exceeds AP by 100 percent (NP/AP >2) are considered non-acid generating and do not require additional testing (NV DEP, 1990). Samples that do not meet this criteria should be tested kinetically. The State of New Mexico recommends determining the acid potential of representative samples using total sulfur and the neutralization potential using either the ABA, modified ABA, BCRI, or alkaline production methods (NMED, 1996). Kinetic tests are suggested for those samples with NP/AP ratios less than 3. Samples with ratios exceeding 3 are considered non-acid generating. The states of Nevada and New Mexico illustrate that states may view different test methodologies as acceptable. Applicants should check with state agencies to determine whether they have preferences that may not be codified.

4.3.2 Kinetic Tests

Kinetic test procedures are designed to accelerate the natural weathering process in order to provide information about the rates of acid consumption and acid production over time. A variety of kinetic test methods are available, including conventional and modified conventional humidity cells, SRK humidity cells, soxhlet extractions, column leach tests, shake flask extractions, modified B.C. Research tests, simulated environment studies, and field lysimeter tests; humidity cells and columns are most commonly used by the mining industry. According to Lapakko (1991), there is no single test that produces all of the chemical information needed to evaluate all mine wastes under all conditions of disposal. Most of the kinetic testing procedures are complex, time-consuming, and require considerable operator skill to produce consistent results.

4.3.2.1 Kinetic Test Methods

The various kinetic tests described below are similar to one another in that a sample is subjected to periodic leaching, the leachate is collected and analyzed, and rates of acid generation, metals release, and neutralization capacity depletion are computed. The methods differ in the amount of sample used in the test, the particle size of the tested material, test conditions (lab vs. field), and test duration. Although not specifically stated in most procedures, it is typical for splits of the starting sample and final leached product to be tested for static acid-base properties and total metals; mineralogical analyses also should be conducted on these samples because these data can provide important constraints to assist the interpretation of test results (Mills, 1998c).

4.3.2.1.1 Conventional and Modified Conventional Humidity Cells

The conventional humidity cell (Sobek et al., 1978) is a bench-scale test that uses a comparatively small amount of sample (200 to 300 g) crushed to particle sizes smaller than 2 mm. A split of the sample is analyzed for metals and other constituents to assist in the evaluation of water quality from the tests. The sample is placed in a sealed plastic box and dry air is passed over the sample for 3 days, followed by moist air for 3 days. Every seventh day, the sample is flushed with a specified volume of water. To simulate the composition of regional acidic rain, the pH of the water may be adjusted to slightly lower pH. The leachant is collected and analyzed for sulfate, pH, acidity, alkalinity, and electrical conductivity. This 7-day process is repeated for 10 weeks, although some samples may require a longer reaction period (Coastech Research, 1989). Test durations of 20 weeks are used commonly in the metal mining industry (see discussion in Section 4.3.2.2).

The modified conventional humidity cell designed by Lawrence (1990) uses a bigger sample size and larger volume of water for the flush cycles. The test is conducted in a manner generally similar to the Sobek method.

ASTM procedure D5744-96 (ASTM, 1998), which was designed specifically for mining wastes and materials, uses a modified column as a humidity cell. The test is conducted on a kilogram of sample crushed to particle sizes smaller than 6.3 mm. The test is run for 20 weeks in a manner similar to the Sobek method, with 3 days of dry air, 3 days of moist air, and a weekly flush with 0.5 or 1.0 liter of water. The procedure includes provisions for pre-leach and post-leach mineralogical and chemical characterization of the solid sample and directions for preparation and use of an optional bacterial (*T. ferrooxidans*) spike.

Few data are available to document the reproducibility of humidity cell data (Mills, 1998c). Experiments designed to test the validity of conventional humidity cell results for tailings and waste rock samples are summarized in Lapakko (1991; 1992). In general, the conventional humidity cell is able to indicate many of those samples that become acid producing. However, some validation tests noted indefinite pH trends that were difficult to interpret and some tests failed to predict acid generation, suggesting that these experiments should have continued for longer durations to permit depletion of the neutralizing capacity. Criticisms of the conventional humidity cell are given in Broughton and Robertson (1992). These authors argue that the small particle size used in the tests masks the influence of particle size on acid generation, making them unsuitable for waste rock samples; however, the particle sizes used in the tests are similar to tailings. Moreover, they point out that the complete sample flush may affect the development of local low pH and disrupt the natural storage and flushing of oxidation products. Other workers, however, feel that the small particle size is not a limiting factor since the most highly reactive products in waste rock piles typically occur in the smaller size fractions (Hinners and SAIC, 1993). For existing waste rock dumps, Price (1997) recommends using only the sub-2 mm size fraction of (i.e., crushing larger clasts should be avoided) in humidity cell tests. For proposed waste rock dumps, Price (1997) recommends crushing drill core material to 80% less than 6 mm. Clay-rich samples can pose problems for humidity cell testing because the clay particles can be easily lost during weekly flushing and they can clog filters used to prevent the loss of fine materials (Mills, 1998c).

4.3.2.1.2 SRK Humidity Cells

Broughton and Robertson (1992) present a modified humidity cell (termed the SRK humidity cell) designed to test coarse waste rock samples. This test uses material crushed to sizes smaller than 10 cm which is placed into a cylindrical column with a diameter of 30 cm and height of 45 cm. Humid air is cycled constantly through the cell. Flush water is introduced at several points along the upper surface of the waste rock so that it percolates downward along discrete pathways. The volume of flush water approximates (per unit area) conditions encountered in the field. The cells can be stacked to allow leach water from one test cell to be used as flush water in an underlying cell.

The SRK design eliminates complete flushing of the oxidation products, permitting local areas of low pH to develop within the cell (Broughton and Robertson, 1992). The coarse size fraction more closely approximates the separation distance between acid-producing and acid-neutralizing minerals in waste rock samples.

4.3.2.1.3 Soxhlet Extractions

Soxhlet reactors recirculate water or other fluids through a sample to simulate conditions of weathering. The method of Sullivan and Sobek (1982) uses distilled water at 25°C to leach a sample over a period of six weeks, although the test duration can vary. A technique described by Renton et al. (1988) uses as the leach material a pulverized coal waste sample that has been oxidized in an oven. The sample is leached in a soxhlet reactor with distilled water at 85°C and the leachate is analyzed for water quality parameters. The sample is returned to the oven for additional oxidation prior to the next leach cycle. The oxidation-leaching cycle is repeated 5 times.

Soxhlet extractions require sophisticated equipment and considerable operator skill, especially for the Renton et al. procedure. Evaluations of the Sullivan and Sobek (1982) method by Coastech Research (1989) indicate that it may provide reliable results for tailings samples. The aggressive oxidation of samples and elevated leaching temperatures used in the Renton et al. method tend to overestimate the acid producing capability of a sample by accelerating the dissolution of carbonate minerals (Bradham and Caruccio, 1990).

4.3.2.1.4 Column Tests

Column test procedures have not been standardized (Mills, 1998c). Consequently, they are highly flexible tests that permit a range of column designs, test material characteristics, and flow rates. Column tests can be conducted in a manner similar to conventional humidity cells, but they can also be run in an “upflow” mode to simulate subaqueous disposal or as subaerial columns without forced oxygenation (i.e., the top of the column is open but air is not forced through the sample) (Mills, 1998c). Columns, which typically have diameters of 15 cm and lengths of up to 2 m, can be constructed with larger diameters and lengths to accommodate larger sample sizes (10 kg to 3 metric tons; Broughton and Robertson, 1992). Particle sizes up to 2 cm are commonly used in these tests. Materials can be inoculated with bacteria or stratified with neutralizing materials (for example, limestone) to test disposal options.

Subaerial columns are used to simulate the effects of precipitation infiltration into and drainage from materials that are exposed to the atmosphere. A fixed amount of water may be added to the column on a regular basis or the amount may be varied and added irregularly to simulate seasonal variability (Mills, 1998c). Moreover, water may be added to specific portions of the column surface to promote flow along preferred pathways, which allows oxidation products to accumulate on particle surfaces within the column (Mills, 1998c).

Subaqueous columns are used to simulate water infiltration into and drainage from materials that are stored under a water cover. To simulate seepage to ground water, columns can be constructed to permit downward displacement of pore waters by supernatant water (Mills, 1998c). They also can be constructed to allow slow upward movement of deoxygenated water in a manner that simulates submarine disposal.

Experiments designed to determine the validity of column tests for tailings and waste rock samples are summarized in Lapakko (1991; 1992). Several of these studies (e.g., Doepker, 1989) concluded that pyrite oxidized more rapidly in columns that remained unsaturated between flushes, producing lower pH leachate than saturated columns. In general, column tests appear to distinguish potentially reactive materials from benign materials, but the leachant compositions may not reflect what occurs under natural settings (Doepker and O'Connor, 1990).

4.3.2.1.5 Shake Flask Extractions

Also termed batch reactor tests, shake flask tests utilize a split of powdered sample immersed in distilled water that may be inoculated with bacteria. The flask is sealed and placed on a shaker table where it is vibrated for a period of days to weeks. Samples are removed periodically and analyzed to determine the sulfate content, pH and other water quality parameters.

The shake flask test is relatively simple and inexpensive. However, for long duration tests, water may need to be added to maintain volume and submersion of the sample may inhibit oxidation of reactive sulfides (BC AMD Task Force, 1989). Interpretation of test results is quite complex if water has been added periodically.

4.3.2.1.6 Field Tests

Field lysimeter tests are conducted using sample quantities that vary from barrel-scale to piles. The tests can be conducted for protracted periods (years) under natural climatic conditions. In cases where samples have a small to moderate amount of neutralization potential, long test durations are required to overcome the effects of neutralization and the lag period that precedes bacterial oxidation (Lapakko, 1991). Test piles are typically equipped with lysimeters or set atop impermeable liners to facilitate collection of drainage samples and are constructed in a manner similar to actual or proposed waste rock or tailings piles. Drainage volumes and concentrations can be used to calculate the mass release rates of metals per unit mass of waste.

A major advantage of field tests is their conduct under the environmental conditions at the disposal site, which provides more realistic estimates of water quality and the rates of acid generation and neutralization than bench-scale lab tests (Price, 1997). In addition, they allow control options, such as limestone addition (Humphreys, 1990), to be tested under natural conditions. However, it is critical that the tests be conducted for durations of sufficient length to smooth the effects of short-term climatic variations. Consequently, their long duration makes these tests difficult to use, especially for evaluating proposed actions.

4.3.2.2 Interpreting Kinetic Test Results

The interpretation of kinetic test results, for which accepted criteria are generally lacking, can range from relatively straightforward to extremely difficult (Ferguson and Erickson, 1988; Price, 1997; Mills, 1998d). All interpretations should be based on knowledge of sample mineralogy, static test data, particle size characteristics, and water flow (Mills, 1998d). Scaling issues are a significant obstacle when using bench-scale kinetic test results to quantitatively estimate acid generation in waste rock and tailings piles. Included are the effects of grain size and reactive surface area, infiltration rates, and flushing rates and volumes (see comments in Hinners and SAIC, 1993).

Most investigators use temporal trends in leachate quality, including pH, sulfate, acidity, alkalinity, and trace metals, to identify the progression of the acid mine drainage process (e.g., Ferguson and Erickson, 1988; Lapakko et al., 1995; Price, 1997; Mills, 1998d). Because trends in leachate composition reflect changing sample mineralogy and geochemical equilibrium conditions, they must be interpreted cautiously. Equilibrium chemical speciation programs, such as MINTEQA2 (Section 5.2.2), can be used to identify the precipitation/dissolution reactions that are likely to control leachate composition. It is important to keep in mind that lab-scale kinetic tests are specifically designed to accelerate the natural weathering process. Consequently, these tests cannot be used to determine when materials may begin to generate acid in the environment (only that they will or will not), and they generally will produce leachates with higher metal concentrations than would be produced naturally (Mills, 1998c). For most bench-scale tests, samples are considered strongly acid generating if leachate pH falls below 3; acid generating with some neutralization occurring if pH is between 3 and 5; and not significantly acid generating (or generated acid is overwhelmed by excess alkalinity) if solution pH exceeds 5 (BC AMD Task Force, 1989; Humphreys, 1990).

Sample mineralogy plays a pivotal role in controlling leachate quality (Mills, 1998d). For samples lacking sulfate minerals, the production of aqueous sulfate may be used to monitor the sulfide oxidation process. In contrast, when gypsum or other soluble sulfate minerals are present, their dissolution will provide aqueous sulfate that can mask sulfate produced by sulfide oxidation. In some cases, high aqueous sulfate concentrations produced by gypsum dissolution may delay the onset of sulfide oxidation in kinetic tests (Mills, 1998d). Test samples collected from existing waste piles may contain previously formed oxidation products that dissolve at varying rates to contribute metals to kinetic test leachates. Hydrolysis of these metals can lead to reduced pH. Depending on reaction kinetics, secondary mineral dissolution is likely to overprint the effects of sulfide oxidation, which complicates calculations of sulfide oxidation rates (Mills, 1998d). Price (1997) provides a list of equations that can be used to interpret laboratory kinetic tests.

Whether kinetic test samples may eventually begin to produce acidic leachates depends on the proportions of acid generating and acid neutralizing materials, their relative dissolution and reaction rates, and the particle size characteristics of the test materials. Kinetic test duration is a critical issue (Price, 1997). Kinetic tests must be conducted for a period of time that is sufficient to permit the dissolution of neutralizing minerals and accumulated oxidation products and to overcome the lag-time that precedes the onset of bacterial oxidation. Although 20-week test lengths are common in the metal mining industry, there is a growing trend toward longer test times. For example, Price (1997) recommended minimum test durations of 40 weeks and Mills (1998c) reported that test lengths commonly exceed 104 weeks in western Canada. In long-term studies reported by Lapakko et al. (1998), some samples did not begin to produce acidic drainage until more than two years into the kinetic tests. Particle size also strongly influences kinetic test results. The reduced particle sizes used in many bench-scale tests enhance reactivity by liberating sulfides enclosed in silicate minerals (e.g., pyrite enclosed in quartz; Broughton and Robertson, 1992; Lapakko et al., 1998; Mills, 1998e). In coarser samples, these sulfides would not be exposed to oxidation. Moreover, smaller particle diameters increase the total surface area of acid generating and acid neutralizing minerals exposed to reaction which, in turn, affects reaction rates and drainage quality (Lapakko et al., 1998; Mills, 1998c).

Finally, it is important to consider that differences between lab test conditions and the natural environment are likely to complicate extrapolation of kinetic test results. Differences between lab and ambient atmospheric temperature, lab wetting cycles and natural precipitation frequency, and complete flushing flows in the lab vs. incomplete or channelized flow in actual waste piles are cited by Mills (1998c) as factors that require consideration.

4.3.2.3 State Recommendations

The states comprising EPA Region 10 presently have not promulgated formal guidelines that cite specific kinetic procedures. The State of Nevada accepts kinetic testing methods that include shake flask extractions, soxhlet extractions, conventional humidity cells, column tests, and field tests (NV DEP, 1990). Although kinetic tests are required for samples of spent ore, tailings, and waste rock, the State does not provide guidelines for the interpretation of test results. The State of New Mexico recommends the use of humidity cells and columns for most kinetic test applications, but will accept soxhlet extraction test results as appropriate (NMED, 1996). The State recommends shake flask extractions for simulating closure conditions that require underwater storage (NMED, 1996). The State does not provide criteria by which to interpret kinetic test results. Applicants should check with state agencies to determine whether they have preferences that may not be codified.

4.3.3 Other Methods

In addition to laboratory analysis of environmental samples, insight into the potential for certain geologic materials to become acid generating can be gained through empirical studies of pre-mining water quality, alteration history (including weathering), mineralogy, and water quality in analogous mined terranes. These types of studies may help to overcome issues related to sample representativeness and the applicability of laboratory conditions to the natural environment (Plumlee et al., 1999). Plumlee and coworkers have shown that geologic features (e.g., deposit and alteration mineralogy), hydrologic setting, climate (e.g., rainfall and evaporation), and mining methods affect drainage composition at hard rock mines. Although empirical field studies can be used to anticipate problems before they occur and to guide laboratory investigations, they should not be used as a basis for quantitative predictions of drainage quality from particular mines, dumps or impoundments.

4.3.4 Mathematical Models

Neither static nor kinetic test results provide the types of data that determine unequivocally the potential for acid generation from waste rock and tailings piles. Instead, test results must be extrapolated to longer time frames and different environmental conditions and scaled to account for the differences in waste volumes, particle sizes, particle separation distances, infiltration rates, flushing rates, and flushing volumes between laboratory test samples and waste deposits. Mathematical models can help to bridge this gap and can help planners determine the potential effects of waste rock and tailings piles runoff.

Empirical models of acid generation utilize trends observed in test results to extrapolate future conditions, typically using "best-fit lines" through test data points (BC AMD Task Force, 1989). The accuracy of an empirical model, which is by definition a site-specific model, depends on the quality of the test data. Major sources of uncertainty include differences in particle-size distributions between test materials and actual waste materials and lack of model calibration to conditions as they will exist in the waste disposal setting (BC AMD Task Force, 1989).

Theoretical or deterministic models solve a series of equations that represent different physical or chemical aspects of the acid generation process in order to predict the temporal evolution of acid generation (see Perkins et al. [1995] for a review of the application of geochemical models to predictions of acid generation). Models include the Reactive Acid Tailings Assessment Program (RATAP) model (SENES and Beak, 1986; 1988); the mine tailings oxidation (MINTOX) model (MEND, 1997); the sulfide oxidation model of Davis and Ritchey (1986); and the MINEWALL model (MEND, 1995). RATAP was developed to assess acid generation and ground water quality in fine-grained pyritic tailings. MINTOX can be used to predict the kinetic behavior of sulfide oxidation within mine tailings impoundments and simulate the speciation and transport of oxidation products through tailings and into downstream aquifers. The Davis and Ritchey model determines an approximate analytical solution that allows a user to evaluate the amount of time required for oxidation of all material in a mass of waste and estimate the amount of time that materials can pose a threat in the environment. The MINEWALL model can estimate water chemistry continuously through operational and closure phases of a mining operation.

Uncertainty is introduced into theoretical models by an incomplete understanding of the system which is being modeled or through use of simplifying assumptions (BC AMD Task Force, 1989). In general, theoretical models may fail to properly describe fluid transport through constructed waste piles, accurately predict thermal gradients that may arise due to the oxidation process, and correctly determine the transport of oxygen and reaction products in compositionally and physically heterogeneous wastes (BC AMD Task Force, 1989; Nicholson, 1992).

4.4 Leaching Procedures

Spent ore, waste rock, or tailings materials that are exposed to the environment can potentially contribute metals or other contaminants to the environment. Metals can be leached from geological materials even under neutral conditions, but it is accelerated by materials that generate acid as a consequence of sulfide oxidation. Consequently, a variety of leaching tests are used to determine which constituents in waste materials are potentially mobile under the expected environmental conditions.

4.4.1 U.S. EPA Procedures

EPA has developed three leach test procedures. Of these, the Synthetic Precipitation Leaching Procedure (SPLP) test and Toxicity Characteristic Leaching Procedure (TCLP) test are the most widely applied by the mining industry. The SPLP test is most applicable to metals removal from mining wastes and materials.

4.4.1.1 EP Toxicity Test

The Extraction Procedure (EP) Toxicity Test (EPA Method 1310A) was developed to determine whether a particular waste material exhibits the characteristics of a hazardous waste. The method, which has been replaced by the TCLP test for regulatory purposes, is outlined in U.S. EPA (1986a), with the most recent version of the experimental procedure dated July 1992, revision 1. The method uses an extraction fluid composed of acetic acid diluted to pH 5.0 ± 0.2. Solid samples of approximately 100 g are crushed to sizes smaller than 9.5 mm and placed into an extraction bottle; special procedures are used for mixed solid/liquid waste. A 16:1 weight ratio of extraction fluid:sample solid is added to the bottle, which is agitated for 24 hours. Following extraction, the leachate is filtered and analyzed for metals.

4.4.1.2 Toxicity Characteristic Leaching Procedure Test

The Toxicity Characteristic Leaching Procedure (TCLP) Test (EPA Method 1311; ASTM Method D5233) was designed to evaluate the mobility of inorganic and organic constituents in liquids, solids, and mixed wastes in a sanitary landfill. The method is outlined in U.S. EPA (1986a), with the most recent version of the experimental procedure dated July 1992, revision 0. For non-alkaline materials, the method uses an extraction fluid composed of acetic acid diluted to pH 4.93 ± 0.05. For alkaline materials, the method uses an extraction fluid composed of acetic acid diluted to pH 2.88 ± 0.05. Samples containing volatile organic components are leached using a zero head space tumbler and the pH 4.93 extract fluid. For non-volatile materials, samples of approximately 100 g are crushed to sizes smaller than 9.5 mm and placed into an extraction bottle. A 20:1 weight ratio of extraction fluid:sample solid is added to the bottle, which is agitated for 18 ± 2 hours. Following extraction, the leachate is filtered, preserved with nitric acid, and analyzed for metals.

4.4.1.3 Synthetic Precipitation Leaching Procedure Test

The Synthetic Precipitation Leaching Procedure (SPLP) test (EPA Method 1312) was designed to determine the mobility of organic and inorganic analytes in liquids, solids, and mixed wastes using a batch leach technique. The method is outlined in U.S. EPA (1986a), with the most recent version of the experimental procedure dated September 1994, revision 0. For areas west of the Mississippi River, the method uses an extraction fluid composed of a 60/40 weight percent mix of sulfuric/nitric acid diluted to pH 5.00 ± 0.05 to simulate regional acidic precipitation. Samples containing cyanide or volatile organic components are leached using special procedures and distilled water as the extraction fluid. For non-volatile materials, samples of approximately 100 g are crushed to sizes smaller than 9.5 mm and placed into an extraction bottle. A 20:1 weight ratio of extraction fluid:sample solid is added to the bottle, which is agitated for 18 ± 2 hours. Following extraction, the leachate is filtered, preserved with nitric acid, and analyzed for metals.

4.4.1.4 Monofilled Waste Extraction Procedure

The Monofilled Waste Extraction Procedure (MWEP) is a sequential batch extraction test developed to predict the composition of leachate produced from solid waste under field conditions. The procedure is outlined in U.S. EPA (1986b). Solid materials are crushed to pass a 9.5 mm sieve and are combined with extraction fluid in a 10:1 liquid:solid ratio. The mixture is tumbled at room temperature for 24 hours. The procedure uses reagent grade water as the extraction fluid, however, the test can be conducted using process waters, ground waters, or other fluids that occur at a site. Following extraction, the leachate is filtered and analyzed. The solid residue is returned to the extraction vessel and the leach process is conducted using fresh extraction fluid. Four leachings per sample are recommended. Not only does this procedure allow single samples to be leached repetitively, but it permits more than one sample to be leached by the same extraction fluid.

4.4.2 State Procedures

The State of Nevada recently developed a leach test specifically for mining wastes. The procedure has been broadly accepted by the mining industry and is being used to test wastes that would be disposed of in other regions.

The State of Nevada uses a single-pass column leach test termed the Meteoric Water Mobility Procedure (MWMP) to determine the potential for waste rock, spent ore, and tailings to release certain constituents to the environment. The test is required by guidance documents issued by the Division of Environmental Protection (NV DEP, 1990; 1996). The procedure is provided in NV DEP (1996) and available (as of February 1999) on the internet (www.enviromine.com/ard/Acid-Base%20Accounting/metal_leaching.htm).

The MWMP test uses 5 kg of material crushed to particle sizes smaller than 5 cm which is loaded into an extraction column. A volume of extraction fluid equal to the dry weight of the sample (milliliters of fluid equal to grams of sample) is passed through the sample in a 24 hour period. Although the procedure states that the pH of the extraction fluid should “reflect the pH of precipitation in the geographic region in which the mine rock is being evaluated,” the procedure uses Type II reagent grade water (distilled or deionized as produced by Method 1080 in APHA et al., 1992) as the extraction fluid. The pH values of the initial leachate and homogenized leachate at the end of testing are recorded. The homogenized leachate is filtered and analyzed for dissolved constituents.

4.4.3 Other Leaching Procedures

Leach test procedures also have been developed by the Province of British Columbia, the U.S. Army Corps of Engineers, and the American Society for Testing and Materials (ASTM). These tests are not widely used by the American mining industry.

4.4.3.1 British Columbia Procedures

The British Columbia Special Waste Extraction Procedure (SWEP) is a single batch extraction that uses an acetic acid lixiviant, a 16:1 liquid:solid mass ratio, and an extraction time of 24 hours. According to Mills (1998f), for mine wastes in British Columbia, it is standard practice to used distilled water or 0.1 N hydrochloric acid as the extract fluid, a liquid:solid mass ratio of 3:1, and an extraction time of 24 hours.

4.4.3.2 U.S. Army Corps of Engineers Procedures

The U.S. Army Corps of Engineers developed a procedure to conduct sequential batch leaching tests (SBLT) of dredged materials (Brannon et al., 1994). This procedure, which determines changes in the equilibrium distribution of a contaminant between solid material and an aqueous phase, can be used to investigate the quality of water that might be expected to occur during episodic flushing of mining wastes (for example, during wet winters and dry summers). The SBLT procedure uses a liquid:solid weight ratio of 4:1 and a 24-hour leaching time for each step. Samples are placed into a tumbler and tumbled using deoxygenated water as the leaching medium. The leachate is separated by centrifuge, filtered, preserved with nitric acid, and analyzed for electrical conductivity and metals. A minimum of four sequential cycles are recommended. The procedure provides a conservative estimate of leachate concentrations under conditions of anaerobic leaching of freshwater sediments (Brannon et al., 1994). The SBLT procedure could be applied to analysis of tailings and other fine-grained materials, such as borrow soils used for growth media and covers. However, the procedure does not define the size fractions that should be tested and its applicability to tests of coarse waste rock has not been demonstrated.

Myers and Brannon (1988) and Myers et al. (1991) describe a procedure developed by the U.S. Army Corps of Engineers for column leach testing of dredged freshwater sediments. These tests are recommended to confirm the results of sequential batch leaching tests and can be used if the potential for contamination is high. The Myers et al. (1991) procedure uses an improved column design that increases the number of pore volumes that can be eluted in a given period of time by using a decreased column length and increased column diameter (producing pore water velocities of approximately 10^{-5} cm/sec). The test, which uses kilogram samples, is conducted using deoxygenated water as the leaching medium.

Graded serial batch tests are described by Houle and Long (1978; 1980). In these tests, solid waste is mixed with an extraction fluid in a liquid:solid ratio of 2:1 and shaken intermittently for 24 hours. The sample is filtered and the leachate analyzed, with residual solid material returned the extraction vessel for subsequent leaching. The liquid:solid ratio is doubled for each succeeding extraction (i.e., 4:1, 8:1, 16:1, etc.), with a total of seven leach cycles recommended for each sample. The extraction fluid can be reagent water or any site-specific fluid, thus permitting a determination of the constituents that can be removed from or adsorbed by the solid waste.

4.4.3.3 ASTM Procedures

The American Society for Testing and Materials provides methodologies for conducting shake flask extractions (ASTM Method D3987) and sequential batch extractions of solid wastes (ASTM Methods D4793 and D5284) (ASTM, 1996). The tests use liquid:solid mass ratios of 20:1 and extraction times of 18 hours. In the sequential batch tests, 10 leachate samples are produced from a single solid waste sample. Methods D3987 and D4793 use water for the extraction fluid whereas method D5284 uses an acidic extraction fluid with a pH similar to that of the average regional precipitation in the disposal area.

4.4.4 State Recommendations

The states comprising EPA Region 10 presently have not promulgated formal guidelines that specify use of a particular leaching procedure. The State of Nevada recommends use of the Nevada Meteoric Water Mobility Procedure to test representative samples of waste rock, spent ore and tailings for their potential to release contaminants (NV DEP, 1996). The State of New Mexico (NMED, 1996) recommends use of EPA method 1312 (SPLP test) to test samples for the potential to release contaminants. Applicants should check with state agencies to determine whether they have preferences that may not be codified.

4.4.5 Comparison of Leaching Procedures

Batch leach tests vary significantly in their ability to extract metals from solid materials depending on the type of extraction fluid employed. The determination of which leach test method should be applied to mining wastes is the subject of continuing regulatory discussions and there may be differences between state and federal requirements. As such, operators should maintain open lines of communication with all regulatory agencies on this topic.

In 1995, EPA stated its position that EPA Method 1311 (TCLP) tests were applicable to evaluations of mineral processing wastes. In general, Method 1311 is applicable to any mining-related material that is not Bevill-exempt. However, where the materials are Bevill-exempt (e.g., waste rock), particularly when they will be managed in a monofill, EPA Method 1312 (SPLP) may be the preferred method because it utilizes strong acids similar to those that would be generated under oxidizing conditions. However, the SPLP test uses a combination of sulfuric and nitric acids as the extraction fluid, which precludes determination of sulfate and nitrate concentrations in test leachates. Because these constituents may be of interest (sulfates as oxidation products of sulfides or hydrolysis products of acid-sulfate minerals; nitrates as blasting residue), it may bedesirable to modify the procedure to substitute a strong acid such as hydrochloric acid, which has similar, albeit less oxidizing, qualities, as the extraction fluid. The SPLP test also can be modified to be more aggressive by decreasing the pH of the extraction fluid. The SPLP test is run under conditions of high fluid to solid ratio (20:1) and short duration (18 hours), which limits the extent to which biological oxidation will breakdown reactive sulfide minerals. States may have their own requirements or preferences, and operators are advised to consult with their state regulatory authorities.

Sequential leach tests provide data regarding the rate at which constituents could be released to the environment. In particular, these tests can show whether the concentrations of metals in a leachate exhibit temporal trends. However, extrapolating the results of sequential leach tests to the expected conditions of waste disposal may not be straightforward since most tests are conducted on material that may have significantly different reaction kinetics than the actual waste (due to particle size) and because extraction durations and the amount of time between extractions do not replicate either natural wet-dry cycles or conditions of atmospheric oxidation.

Many leaching tests use reagent-grade water as the extraction fluid (e.g., Nevada MWMP), which may not simulate the expected natural conditions, for example, where acidification occurs at depth in a waste pile. To more closely approximate leaching in regions where rainfall is acidic or where percolating water contacts oxidation products, reagent water can be acidified using strong acids to pH values typical of the regional precipitation. A more acidic extraction fluid makes leaching tests chemically more aggressive; consequently, their results provide a more conservative estimate of the potential impacts of mining materials on water quality.

A recent study by Doyle et al. (1998) leached samples of mining wastes using batch (SPLP) and continuous column procedures. They found that batch tests frequently, but not always predicted higher metals leachability than the column tests, suggesting that they typically provide a more conservative estimate of environmental behavior. However, the study did not indicate which test methods better represented actual field conditions.

5.0 ANALYSIS OF FATE AND TRANSPORT

Analyzing chemical fate and transport at mine sites is a complex task due to the interactions between the hydrologic cycle, pollutant cycle, and sedimentation (watershed) cycle (Bonazountas, 1983). Consequently, fate modeling includes processes that occur on the land surface (soil, atmosphere and water), the unsaturated zone, and the saturated zone (Bonazountas, 1983). Anderson and Woessner (1992) describe a modeling protocol for ground water systems that can be extended and applied to mine sites. It includes establishing the purpose of the model, developing a conceptual model, selecting governing equations and an appropriate computer code, and designing, verifying and calibrating a numerical model.

5.1 Developing a Conceptual Model

A conceptual model is a pictoral representation of a complex system, frequently in the form of a block diagram or cross-section (Anderson and Woessner, 1992). The conceptual model simplifies a complex field problem and makes it more amenable to modeling. In particular, it helps to determine the dimensions of the numerical model and the design of an appropriate grid. An example of a conceptual physical ground water model taken from Anderson and Woessner (1992) is shown in Figure C-1. A conceptual physicochemical model of metal transport in a river, taken from Schnoor (1996), is shown in Figure C-2.

Four information components are needed to develop a conceptual site model (Bedient et al., 1994). Geology provides the physical framework within which subsurface fluids collect and flow and an understanding of the characteristics of the materials and solid wastes that must be handled. Hydrology describes the movement of fluids across the surface and through the physical framework (subsurface). Chemistry defines the nature of the chemical constituents transported by the surface and subsurface flow systems, including aspects of biochemistry as they apply to fluid chemistry. Climate provides data to describe interactions between precipitation, evaporation, surface flow, subsurface flow, and infiltration.

The amount of data required to develop a mine-site conceptual model of fate and transport are considerable (Schnoor, 1996; Hemond and Fechner, 1994; U.S. EPA, 1989). The mine plan provides information about the locations, character, and volumes of materials and wastes, surface and subsurface disturbances, ground water withdrawals, surface water diversions, and outfall locations and discharges. The solids balance describes the amount and character of material that will be excavated, processed, and disposed. The water balance characterizes the effects of climatic variations, drawdown, surface water diversion, and waste water discharge. Surface water
hydrology provides information regarding discharges and their seasonal variation, surface water chemistry, and storm runoff. Ground water hydrology describes flow rates (flux), hydrologic gradients, ground water volumes, ground water chemistry, and flow paths. Geology provides data on vertical stratigraphy (including aquitards), lateral changes in stratigraphic relations, the locations and density of faults and fractures, and mineralogy. Aquifer characteristics include physical aspects such as hydraulic conductivity, porosity, and fracture and matrix flow and chemical aspects including adsorptive or neutralizing components and biogeochemical processes. Contaminant characteristics describe the chemistry, density, discharge, volume, and chemical and physical stability of solid and liquid wastes and materials.

5.2 Mathematical Models

Mathematical models that couple physical flow and chemical mass balance equations are used to simulate the flow and transport of contaminants through the environment. Because models used for predictive purposes are only as good as the data input to them, high quality, site-specific data are required to produce confident and realistic model predictions.

5.2.1 Categories of Mathematical Models

Mathematical models can be grouped into three general categories (Knox et al., 1993). *Analytical models* solve governing equations using simplifying assumptions. They are generally one- or two-dimensional models that assume steady-state flow. *Stochastic models* incorporate uncertainty by using mean values coupled with a measure of variance. *Numerical models,* which are the most commonly used model form, are computed solutions to coupled partial differential equations of flow and mass balance equations of contaminant fate. Numerical models are solved in one-, two-, or three-dimensions using either finite element, finite difference, or method of characteristics techniques. Detailed discussions of each of these methods can be found in Knox et al. (1993) and Bedient et al. (1994).

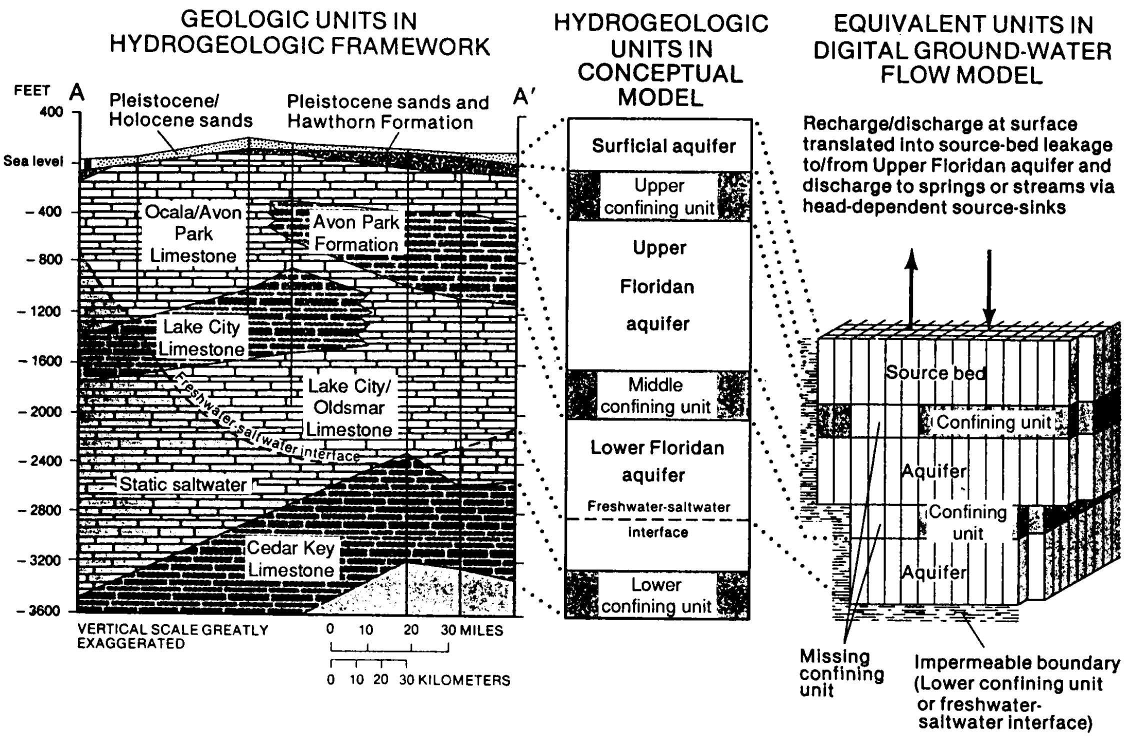

Figure C-1. Conceptual physical model of ground water flow from Anderson and Woessner (1992).

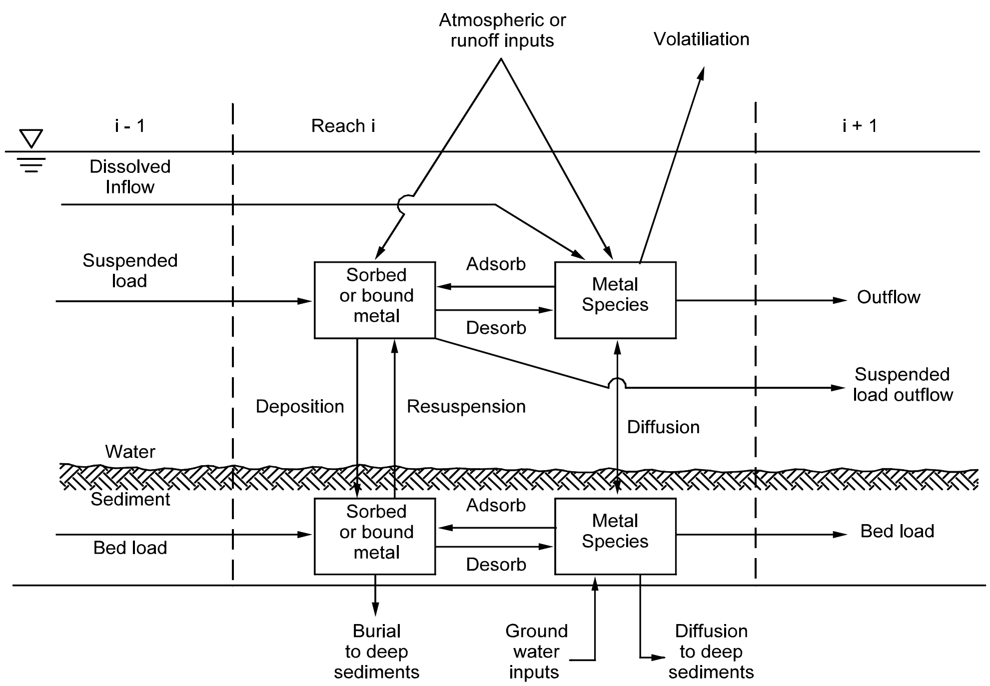

Figure C-2. Conceptual physicochemical model of metal transport in a river from Schnoor (1996).

5.2.2 Chemical Equilibrium Models

Numerous physical, chemical, and biological processes occurring in surface and subsurface environments can affect the transport and fate of contaminants. These can be divided into abiotic and biotic processes (Keely, 1989a). Abiotic processes are physical and chemical interactions that cause contaminants to move at a rate different from than that of surface or ground water. They include hydrolysis, sorption, cosolvation, immiscibility, ionization, radionuclide decay, complexation, volatilization, photodegradation, precipitation, dissolution, and reduction-oxidation (Johnson et al., 1989; Schnoor, 1996). Biotic processes are microbially mediated transformations or adsorbtion of contaminants. They include biodegradation and bioaccumulation. Other physical processes that may affect contaminant concentrations include hydrodynamic dispersion, molecular diffusion, and density stratification (Knox et al., 1993).

Chemical equilibrium models calculate changes in chemical concentrations assuming equilibrium. Aqueous models of trace metal concentrations compute chemical species by accounting for aqueous-phase complexation (e.g., by naturally occurring humic acids), surface complexation (e.g., by ion-exchange on the surfaces of clays), adsorption and sedimentation by particles (e.g., lead adsorbed on the surface of ferric hydroxide), mineral precipitation (e.g., ferric hydroxide), mineral dissolution (e.g., calcite dissolution by acid), aggregation/flocculation (e.g., the formation of colloidal suspensions by electrostatic processes), redox reactions that affect solubility (e.g., Cr^{+3} and Cr^{+6}), and adsorption by soil particles (Johnson et al., 1989; Schnoor, 1996). Summary descriptions of three chemical equilibrium models, MacµQL, MINEQL+, and MINTEQA2, are given in Schnoor (1996).

5.2.3 Physical Flow and Transport Models

Flow and solute (mass) transport models are available for surface water, ground water (saturated zone), and the vadose zone (unsaturated zone). They typically are used in conjunction with one of the equilibrium chemical models described above. The mathematical development of the governing flow and transport equations used in many of these models is given in Schnoor (1996).

Models commonly used to compute river water quality include QUAL2EU, NONEQUI, and WASP (summary descriptions are given in Schnoor, 1996 and are available via the internet n sites for the U.S. EPA's Robert S. Kerr Environmental Research Lab and Center for Exposure Assessment Modeling). QUAL2EU is a steady-state model for pollutants in branching streams and well-mixed lakes that incorporates uncertainty analysis into the model results.

Keely (1989b) points out that many ground water models are inappropriate for use in areas where subsurface flow is controlled by fractures or karst features. Consequently, the choice of models determines whether realistic model predictions can be computed for these areas. Bedient et al. (1994) provide summary model descriptions and a listing of modeled processes for a variety of unsaturated and saturated flow and solute transport models. Included are 6 vadose-zone flow models, 11 vadose-zone solute transport models, 12 saturated zone flow models, and 9 saturated zone solute transport models. Additional model descriptions are available via the internet from the U.S. EPA's Robert S. Kerr Environmental Research Lab. Among the more widely used saturated zone models are MODFLOW, a three-dimensional finite difference model, and USGS-MOC, a two-dimensional finite difference and methods of characteristics model for ground water flow and solute transport. Anderson and Woessner (1992) describe three conceptual models that can be used to approximate flow through a fractured system for input to models based on saturated or unsaturated flow. Each of these conceptual models uses assumptions that oversimplify flow through the fractured system.

6.0 SAMPLING PROGRAMS

The environmental sampling process should follow a sequence of steps to ensure that collected samples are representative and adequate (Triegel, 1988). It is important to first identify the goals of the sampling program and the levels of confidence required. The number of required samples then can be determined by characterizing the sources of variability (e.g., sample heterogeneity). Using these data, the sample program can be designed. The design should consider the types of analyses that will be conducted on the samples and include the number and distribution of samples and their manner of collection. The following sections specifically address geochemical testing programs.

6.1 Objectives of a Geochemical Sampling Program

Establishing a reliable geochemical testing program is a difficult, but critical, aspect of mine site development. By indicating whether control technologies or alternative disposal methods should be added to the existing mine plan, a robust program that uses representative samples can diminish, perhaps eliminate, the costs of contamination mitigation and control that would be encumbered should environmental problems arise in the future (Robertson and Broughton, 1992).

The geologic history and nature of mineralization observed at a mine site is unique to that particular location. As a result, geochemical sampling programs will differ from site to site. Nevertheless, all sampling programs should strive to capture the range of variability that occurs, provide an accurate statistical representation of the materials present, and objectively test the feasibility of the disposal methods described by the proposed mine plan. A geochemical sampling program should consider several factors that could affect the chemical or physical character of samples and, consequently, impact test results. Included are the method of sample collection, the length of time that a sample will be (or has been) stored prior to analysis, and the environment in which samples are (or were) stored (U.S. EPA, 1994).

For proposed mines, sampling and testing programs use fresh samples to predict the potential for acid generating conditions to develop or metals to leach from materials and wastes (Robertson and Broughton, 1992). A sampling program should be developed within the context of geochemical rock units and be related directly to a mine plan that outlines the area to be mined, the locations of pit walls and benches or underground workings, the locations and amounts of ore and waste rock that will be excavated, and the approximate timing of excavation and final placement of the materials (BC AMD Task Force, 1989; Price, 1997). The latter is especially important for determining the potential for contaminant release from waste rock dumps and other managed materials because these features can vary in particle size, mineralogy, and chemical composition over short distances and over the life of the mining operation. The sampling program also should include materials (e.g., tailings) produced during bench-scale or pilot-scale processing tests of samples that encompass the range of materials that will be processed over the life of the operation. Geochemical and mineralogical variability can be evaluated using three-dimensional geostatistical techniques similar to those used to characterize the ore body (Robertson and Broughton, 1992). While these methods are well-developed, they are beyond the scope of this appendix.

Sampling and testing programs at existing or abandoned mines should address questions regarding the quantity of acid products stored in the materials and wastes and how contamination emanating from them is likely to change in the future (Robertson and Broughton, 1992). For studies of existing waste rock dumps, spent ore heaps, or tailings piles, a sampling program must establish the physical, mineralogical, and chemical variability of the materials and wastes (see Nash et al., 1998).

6.2 Sample Representativeness

Samples used in geochemical tests should be representative of the materials that will be mined and processed. According to Smith et al. (1988), representativeness expresses the degree to which data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or a process or environmental condition. Indeed, the major source of uncertainty in a sampling and testing program lies in the samples themselves. In particular, the question of how accurately a sample represents a larger volume of material can only be addressed by establishing the variation inherent in the geochemical rock unit by taking multiple samples and examining their frequency distribution (BC AMD Task Force, 1990). In this regard, sampling programs should establish criteria for sample size, the appropriateness of compositing samples, and collection method to meet data quality objectives related to representativeness.

6.2.1 Proposed Mine Sites

Tests to determine physical and geochemical variability should be conducted initially on each lithologic unit that will be excavated, exposed or otherwise disrupted in a mine site area. They should use as their basis the mineralogical zonation observed within the ore body and, if possible, the mineralogical distinction that separates ore material from waste rock. The results of initial tests can be used to define units with similar geochemical and leachate production attributes (i.e., geochemical rock units; Brodie et al., 1991). In some cases, test results will require that a heterogeneous lithologic unit be divided into two or more geochemical rock units, whereas in other cases, two or more homogeneous lithologic units may be grouped together. Each geochemical rock unit should be tested further to define the range of its geochemical characteristics. In essence, a sampling program should use an iterative process to assess variability and it should be designed to be sufficiently flexible to respond to changes in the mining plan (Robertson and Broughton, 1992).

Geochemical test samples should be collected from each geochemical rock unit over the full vertical and areal extent of the mine site or area of interest. Geographical representativeness can be depicted using maps and cross-sections. The number of samples that should be tested depends on the volume and variability of the rock unit in question. In general, sample requirements increase with chemical and mineralogical heterogeneity, but there are no widely accepted guidelines. For example, the BC AMD Task Force (1989) recommended a minimum number of acid-base accounting test samples appropriate for a rock unit with a given mass. As shown on Figure C-3, this approach can lead to extensive sampling requirements for large facilities and result in high sampling costs. Price (1997) also provides minimum sample numbers based on unit tonnage. Alternatively, Runnells et al. (1997) suggested that the number of required samples should reflect the heterogeneity of the materials within the facility. The appropriate number of samples is obtained when statistical variability in sample results is within acceptable limits. Using this approach, the number of samples needed to characterize a facility will vary from one facility to another because each facility is unique. The Runnells et al. (1997) method can be applied easily to existing facilities, but may be difficult to apply to materials that would be disposed of in proposed facilities. Nevertheless, sampling programs that use a fixed-frequency sampling approach should be designed to ensure that sample variability can be described with statistical validity (e.g., BC AMD Task Force, 1990).

Geologic materials, which are composed of one or more minerals, are by definition composite materials. For the purposes of geochemical testing, sample sizes should be large enough to smooth the effects of small-scale heterogeneity, but small enough to reveal the variations present in the rock unit of interest. The effects of composite sample size on the distribution of net neutralization potential values obtained from a highly variable rock mass are described by Robertson and Broughton (1992). For waste rock and overburden materials, samples are commonly lengths of drill core or drill cuttings. Robertson and Broughton (1992) suggest restricting drill core lengths to less than 0.5 meters for acid-base accounting tests to ensure that the chemical behavior of a waste rock pile can be evaluated on small and large scales.

6.2.2 Existing or Abandoned Mine Sites

Existing or abandoned mine sites can pose special problems for geochemical test sampling because the history of the mine and the detailed composition of materials and wastes may be unknown or unrecorded. Changes to processing methods and efficiency that may have occurred during active production or time gaps when mining did not occur can produce chemical and physical heterogeneity within piles of materials that are not evident from their exposed surfaces. Consequently, sampling programs designed for existing or abandoned mine sites should determine the variability of all materials disposed of or exposed on the surface (see discussion of Runnells et al. 1997 in Section 6.2.1 and Nash et al., 1998) or through a well-planned composite sampling program (Smith et al., 2000). For pit walls, this will require

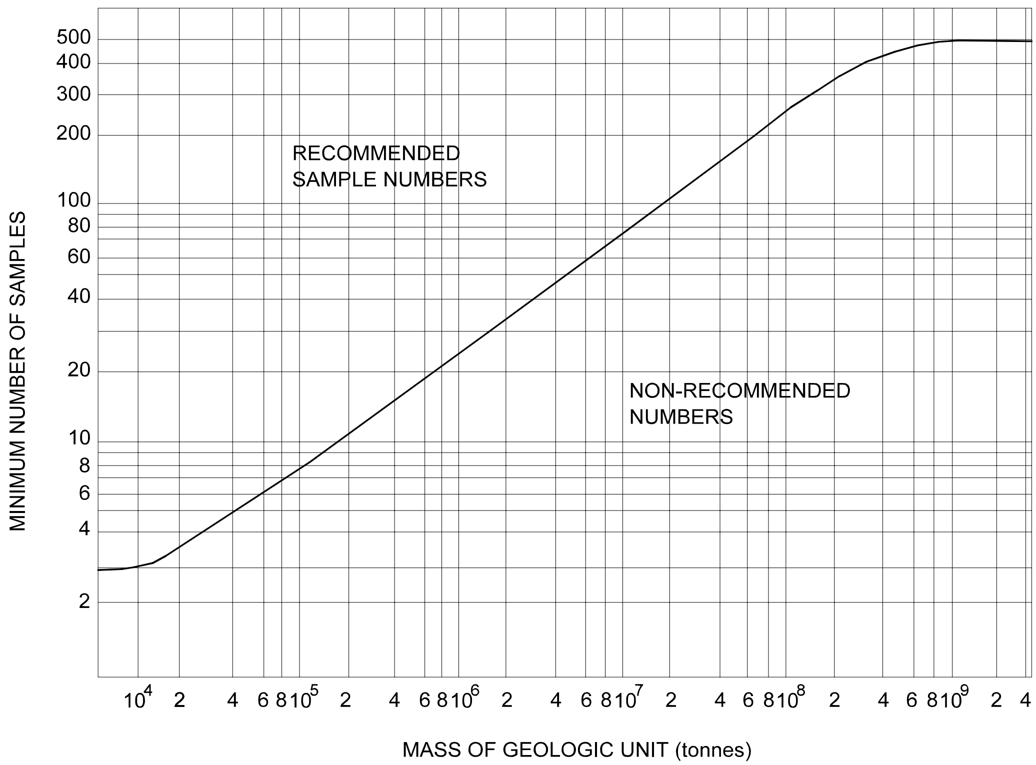

Figure C-3. Minimum number of samples as a function of rock mass recommended by the BC AMD Task Force (1989) collecting samples vertically and laterally across the exposed rock faces. For waste rock dumps, spent ore heaps, and tailings impoundments, it will require collecting samples laterally and vertically throughout the deposit (typically by drilling) (Nash et al., 1998). Data gathered from these samples can be used to construct a three-dimensional image of the volume and chemical and physical character of the waste materials. As described in the previous section, the number of samples required by the program depends on the volume and variability of the materials in question, but generally increases with chemical, mineralogical, and physical heterogeneity.

6.3 Quality Control and Quality Assurance

A recent report by Downing and Mills (1998) describes the application of quality assurance and quality control procedures as they apply to acid rock drainage studies. QA/QC guidance and procedures prepared by EPA are available in Adobe format on the EPA Region 10 QA website (www.epa.gov/r10earth/offices/oea/qaindex.htm). New guidance for the preparation of QAPP documents is in review and is scheduled for issue in early 1999.

6.3.1 Quality Control

Taylor (1988) defines quality control as the application of good lab practices, good measurement practices, and standard procedures for sampling. The latter should include specifications for chain-of custody, storage and preservation, stabilization methods, labeling, and sample containers.

Physical and geochemical tests conducted using approved methods (EPA or otherwise) will produce analytical results with accuracy and precision sufficient for all likely applications, providing that methods are chosen for their ability to meet the data quality objectives described in the next section. In this regard, it is important for applicants to select analytical methods that have the necessary detection limits. Applicants should periodically submit replicate samples for testing and analysis to confirm laboratory assessments of analytical performance.

6.3.2 Quality Assurance

Quality assurance is the process of monitoring for adherence to quality control protocols (Taylor, 1988). Smith et al. (1988) list five data quality objectives of a quality assurance project plan (QAPP): precision, bias, representativeness, completeness, and comparability (cf. U.S. EPA, 1980; 1998a; 1998b). Precision leads to a measurement of variance (e.g., standard deviation) and is the mutual agreement among individual measurements under prescribed similar conditions. Bias refers to the degree to which a measurement reflects an accepted true or reference value, commonly expressed as a percentage. Representativeness, as described above, expresses the degree to which data accurately represent a characteristic of a population. Completeness is a measure of the amount of valid data compared to the amount expected to be obtained under normal conditions. Comparability is a measure of confidence that one data set can be compared to another.

A QAPP will ensure that procedures are established prior to the beginning of sample collection and will help to balance the costs of implementing a quality-assured program against the liabilities of a poorly designed and executed sampling program.

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APPENDIX D

EFFLUENT QUALITY

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Hard rock mining operations can generate large quantities of effluent that are discharged to surface and ground water. The primary sources of effluent include drainage from mine workings, seepage and run-off from tailings impoundments or dry tailings piles, seepage and run-off from waste rock and spent ore dumps, and run-off from disturbed areas. The quantity and quality of effluent generated from each of these areas and facilities is a function of hydrological and geochemical factors as well as the engineering design for the facility. It is essential for mine operators and applicants to predict with a high degree of certainty the quality of all effluents from mine operations and waste disposal facilities that will or may be discharged to surface waters during all stages of a mine's life—development, operations, closure, and thereafter. This will enable the operator to predict and assure compliance with water quality standards, and to predict impacts to surface and ground water resources.

A detailed discussion of water quality standards and designated uses of receiving waters is provided in the main text and in Appendix B, *Receiving Waters*. This information is briefly summarized in Section 1.1 below. In addition, the main text presents a discussion of the regulatory classification of the various discharges to surface waters and of the water quality-based and technology-based standards that are incorporated into NPDES permits.

The principal goals of this appendix are to outline the methods and analytical procedures commonly used to characterize the quantity and quality of effluent generated at mine sites, and to identify the information related to effluent quality that must be provided to EPA under NEPA and the Clean Water Act. If predicted or tested effluent water quality does not meet applicable water quality- and technology-based effluent limitation standards, an applicant must demonstrate through its mine plan that appropriate management practices and/or water treatment systems will be employed to meet these standards prior to discharge. Accurate characterization of effluent water quality relies heavily on studies to characterize other resources such as site hydrology and meteorology, hydrogeology, water quality and waste and materials geochemistry. The fate and transport of effluent also is related to the design of the mine (either surface or subsurface) and its facilities, including tailings impoundments, dry tailings embankments, and waste rock dumps. The materials in this appendix complement discussions of resource characterization and waste management that are presented in Appendix A, *Hydrology,* Appendix B, *Receiving Waters*, Appendix C, *Characterization of Ore Waste Rock and Tailings,* Appendix E, *Wastewater Management,* and Appendix F, *Solid Waste Management.* The reader is referred to these appendices for more detailed discussions of these topics.

1.1 Water Quality Standards and Effluent Limitations

Water quality standards for receiving waters are discussed in Appendix B, *Receiving Waters.* Under the Clean Water Act, each State must classify all of the waters within its boundaries by their intended use. Once designated uses have been determined, the State must establish numeric and narrative water quality criteria to ensure the attainment and/or maintenance of the use. State water quality standards and implementing provisions are approved by EPA and are codified in State regulations.

The CWA provides that the discharge of any pollutant to Waters of the United States is unlawful except in accordance with a National Pollutant Discharge Elimination System (NPDES) permit. Section 402 of the Clean Water Act establishes the NPDES program which is designed to limit the discharge of pollutants into Waters of the U.S. from point sources through a combination of various requirements, including technology-based and water quality-based effluent limitations (40 CFR 122.1 (b)(1)). An NPDES permit must contain any requirements in addition to, or more stringent than, promulgated effluent limitation guidelines or standards necessary to achieve water quality standards, including State narrative criteria for water quality. NPDES permits are required to limit any pollutant or pollutant parameter that is or that may be discharged at a level that causes, has the reasonable potential to cause, or contributes to an excursion above any water quality criterion. See the main text for a more detailed discussion of the development of NPDES permit conditions, including effluent limitations.

It is important that applicants be able to predict effluent concentrations in light of the applicable water quality standards. A common problem encountered in many mining-related discharge permit applications is that metals are analyzed by methods with detection limits that are higher than the water quality criteria. It is important for any sampling and analysis program to ensure that:

- Appropriate methods and detection limits are used,
- All necessary constituents are measured,
- Data are obtained for total and dissolved phases of most metals, and
- The number of samples collected is adequate to accurately characterize expected variability in effluent quality (Sampling and Analysis Plans are described in more detail in Appendix B, *Receiving Waters*).

1.2 Considerations Regarding Predictive Modeling of Effluent Quality

Predictions of effluent quality often are based on modeling that uses water quality and hydrological data to calculate the geochemical species present at equilibrium, the geochemical reactions that are likely to occur under the physical conditions that prevail, and physical transport. They require a forward modeling approach in which assumptions regarding the initial state of a system and its boundary conditions are used to simulate the consequences of particular geochemical reactions (Alpers and Nordstrom, in press).

Alpers and Nordstrom (in press) discuss limitations to geochemical modeling and cite several cautionary measures that should be followed by those who create and interpret models of effluent quality. These measures apply to each of the modeling discussions below and are not repeated therein. Important considerations cited by Alpers and Nordstrom include:

- Modeling is an inexact science subject to numerous uncertainties and limitations.
- Models are not reality and may not be a reliable, correct, or valid representation of reality; they are only a tool to increase understanding.

- Geochemical models can never be proven as true in an absolute sense, their results are useful only insofar as they can be used to improve or disprove the original conceptual model.
- Analytical and thermodynamic data must be scrutinized for accuracy and internal consistency prior to their use.
- Chemical data used as input should be highly accurate and precise because errors can be exaggerated when propagated through model calculations.
- Standard errors should be clearly identified during sensitivity analyses.
- Model assumptions should be clearly identified, especially with regard to parameters such as redox potential.
- Speciation calculations indicate those reactions that are thermodynamically favored, not necessarily those that are likely to occur.
- Interpretations of ground water chemistry require knowledge of the flow system, aquifer mineralogy, and effects of sampling.
- Forward modeling places more responsibility on the user to make appropriate choices with regard to phase, components, and reaction equilibria.

Types of modeling applicable to different types of effluent is discussed in more detail in the following sections. Regardless of the specific model that is used, information such as the following should be submitted to EPA to substantiate modeling used for regulatory purposes:

- Description of the model, its basis, and why it is appropriate for the particular use
- Identification of all input parameters and assumptions, including discussion of how the parameters were derived (whether by measurement, calculation, or assumption), and whether they represent conservative conditions
- Discussion of uncertainties
- Sensitivity analysis of important input parameters.

Appendix A (Hydrology; Section 6.0) provides additional information related to the use of modeling for regulatory purposes. This appendix discusses a number of specific models that are commonly used to characterize effluents. Applicants should recognize that it is not the intent of this appendix to provide a comprehensive list of available models nor to suggest that these are the only models that can or should be used.

2.0 MINE DRAINAGE

Mine drainage includes waters that drain from or infiltrate into historical workings and that are pumped from active surface or subsurface mining operations. Although drainage can be sampled directly from active or historical workings, applicants for proposed mines will need to estimate the quantities and compositions of these waters. The NEPA review and CWA permitting processes will require applicants to provide accurate assessments of mine drainage volumes and quality during operations and after closure. (The main text describes the regulatory definition of “mine drainage”).

2.1 Determining Mine Drainage Quantity and Discharge

Mine drainage from historical workings can be measured using techniques similar to those for measuring surface discharge. Typically this requires installing a stream gauge or other measuring device at the point of discharge. Some subsurface mines, particularly shallow adits and underground workings, may exhibit seasonal flow that occurs in response to snowmelt or other climatic factors. Where this occurs, applicants will need to characterize the magnitude of seasonal flow from all historic workings. For mines that are flooded and will be dewatered, maps of historic workings (if available) or records of mine production can provide some measure of the volume of drainage water that will require disposal.

Dewatering (e.g., pumping ground water from) mine workings, adits, or open pits is required when the mine elevation extends below the potentiometric surface in confined aquifers or below the water table in an unconfined aquifer. When an underground mine is excavated, the workings serve as a ground water sink that affects the natural ground water system. A mine can capture ground water recharge and stream flow and can drain ground water from storage. Underground and pit mines are typically dewatered using in-shaft or in-pit wells, perimeter wells, and/or sumps. Pumping ground water lowers the water table by creating a “cone of depression” in proximity to the mine. The quantity of water produced by pumping operations depends on the pumping rate, aquifer hydraulic conductivity, transmissivity and storage, and the homogeneity of the aquifer. Water produced from mine dewatering operations may be used for process operations, disposed via evaporation or infiltration ponds, and/or discharged to surface waters.

Applicants proposing operations in which a pit lake is expected to form after dewatering operations cease will be expected to estimate the rate at which the lake will form and its final elevation. A lake water balance must consider factors such as the rate of ground water inflow, contributions from surface run-off and precipitation, and losses from evaporation, seepage, or discharge. The water balance should lead to estimates of the equilibrium lake level and the amount of time it will take until this level is achieved. Applicants should also determine whether there will be a discharge from the pit lake, and the quantity and seasonality of any discharge.

Methods to characterize hydrogeology and ground water discharge at mine sites are discussed in Appendix A, *Hydrology*. Hydrogeologic characterization studies should include geological descriptions of the site, including descriptions of rock types, intensity and depth of weathering, and the abundance and orientation of faults, fractures, and joints. Although difficult to evaluate, the hydrologic effects of fractures, joints, and faults are especially important to distinguish and characterize. Water moves more easily through faults, fractures, and dissolution zones, collectively termed secondary permeability, than through rock matrices. Secondary permeability can present significant problems for a mining facility because it can result in a greater amount of ground water discharge to a mine than originally predicted.

Three methods are used to estimate ground water inflow to a mine; all are generally applicable to both open pit and underground mines:

- Analytical solutions for flow to a simplistic analog, such as a well or trench;
- Numerical ground water flow models based on a representative conceptual hydrogeologic model and a mine plan, and;
- Hydrologic control volumes to calculate inflows.

Applications of these general methods are briefly described below. Regardless of the methodology used, the quantity of ground water discharged to a mine and the resulting volume of mine water produced must be accurately characterized. This often requires applicants to determine whether mine development activities (e.g., blasting) would affect seasonal inflow or change recharge/discharge relationships, either of which could impact the amount of drainage. The discharge of water to a mine can potentially affect the effluent quality of both of the mine water and of ground water flowing down-gradient within an aquifer. Accurate determinations of the rate of inflow is specifically required to design water treatment systems. It is important, therefore, to couple studies conducted to determine the volume of water discharged to or from a mine with those to characterize water quality.

2.1.1 Analytical Solutions

A common method to analyze ground water in relation to a mine relies on a simple analytical solution in which the mine pit is approximated as a well. This method uses the constant-head Jacob-Lowman (1952) equation to calculate flow rates. Although not as accurate as a numerical (modeling) solution, this method gives a good approximation of the rate of water inflow to a proposed mine. It generally yields a conservative estimate of the pumping rates required to dewater a mine (Hanna et al., 1994). A second analytical method uses the technique of interfering wells, where each drift face of the proposed mine is considered to be a well. The cumulative production of the simulated wells is used to estimate the total influx into the mine and the extent of drawdown.

2.1.2 Numerical Models

Numerical ground water models can be used to simulate heterogeneous systems in which a variety of coupled processes describe the hydrology of near surface and deep aquifer systems. Available models vary in sophistication but incorporate either finite-difference or finite-element methods for solving the governing equations for ground water flow. A comparison of finite-difference and finite-element numerical methods is detailed by Pinder and Gray (1977). Both schemes are widely used to simulate transient flow in aquifers (Freeze and Cherry, 1979). Descriptions of commonly used numerical ground water models are given in Appendix A, *Hydrology* and Section 3.1.2. MODFLOW (McDonald and Harbaugh, 1988) is perhaps the most widely applied ground water flow model and its use is accepted by most regulatory agencies. In addition to simulating subsurface flow, this model has been used to simulate inflow to a mine pit and the development of a pit lake after dewatering operations cease (Bursey et al., 1997). Applicants preferring to use other software packages should check with regulatory agencies prior to beginning their modeling efforts.

The predictive capabilities of numerical models depend on the quality of input data. The accuracy and efficiency of the simulation depend on the applicability of the assumptions and simplifications used in the model, the accurate use of process information, the accuracy and completeness of site characterization data, and the subjective decisions made by the modeler. Where precise aquifer characteristics have been reasonably well established, ground water models may provide the most viable, if not the only, method to adequately predict inflow to a mine, evaluate dewatering operations, and assess mining operational variables.

Estimates of the fate and transport of potentially contaminated ground water discharging from an abandoned surface or underground mine down-gradient or to surface water bodies generally require numerical modeling. Estimates of the transport of dissolved constituents through porous media is highly dependent on accurate input data to characterize transport mechanisms such as convection, hydrodynamic dispersion, chemical sorption, and first-order decay.

2.1.3 Calculations Based On Hydrologic Control Volumes

This method estimates the volume of ground water recharge and discharge that would occur in a given control volume. For mine drainage determinations, the control volume would be defined as the volume of water-bearing rock that would be impacted by a mine. In general, the method applies water balance calculations to determine the volume and rate of water inflow to the exposed mine area (e.g., exposed aquifer) (Singh and Atkins, 1984). A water balance calculation is first applied to estimate the volume of ground water recharge that would be expected to enter a mine based on average or estimated values for precipitation, run-off, evapotranspiration and the surface area of the exposed aquifer. A second water balance is then applied to estimate the volume of ground water that would be expected to enter a mine from depletion of ground water storage. This estimate is based on measured or estimated factors for specific yield or drainable porosity, the surface area of the exposed aquifer, and the difference in the elevational head between the pre-mining water table and the lowest portion of the mine. These two calculations are then combined to estimate the total volume of ground water expected to enter the mine from recharge and subsurface sources.

The control volume method should only be applied when ground water data are insufficient to perform numerical or analytical analyses. The method is subject to errors associated with temporal variations in, and long-term measurements of precipitation run-off and stream flow. In addition, depending on hydrogeological conditions, the method potentially underestimates peak inflows during the early stages of mine development. After ground water has been drained from storage, most ground water discharge to a mine occurs from recharge by precipitation and stream infiltration.

2.2 Determining Mine Drainage Effluent Quality

Applicants will need to estimate the quality of mine drainage effluent produced by their operations. For sites with historical workings, mine drainage can be sampled and analyzed. Mine drainage may also be available for analysis from exploration activities. For new mine sites, mine drainage quality will need to be estimated using geochemical models and testing. In cases where pit lakes are expected to develop after mining ceases, applicants will be required to estimate the long-term quality of these waters.

2.2.1 Considerations Regarding Constituent Analyses

For NPDES permitting purposes, the constituents that should be analyzed/predicted in effluents that are to be discharged to surface waters are the parameters identified in applicable effluent limitation guidelines and any pollutant that the applicant knows or has reason to believe may be present in the effluent. The latter is in turn governed by mineralogy, mining activities (e.g., blasting agents that may be added) and site characteristics. The level of analysis (e.g., detection limits) depends on applicable water quality standards. Constituents not necessarily important for NPDES purposes (such as conductivity and major constituents) may be important for geochemical modeling, selecting wastewater treatment processes, etc.

Initially, it is usually important to evaluate a relatively large number of metal species in order to determine whether any exhibit concentration changes that vary with discharge or time. Analyses should be conducted for major constituents such as iron, aluminum, and magnesium, as well as for trace metals such as antimony, arsenic, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc. Analyses of other trace metals may be appropriate when dictated by the mineralogy of the geologic units encountered and on the water quality standards designated for the receiving water. In general, analyses should be conducted to determine both dissolved and total metal concentrations (see Appendix B, *Receiving Waters*). Where static, kinetic, and leach testing are performed to indicate water quality (see Appendix C, *Characterization of Ore, Waste Rock, and Tailings*), data analysis should include evaluations of stable and expected species in relation to measured pH and Eh.

In determining mine drainage quality, applicants need to consider constituents that may be introduced through chemicals used in mine development and operation. Specifically, residual chemicals may be present in mine drainage due to use of explosives. For example, blasting operations that use ANFO can produce elevated levels of ammonia (NH_4) and nitrate (NO_3) in mine effluent. Similarly, applicants need to account for potential effects on mine drainage from any materials that will be backfilled to the mine (e.g., tailings)

Beyond individual constituent analyses, tests to determine whole effluent toxicity (WET) will need to be conducted for effluent discharges. As with chemical parameters, WET limits are required when WET test results show that the discharge has the “reasonable potential” to cause, or contribute to, an instream excursion of a numeric WET water quality standard or a narrative standard (e.g., “no toxics in toxic amounts”). Applicants should coordinate with EPA and State permitting authorities in determining the number and type of WET tests that should be performed.

2.2.2 Direct Measurement of Mine Drainage Quality

Direct measurement of mine drainage quality is possible at sites where historic workings are present. In these instances, applicants can use sampling and analysis procedures similar to those used to determine baseline surface and ground water quality (see Appendix B, *Receiving Waters*). Although direct measurements provide valuable data, applicants should exercise caution when extrapolating these values to a proposed project. For example, an operation proposed at a site with historic workings may extract ore that is mineralogically different from that which was mined previously. In cases where historic operations were conducted in oxide ore and proposed operations will operate in sulfide ore, historic water quality is likely to be a poor indicator of future water quality. Moreover, historic workings may contain multiple water sources with different water quality characteristics (e.g., Reisinger and Gusek, 1998), each of which may require evaluation in light of host rock and aquifer properties. Similarly, drainage from exploration activities may not be representative of full-scale mine development.

Studies and sampling designed to characterize the quality of ground water removed by dewatering operations should:

- Characterize the existing ground water quality in the vicinity of the proposed mine
- Determine the impacts to water quality from mine development (e.g., effects of blasting and the potential for acid generation from exposed surfaces)
- Define temporal differences in water quality that could occur seasonally or over the long-term. In general, natural ground water quality does not significantly change on a seasonal basis, but it may exhibit seasonality when acid generating mineralogy is exposed, near salt water intrusion areas, and near intermittent and influent streams (A. Brown, 1997).
- Characterize the ground water flow regime in all three dimensions.
- Characterize each lithologic unit the mine will intersect, and units at depths up to 1.5 times the depth of the proposed mine (A. Brown, 1997)
- Define water quality in both primary and secondary porosity systems, but focus on depths and lithologic units with the highest permeability, since these materials are the principal conduits for water and dissolved species (A. Brown, 1997).

There is no specific guidance for determining the number of samples that should be collected to characterize mine drainage quality. Because each mine site occurs in unique lithological and hydrological settings, the number of samples collected should be adequate to accurately define the average, median, and range of constituent concentrations, and to quantify the influence, if any, of seasonal changes in effluent quality.

The required sampling frequency depends on specific site conditions, lithology, and effects from temporal variations in recharge/discharge relationships. At a minimum, sampling should be conducted quarterly for at least one year to define potential temporal effects and sampling should continue throughout mine development and operation.

2.2.3 Predictive Modeling of Mine Drainage Quality

Predicting the quality of mine drainage is not a simple task (see Section 1.2). The following discussion considers three possible scenarios:

- Mine drainage that does not contact mine workings
- Mine drainage that contacts mine workings
- Mine pit lakes.

Mine drainage includes ground waters that are pumped from aquifers by dewatering operations. In areas where this water is removed from ground water storage without contacting mine workings or materials, mine drainage quality can be estimated using the measured baseline ground water quality, as discussed in section 2.2.1. Some mines may pump water from two or more aquifers and manage these waters together. In these cases, aqueous equilibrium geochemical models can be used to determine whether mixing will cause chemical effects such as mineral precipitation or desorption.

Dewatering operations may permit ground waters to contact mine workings prior to removal. In such cases, estimates of mine drainage quality will need to account for possible constituent contributions from the mine workings. The results of leach tests, kinetic tests, or minewall washing procedures can be used alone or in combination with computer models such as MINEWALL to estimate contributions from exposed, reactive rock surfaces (MEND, 1995; Morin and Hutt, 1995).

Open pit mines may flood and form pit lakes after dewatering operations cease. Applicants will be expected to estimate the quality of lake water and demonstrate a general understanding of how it may evolve with time. The process is complex, as illustrated in Figure D-1, which shows a conceptual model of the important components affecting pit-lake water quality, including:

- Lake water balance,
- Ground water composition,
- Geochemical reactions, and
- Wall rock contributions.

Of particular importance are any intermittent or permanent discharges, and applicants must predict the timing, quantity, and quality of any such discharges.

The lake water balance, described in Section 2.1, is a critical piece of information required to evaluate lake water quality (Kempton et al., 1998) and the potential for discharge. In addition to determining the rate of inflow and final lake volume, the water balance indicates the volumes of water and the constituent loads that would be contributed from different sources (Bursey et al., 1997). Importantly, different water sources are likely to have different water quality characteristics. For example, run-off from exposed pit walls will have characteristics that differ from seepage emanating from a waste rock pile. These compositions can be estimated from kinetic and leach tests of samples of materials that will be exposed in the pit walls. Ground water is likely to comprise yet another source. Waters contributed from each source can be mixed in the proportions in which they are expected to occur using an equilibrium geochemical model such as PHREEQC. This weighted mix can be used as an estimate of water quality (Bursey et al., 1997).

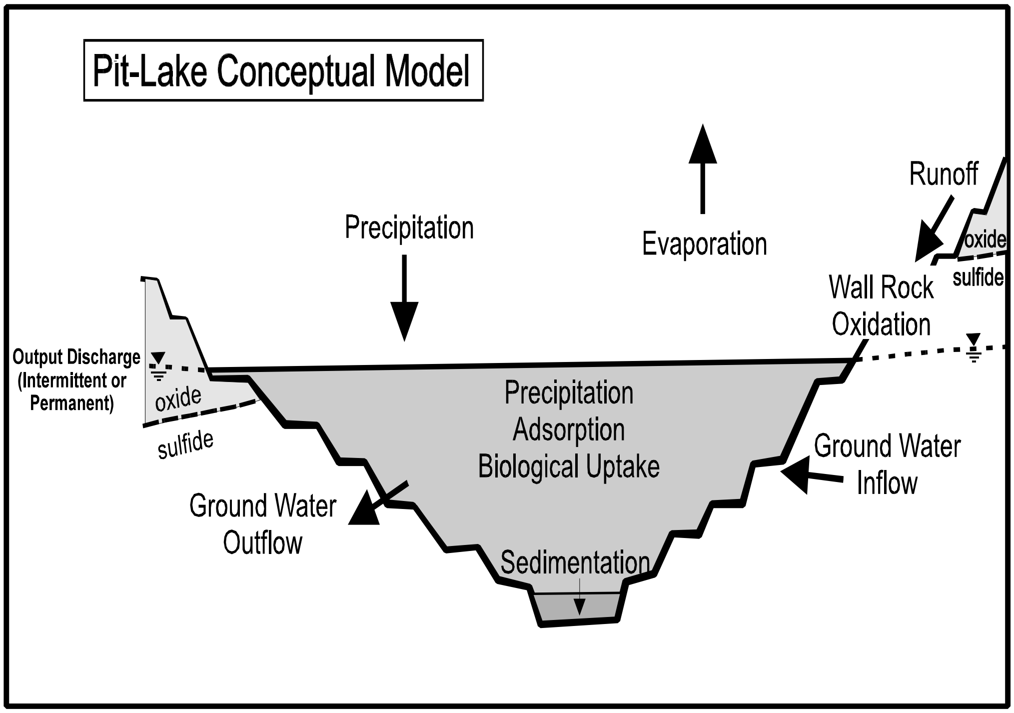

Figure D-1. Conceptual model of components that affect pit lake water quality (modified from Kempton et al., 1998)

Assigning source compositions will require applicants to use best professional judgement in the application of kinetic test results, leach test results, and surface and ground water quality analyses.

Equilibrium geochemical models can be used to evaluate how baseline water quality might evolve in light of the final physical character of the lake (e.g., outflow or terminal; volume; surface area, etc.). These calculations would determine how water quality would change in response to reactions between lake water and wall rock, through precipitation of mineral phases, as a result of adsorption reactions, and in response to biological activity (see Kempton et al. (1998) and Bursey et al. (1998) for a detailed discussion of the wide number of variables that applicants may need to consider). Final pit lake water quality will also require consideration of the physical limnology of the pit lake (Atkins et al., 1997; Doyle and Runnells, 1997) and the effects of long-term processes such as evapoconcentration (Bursey et al., 1997). Physical limnological considerations include chemical or physical stratification of the water column, seasonal overturn, and circulation.

3.0 WASTE ROCK AND SPENT ORE PILES

Seepage and run-off from waste rock dumps and spent ore (e.g., heap leach) piles[1] are sources of effluent. It is important that effluent from these units be predicted during both operations and closure. The materials in these units are composed of comparatively coarse-grained materials that are unsaturated to partly saturated. The potential for seepage is high in wet environments, but less certain in areas where annual precipitation is less than about 380 mm/yr (Swanson et al., 1998).

To accurately predict leachate and run-off water quantity and quality requires an understanding of both the hydrology and geochemistry of the pile. These characteristics are determined by the physical configuration of the pile, its engineering design and method of construction, the distribution of geologic materials within it (especially the acid producing and acid neutralizing materials), the addition of amendments or process chemicals to the pile, and the transport of water through it (SRK, 1992). The situation can be made more complex in cases where dumps have been fitted with engineered caps or soil covers during partial or complete closure. Such covers are likely to alter the flow of water and air through a pile that may have been exposed to the elements for many years. Consequently, pre-cap and post-cap configurations may need to be considered. According to SRK (1992), it is extremely difficult to predict the quality of water that will emanate from a waste rock or spent ore pile because there is no single analytical method or model that accurately combines algorithms for temperature, air and water transport, oxidation, neutralization reactions, and attentuation. Such models are presently being developed (e.g., Lin et al., 1997; Lopez et al., 1997; Newman et al., 1997). It is important for mining hydrologists and geochemists to combine programs for geochemical testing with hydrological studies to provide conservative estimates of effluent quality.

3.1 Determining Water Quantity and Discharge from Waste Rock and Spent Ore Piles

Precipitation that falls onto the surface of a waste rock dump or spent ore pile either infiltrates or flows laterally as run-off.

Swanson et al. (1998) describe a conceptual model of the hydrology of a pile of coarse waste materials that can be used as a basis for hydrological modeling. It contains three major components (see Figure D-2):

- Infiltration through the active surface zone,
- Percolation through the waste materials, and

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[1] Spent ore is ore from which it is no longer economic to leach or otherwise remove valuable minerals. Spent ore can be in the heaps or dumps where leaching occurred or in repositories where leached ore is moved following detoxification. (Note that applicants should predict effluent quality during active operations for any discharges that may occur, including discharges under the NPDES "storm exemption." The latter is important when the predicted mine life amounts to a substantial proportion of the return interval of the facility's storm-surge capacity—a predicted 15-year mine with capacity to store all precipitation from a 25-year storm, for example.)

- Seepage at the base of the facility.

Under unsaturated conditions, water percolating through a disposal unit will gradually wet the materials and, depending on local conditions and material properties, will be stored in pores within the pile. For homogeneous piles of coarse rock, water is likely to be transmitted quickly to the base of the pile (Smith et al., 1995). Many waste rock dumps, however, are not homogeneous piles of coarse material, but instead are composed of a mix of coarse and fine materials that have undergone some degree of segregation through end-dumping or other construction practices. Particle segregation can create unit-specific hydrological characteristics that can lead to preferential flow through fine-grained waste rock layers as described by Newman et al. (1997) and Swanson et al. (1998). Seepage from the base of the pile may occur when storage is depleted or the hydraulic head is sufficient to force water through the toe of the dump. Depending on the nature of the foundation materials and the topographic setting of the dump, seepage may flow laterally from the base of the dump or percolate downward into the substrate. Flow through a heap could be somewhat different, since the materials, and the subsurface are likely to be somewhat different themselves. Although nominally homogenous, ore may have been agglomerated with cement or other materials, and there may be zones of low permeability throughout a heap or dump. Flow through heaps and dumps should have been modeled during site planning, and these data may be useful in predicting seepage and other flows through spent ore piles and dumps.

Aspects of engineering design influence the production of effluent from waste rock

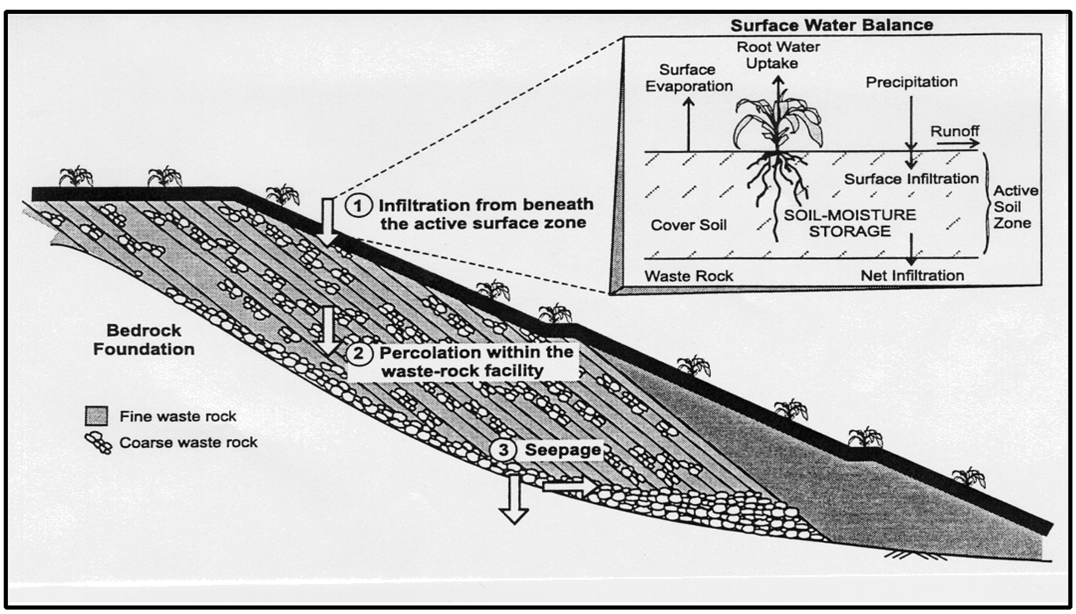

Figure D-2. Conceptual model of water flow through a reclaimed waste-rock facility (from Swanson et al., 1998) dumps and spent ore piles (see Kent, 1997 and Appendix F, *Solid Waste Management*). These include the:

- Range of geotechnical and hydrological properties of the waste materials;
- Topographical location of the dump (e.g., steep mountainous terrain versus valley fill sites);
- Mode of disposal and the expected particle size segregation that would occur from the dumping method;
- Lift construction and thickness;
- Loading rates;
- Pre-loading site preparation, such as placement of low-permeability clays or other soils and/or compaction of native soils or placed materials;
- Design of drainage systems, including internal drainage layers and foundation drains;
- Methods employed to isolate potentially acid or other contaminant generating materials;
- For spent ore, agglomeration or other means of treatment; and
- Physical and hydrological properties of the foundation.

In evaluating effluent production, applicants should consider factors in addition to engineering design. Certain operational practices, such as concurrent reclamation, use of daily or periodic covers, or seasonal operations, all would affect the quantity of effluent from dumps and piles. Similarly, actions taken at closure, such as topsoil replacement, design of the final cover, compaction of cover materials, or revegetation would affect effluent quantity. Applicants should consider and account for all variables that could affect the production of effluent through all mine life stages.

Most methods to characterize the hydrology and estimate the volumes and rates of run-off from and seepage through waste rock or spent ore piles use a water balance approach. In typical water balances, analytical methods to determine run-off and infiltration are combined with analytical or numerical solutions to estimate unsaturated and saturated flow through the embankment. The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994) combines several analytical hydrological procedures and provides volume estimates of surface run-off, subsurface drainage, and leachate that are likely to result from different waste pile designs. Because of its widespread application, the HELP model is described in detail below. Other models that have been used to characterize waste pile hydrology include MODFLOW, SUTRA, SEEP/W, and FEMWATER/FEMWASTE; these models are briefly described in Section 3.1.2 (FEMWATER/FEMWASTE is described in Appendix A, *Hydrology*).

3.1.1 Hydrologic Evaluation of Landfill Performance (HELP) Model

The HELP computer program (Schroeder et al., 1994) is a quasi-two-dimensional model that can be used to compare effluent generation and run-off from various waste pile designs. The model uses meteorological, material, and design data to compute analytical solutions and estimate parameters such as surface storage, snowmelt, storm water run-off, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembranes or composite liners. HELP can be used to evaluate various combinations of reclaimed or unreclaimed surfaces and surface soil caps, waste cells, lateral drain layers, low permeability barrier layers, and synthetic geomembrane liners. Results are expressed as daily, monthly, annual, and long-term average water budgets.

HELP simulates precipitation and other meteorological conditions using the weather generation model (WGEN) developed by Richardson and Wright (1984). Daily rainfall data may be input by the user, generated stochastically, or taken from an historical data base contained in the model. Daily temperature and solar radiation data also can be input by the user or generated stochastically. Determinations of run-off are calculated using the United States Department of Agriculture Soil Conservation Service (SCS) curve number method (SCS, 1985), which is described in Appendix A, *Hydrology*. Potential evapotranspiration is calculated using the Penman method (Penman, 1963). The HELP model also incorporates routines for estimating interception (Horton, 1919), snowmelt (Anderson, 1973), and frozen soil (Knisel et al., 1985). Vertical drainage is modeled using saturated and unsaturated relationships described by Campbell (1974). Lateral drainage is determined using approximations of the steady-state solution of the Boussinesq equation and the Dupuit-Forchheimer assumptions for lateral flow. Each of these processes is linked sequentially by the HELP model, starting with determinations for run-off and a surface water balance. It then applies evapotranspiration from the soil profile and finally determines drainage and water routing, starting with infiltration at the surface and then calculating seepage through the pile.

3.1.2 Other Models

MODFLOW (McDonald and Harbaugh, 1988) is a block-centered finite difference program that can be used to simulate steady-state and transient flow in two or three dimensions. Simulations can be run for porous media in confined and unconfined aquifers above an impermeable base.

SEEP/W (Geo-Slope International, 1995) is a two-dimensional finite element program for ground water seepage analysis. The program permits analysis of saturated and unsaturated flow, seepage as a function of time, precipitation infiltration, migration of a wetting front, steady-state or transient flow, confined or unconfined flow, and excess pore pressure dissipation. The software was used by Newman et al. (1997) to model flow through columns constructed to simulate a structured waste rock pile composed of layers of coarse and fine waste rock materials.

SUTRA (Voss, 1984) uses a two-dimensional, hybrid finite element and integrated finite difference method to approximate the governing equations and simulate fluid movement and the transport of either energy or dissolved substances in the subsurface. The program calculates fluid pressures and either solute concentrations or temperatures as they vary with time. Flow simulation may be used for cross-sectional modeling of saturated and unsaturated flow and areal modeling of saturated flow.

3.1.3 Considerations for Model Selection

It will be difficult to accurately predict the hydrological behavior of a waste rock dump or spent heap leach pile prior to its construction. This is because the physical characteristics of the pile (development of layering, grain-size variability, lithological changes, etc.) cannot be known with any degree of certainty. Consequently, applicants may need to model a variety of scenarios that cover the range of expected structures. As discussed by Hutchinson and Ellison (1991), drainage through a waste pile should be estimated using unsaturated ground water flow models which can account for the upward movement of water caused by capillarity. However, once a mine has been brought on-line, operational monitoring of meteorological variables and of the hydraulic conductivity of different geotechnical layers within a waste pile can be used to refine pre-construction models of effluent quantity.

Most numerical ground water models require separate analyses or modeling to create input for precipitation, infiltration, evapotranspiration, and run-off. One advantage of the HELP model is that it combines analyses of surface and ground water components. HELP also allows meteorological data to be determined stochastically. However, a disadvantage of the HELP model is that it employs a less accurate method (SCS curve number) to estimate infiltration and run-off. Run-off can be determined more accurately using the Kinematic Wave Method (Linsley et al., 1975; COE, 1987; see Appendix A, *Hydrology*). Infiltration can be more accurately determined using mathematical methods such as Green and Ampt (1911) or the Richards equation (Philip, 1969), empirical models such as Horton (1940) and Holtan (1961), or by using variations of these methods (U.S. EPA, 1998a, 1998b; see Appendix A, *Hydrology*). However, the application of these alternative methods requires detailed knowledge of several physical variables that may be unknown or difficult to estimate prior to construction of the waste rock or spent ore pile. U.S. EPA (1998a; 1998b) evaluates the variety of available infiltration methods and provides recommendations on their application; readers should refer to these documents for more information.

3.2 Determining Effluent Quality from Waste Rock and Spent Ore Piles

The composition of effluent associated with an existing waste rock or spent ore pile can be determined by sampling seeps or pore waters. In contrast, predicting the quality of effluent that would be generated from a proposed waste rock dump or spent ore heap prior to its construction is difficult and presently cannot be accomplished with a high degree of certainty. This is because the processes that govern effluent quality operate at rates that are difficult to predict under field conditions. This is especially true for ARD chemical reaction kinetics, bacterial growth kinetics, and their interactions (Lin et al., 1997). The problem is made even more difficult when the disposed materials vary in grain size and/or mineralogy, when materials have been subjected to leaching by process chemicals, when construction methods produce preferential fluid pathways, and when chemical additives (e.g., limestone, chelating agents, bactericides) are used as amendments during construction or closure. Consequently, two approaches are used to predict leachate quality from proposed facilities. *Empirical* approaches use the results of geochemical testing to provide a measure of the future behavior of waste materials (Pettit et al., 1997). *Modeling* approaches use equilibrium geochemical models, mass transfer models, or coupled mass transfer-flow models to predict leachate quality (Lin et al., 1997; Perkins et al., 1997).

In general, the constituents of concern would be similar to those for mine drainage (see section 2.2.1). Of particular concern in gold heap leach facilities would be cyanide or other chemicals used as lixiviants, their breakdown products (in the case of cyanide, these would include ammonia and nitrate), and chemicals used to detoxify cyanide or other lixiviants. Applicants should ensure they conduct the proper cyanide analyses (weak acid dissociable or WAD versus total, for example), which would depend on applicable water quality standards.

3.2.1 Measuring Effluent Quality at Existing Facilities

The quality of effluent produced from an existing waste rock or spent ore pile should be determined from surface seeps and/or pore waters (for seepage) and run-off. In essence, the process is similar to that for sampling surface and ground waters described in Appendix B, *Receiving Waters*. Applicants should be certain to collect enough samples to permit an evaluation of seasonal changes in discharge quality and to determine whether pore water compositions vary with depth or position in a dump.

3.2.2 Empirical Predictions of Effluent Quality from Proposed Facilities

Appendix C, *Characterization of Ore, Waste Rock and Tailings,* describes the variety of geochemical and mineralogical tests that can be conducted on waste rock, ore, and heap leach residues. In general, the results of these tests provide only an indication of the chemical characteristics that an effluent may be expected to have and they cannot be used to provide an absolute measure of water quality. In part, this is because leach tests use (comparatively) short experimental times, simulated leach solutions, and materials with altered particle-size characteristics (most tests require crushing) that affect chemical and physical controls such as oxidation rates, mineral availability, and fluid flow.

Several factors influence the quality of run-off that is generated during a given storm event. They include the composition of the solid materials exposed on the surface of the waste dump, the contact time between run-off and waste rock materials (i.e, run-off flow path), the duration of the precipitation event, the length of time since the previous run-off event (i.e., oxidation time), and the climatic conditions. In general, these factors determine the composition and quantity of constituents present on the surface of the waste rock dump that potentially could be dissolved and transported by precipitation run-off. For example, a pyritic waste rock dump situated in a humid environment would undergo oxidative weathering between storm events that would result in a build-up of oxidation products on the surface of waste rock fragments. Precipitation run-off could dissolve and transport these products, leading to an initial “flush” of constituents as the most easily dissolved compounds are mobilized; continued run-off may show significantly lower constituent values.

Predicting run-off quality is a difficult undertaking for which a set methodology has not been established. In general, the results of leachate tests are used to estimate run-off quality. Most standard leach tests (e.g., TCLP, SPLP, ASTM) are thought to provide conservative estimates of leachate composition due to the comparatively long leachate-rock contact time (typically 18 to 24 hours), the exaggerated particle surface area (test samples are typically crushed to sizes substantially smaller than actual waste rock), and the aggressive character of the lixiviants used in some tests (pH values for some tests are lower than natural precipitation). Applicants should keep in mind that a disadvantage of standard leach tests is that they do not permit an evaluation of the potential effects of oxidative weathering. Kinetic tests (e.g., humidity cells or columns) can be used to constrain the potential importance of oxidation and "flushing".

Seepage quality will be partly a function of the methods by which a waste rock or spent ore pile is constructed. This will be especially true for mines that dispose of materials with widely different leaching and acid generating characteristics. Construction techniques dictate important factors such as the rate and path of water flow through the pile, the residence time of water in the pile, and the distribution of acid generating and acid neutralizing materials within the pile (e.g., Morin and Hutt, 1994). Moreover, dump design can play a major role in determining whether "hot spots" of acid generation form within a dump (e.g., Garvie et al., 1997) or whether a dump behaves in a chemically uniform manner because materials have been evenly distributed through layering or blending (Mehling et al., 1997). Operations and closure influence effluent quality as well, as was noted previously, and appropriate operational and closure aspects should be considered in predicting effluent quality during specific times of a mine's life.

In general, statistical analyses of geochemical test results are used to assess the characteristics of waste rock materials and the quality of effluent that would be generated from waste rock piles. Pettit et al. (1997) describe applications of multi-variate techniques such as cluster analysis and discriminant analysis. These analyses can indicate waste rock types that have similar behavior.

An empirical approach described by Morin and Hutt (1994) predicts seepage quality from kinetic leach test results. Geochemical production rates (mg of constituent/kg of rock/week) are estimated from test results using "best-fit lines" through test data points. Estimated long-term production rates are combined with assumed precipitation volumes and total waste rock volume to yield predicted constituent concentrations. Constituent concentrations determined using this method depend heavily on the estimate of long-term production rate, which requires careful long-term kinetic testing. Because this model ignores many of the hydrological and chemical complexities associated with waste rock piles, it should be used only to approximate seepage quality.

3.2.3 Predictive Modeling of Effluent Quality from Proposed Facilities

Perkins et al. (1997) review the applicability of numerous types of computer models to predictions of water quality from waste rock dumps or from leach heaps or dumps. They describe four general model classes that can be used to predict water quality:

- Aqueous Geochemical Equilibrium Models,
- Geochemical Mass Transfer Models,
- Coupled Geochemical Mass Transfer-Flow (Reaction-Transport) Models, and
- Applied Engineering Models.

From an environmental perspective, every waste rock or spent ore pile is unique. Consequently, there is no standardized approach for modeling effluent quality from these facilities. The choice of a predictive model depends on the conceptual model developed for the site (see Section 1.2). In all cases, it is important for applicants to select tools capable of addressing the task at hand and to clearly state the assumptions used to generate model simulations. At most sites, the modeling process will require an iterative approach in which the results of early numerical models are used to refine the conceptual site model. Several models that have been used are described below.

A mathematical model of pyrite oxidation and oxygen diffusion through a waste rock dump was developed by Davis et al. (1986). The Davis-Ritchey model views oxidation as a moving front that proceeds inward from the edges of pyrite grains to their cores (the "shrinking core" model). The approach has been incorporated into numerical models such as PYROX (Wunderly et al., 1996). The shrinking core model has recently been criticized as underestimating the decrease of oxidation rate that occurs as grain size increases (Otwinowski, 1997).

Aqueous geochemical equilibrium models are static models that use water composition, temperature, and pressure to compute equilibria among aqueous species. They are widely used in studies of acid rock drainage and background stream composition to estimate the precipitation and dissolution of mineral phases and identify the maximum solute concentrations that can occur. Geochemical equilibrium models utilize thermodynamic data to compute equilibria; the quality of these data and the number of species contained in the dataset govern the quality of the computed results. Shortcomings of this class of models are that they do not consider flow and they cannot be used to provide a 2- or 3-dimensional picture of chemical equilibrium (e.g., in a waste rock dump). Examples of this model class include MINTEQA2 and PHREEQC, which are described in more detail in Appendix B, *Receiving Waters.*

Geochemical mass transfer models are dynamic models that use initial fluid composition, mineral composition, and mineral mass and surface area to compute a final fluid composition following fluid-mineral reactions in a closed system. Mass transfer models compute how fluid composition changes as host minerals dissolve and new minerals precipitate until equilibrium is achieved. These models have not been widely applied to predictions of effluent quality from waste rock or spent ore piles. Deficiencies of this class of models are that they cannot accommodate flow and that important mineral reactions may be overlooked if the computational reaction step size is too large. Use of an appropriately small reaction step has the negative effect of greatly increasing computing time. Examples of this model class include React!, which is available commercially.

Coupled geochemical mass transfer-flow models (also termed reaction-transport models) are similar to mass transfer models, but have been expanded to accommodate open systems. Consequently, they are capable of handling fluid composition changes that occur due to dilution by infiltrating precipitation, and concentration by evaporation. These models are complex but hold the most promise for producing accurate predictions. At present, Perkins et al. (1997) do not recommend use of most coupled mass transfer-flow models, because they generally do not combine sufficiently rigorous geochemical and flow analyses. However, Lin et al. (1997) presently are developing a new mass transfer-flow model (ARD-UU) specifically for predicting acid rock drainage from waste rock dumps under unsaturated conditions. In addition, Wunderly et al. (1996) have combined the PYROX and MINTRAN codes to produce the program MINTOX, which is a 3-dimensional coupled mass transfer-flow model that simulates pyrite oxidation, gas diffusion, and the formation of oxidation products in mining wastes.

Empirical models do not compute equilibrium geochemical relations, but instead use a limited set of geochemical and physical processes to simulate the observed geochemistry. These models, which can be applied only to the site of interest, are best used for comparing different management options because they have limited predictive applications. An empirical approach described by Morin and Hutt (1994) was described in the Section 3.2.2.

4.0 TAILINGS FACILITIES

Effluent from tailings impoundments and dry tailings facilities can include process waters that are either discharged directly or through seepage and run-off from the facility area. Discharges may be continuous or they may occur only under high precipitation conditions. Tailings impoundments often are used to manage other waters from the site (e.g., mine drainage, sanitary wastes, wastewater treatment plant sludge). Consequently, flows from other sources need to be addressed when determining tailings unit effluent quantity and quality.

It is extremely important that effluent quality be characterized during all stages in a tailings facility's life. Even if a facility is designed not to discharge during its active life, there may be a need to discharge during and after closure. The quantity and quality of that effluent should be predicted. In addition, applicants should take note of the relationship between the reasonably anticipated life of the mine and the return interval of the design storm. If the life is a significant proportion of the return interval, then it is likely there will be a storm-related discharge during the mine's life (see the main text for a discussion of the so-called "storm exemption" to the NPDES effluent limits). Applicants should predict the quality of discharges under various storm scenarios, including the probable maximum flood.

4.1 Determining Water Quantity and Discharge from Tailings Facilities

Every tailings impoundment will behave in a slightly different hydrological manner that reflects the impoundment design, construction and management; its physical, hydrological and climatological setting; and the physical and chemical characteristics of the materials contained within it. In general, tailings solids are retained by an embankment or perimeter dike and are maintained under a partial to complete water cover. Most facilities are unlined; some have embankments with impermeable cores or grout curtains to preclude seepage (Vick, 1990; see Appendix F, *Solid Waste Management*). It is assumed that the catchment area contributing run-off to the impoundment will be minimized by designing and constructing appropriate stream and/or run-off diversion structures around the impoundment. This is important for minimizing the amount of effluent that may need to be discharged. Although filled with generally fine-grained materials, the method of tailings disposal can create particle size differences that affect permeability and transmissivity. Moreover, facilities that contain pyritic tailings under partially saturated conditions may develop hardpan layers that complicate lateral and vertical flow paths (Blowes et al., 1991).

In dry tailings facilities, tailings are dewatered prior to placement and maintained under unsaturated conditions (see Appendix F, *Solid Waste Management*). They are typically reclaimed concurrent with operation. The materials comprising these facilities contain moisture only in the form of residual process water or precipitation that falls onto exposed tailings materials.

Estimating effluent volumes from a tailings facility (wet or dry) begins with the need for an accurate site water balance throughout the predicted life of the unit. The water balance must include both process water inputs and outputs including run-on/run-off, evaporation, and seepage. In addition, applicants should predict estimated discharges during and after closure.

Seepage from tailings facilities can be predicted using empirical, analytical, or numerical methods like those described in Section 3.1. Similar to predictions of drainage from waste rock dumps, predictions of seepage from tailings facilities require knowledge of the proposed engineering design of the facility. In addition to the engineering factors cited in Section 3.1, tailings seepage predictions require knowledge of the permeability, transmissivity, and storage capacity of the substrate; local and regional ground water hydrogeology; and embankment permeability.

Programs such as SEEP/W and MODFLOW (Section 3.1.2) can be used to analyze seepage from impoundments. These models can be used to simulate the migration of a wetting front into the underlying substrate, the development of a ground water mound beneath the impoundment, and seepage through an embankment (e.g., Vick, 1990). For dry tailings facilities, the HELP model (Section 3.1.1) can be used to determine parameters such as infiltration, storage, and drainage.

Besides estimating the quantity of seepage that may emerge from a tailings facility, applicants also should estimate quantities of run-off under various storm conditions, and any discharges of process wastewater in net precipitation zones that are allowed under the regulations (see Section 2.2 in the main text).

A detailed description of methods used to quantify volumes of ***surface run-off*** is provided in Appendix A, *Hydrology.* In general, the most appropriate methods for developing and analyzing run-off from sub-basins or facilities at mine sites, including areas with tailings impoundments, use a unit hydrograph approach (see Appendix A, *Hydrology*). A unit hydrograph is a hydrograph of run-off resulting from a unit of rainfall excess that is distributed uniformly over a watershed, sub-basin or mine facility in a specified duration of time (Barfield et al., 1981). The unit hydrograph represents the run-off characteristics for the specific facility or sub-basin for which it was developed and is used to quantify the volume and timing of run-off . Common methods to develop and use unit hydrographs are described by Snyder (1938), Clark (1945), Chow (1964), Linsley et al. (1975) and SCS (1972).

Estimating the volume and timing of discharges from mine facilities in regions with net precipitation requires an accurate understanding of the site water balance. A detailed description of methods and approaches used to develop a site water balance are provided in Appendix A, *Hydrology*. In general, an accurate site water balance is required to successfully manage storm run-off, stream flows, and point and non-point source pollutant discharges; and to design control and discharge structures. M.L. Brown (1997) describes methods to determine a site water balance using both deterministic and probabilistic approaches. To provide insight into the range of conditions that could be expected to occur, deterministic water balances should be computed for average, wet, and dry conditions. In contrast, the input values used in probabilistic approaches are sampled from probability distributions (e.g., annual precipitation probability). Computer spreadsheets are used to iteratively calculate inflow and outflow probabilities. According to M.L. Brown (1997), probabilistic approaches result in better facility designs because they can indicate which parameters have the most effect on model results and may reveal potential design weaknesses.

4.2 Determining Effluent Quality from Tailings Facilities

Determining the quality of effluent from tailings management facilities requires an understanding of ore mineralogy, beneficiation processes, tailings facility design, mine site water flow, closure plans, and surface and ground water quality. Consequently, the process used to estimate tailings effluent quality will vary from site to site. Tailings management plays a pivotal role in determining the potential for water quality impacts. For example, sites may treat process chemicals (e.g., cyanide) contained in tailings water prior to discharge or they may maintain a water cover over reactive tailings to prevent oxidation of pyritic materials. In general, the metals leaching potential of tailings depends on the mill process, ore mineralogy, and particle size (Price et al., 1997).

Constituents of concern should be identified as described in section 2.2.1. In addition, applicants should monitor for residual process chemicals (cyanide, xanthates, etc.) as well as for pollutants in other wastes that may be disposed with tailings (for example, fecal coliform and BOD if sanitary wastes are disposed).

4.2.1 Measuring Effluent Quality at Existing Facilities

Tailings effluent quality can be measured at existing facilities by collecting and analyzing impoundment water quality, pore water samples, and samples collected from seepage ponds and surface seeps. In essence, the process is similar to that for sampling surface and ground waters described in Appendix B, *Receiving Waters*. Applicants should be certain to collect sufficient samples to permit an evaluation of seasonal changes in discharge quality and to determine whether pore water compositions vary with depth or position in an impoundment.

4.2.2 Predicting Effluent Quality from Proposed Facilities

From an environmental perspective, every tailings impoundment is unique. Consequently, there is no standardized approach for modeling effluent quality from these facilities. The caveats stated with regard to predictive modeling of waste rock and spent ore piles (Section 3.2.3) apply to models of tailings effluent as well (also see Section 1.2).

Tailings management is a critical issue, particularly for sites that would produce tailings containing pyrite or residual cyanide. Studies of active impoundments show that water quality can vary throughout an impoundment due to differences in the rate of pyrite oxidation (e.g., Robertson et al., 1997). For example, subaerially exposed tailings that occur on a beach near the discharge point may contain pore waters with significantly lower pH and higher (by an order of magnitude) sulfate and metals concentrations than tailings that remain saturated. For cyanidation tailings, impoundment design, water balance, and climate can influence the rate of natural cyanide degradation (Botz and Mudder, 1999).

Predictions of effluent quality need to consider the range of environments (e.g., subaerial, unsaturated vs. subaqueous, saturated) that would be present throughout the life of the facility and the volumes and compositions of materials that would be stored under the different environmental conditions. Assumptions regarding the behavior of these environments (steady-state or transient) are a necessary part of these considerations (Alpers and Nordstrom, in press). However, broad assumptions regarding the behavior of pyritic or cyanidation tailings should be avoided. For example, Li et al. (1997) showed that water covers may not preclude sulfide oxidation as is often assumed. Instead, their work indicated that sulfide oxidation rates, although low, vary as a function of water depth, wave action, and particle resuspension (Figure D-3). Studies such as this illustrate the importance of developing a conceptual model that incorporates aspects of engineering design, facility water balance, climate, and materials properties and compositions when predicting effluent quality. The conceptual model serves as the basis for developing numerical models of water quality (see Section 3.2.3 for model descriptions; Botz and Mudder (1999) describe a model for natural cyanide degradation that presently is being calibrated and tested).

In general, the models described for waste rock and spent ore piles in Section 3.2.3 also can be applied to predictions of effluent quality from tailings facilities. These include equilibrium models such as MINTEQA2 and PHREEQC and coupled mass transfer-flow models such as MINTOX. Similarly, the methods described in section 3.2.2 should be suitable for predicting run-off quality; besides considering constituent additions from native minerals, however, applicants should consider how constituents in process water quality will affect run-off quality from tailings facilities.

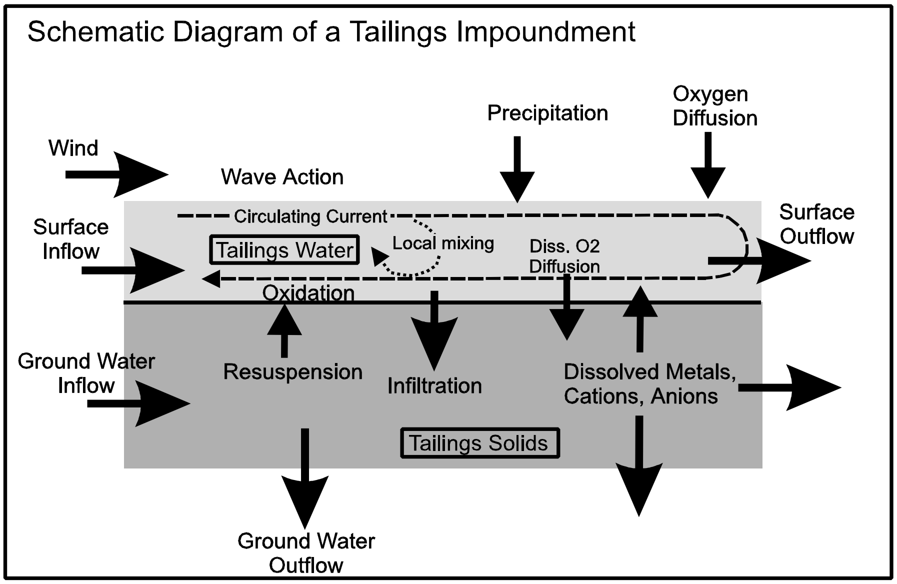

Figure D-3. Processes that affect subaqueous sulfide oxidation in tailings impoundments and the quality of tailings impoundment water (modified from Li et al., 1997).

It is assumed that applicants will perform pilot-scale testing for beneficiation operations to determine/optimize metals recovery. It is important that these tests be conducted with representative ore feeds with the reagent chemicals expected to be used at the mine. Tailings solids generated from these tests should be used for geochemical analyses (i.e., static acid-base accounts, kinetic humidity cell tests, leach tests, and mineralogical tests; see Appendix C, *Characterization of Ore, Waste Rock and Tailings*). Water produced during pilot-scale tests should be analyzed to indicate the general composition of water to be discharged to tailings management units, including residuals from any chemicals used in the process. Geochemical analyses and pilot-scale test results can be used to predict effluent quality directly or as input to predictive models.

Price et al. (1997) cite several factors that should be considered in predictions of tailings effluent quality:

- Tailings composition may change with time due to processes such as pyrite oxidation or the formation of ferricrete hardpan layers;
- The particle-size characteristics of tailings influences the surface areas of minerals susceptible to weathering;
- The particle-size characteristics of tailings determines the permeability of tailings to water and oxygen; and
- The method by which tailings are deposited can segregate particles by size and mineral type which, in turn, can create zones with different metal leaching potential.

Other questions that may need to be addressed for long-term predictions of effluent quality include:

- Will the impoundment be used to store storm water run-off?
- Will facility closure permit oxidation (e.g., through dewatering)?
- Will residual process chemicals (e.g., cyanide) remain in the tailings?
- What is the mineralogy of the residual tailings solids?
- What is the alkalinity of the residual tailings solids?

5.0 FLOW ROUTING AND EFFLUENT QUALITY FROM A MINE SITE

The preceding sections describe methods to estimate effluent quality from different types of mine facilities. At many mine sites, water management plans may dictate that multiple effluent streams be combined. In such cases, applicants will initially need to determine the quantity and quality of effluent from each source. An accurate site water balance is required to demonstrate how each contributing flow will vary with time, site conditions, and facility operations. Appendix E (*Wastewater Management*) discusses the importance of performing detailed water balance calculations, and describes wastewater management in some detail. Based on the water balance, applicants should then determine the quantity and quality of the combined effluents.

Expected variations in flow and water quality from each source can be combined using mass balance calculations or modeling. For example, equilibrium geochemical models such as MINTEQA2 or PHREEQC may be used to compute flow-weighted effluent quality. Such calculations should determine the average effluent quality and the range of possible effluent compositions that could occur. If the effluent is to be discharged, the maximum values of effluent parameters are important. The estimated quality of the combined effluent can then serve as the basis for determining management practices and/or treatment requirements. Treatment may be required for individual effluent streams only or for the combined effluent stream. Where treatment prior to discharge is a component of wastewater management, effluent quality and quantity (average and maximum, variability, etc.). following treatment must be predicted. Treatability studies may be required to make such predictions. This is discussed in Appendix E.

6.0 STORM WATER

Storm water discharges from active and inactive mining areas and reclaimed areas, that are not combined with mine drainage or process water, may be authorized under individual or general NPDES storm water permits (e.g., the Multi-sector General Storm Water Permit, Sector G for Mining; see Section 2.4 of the *Source Book* main text) provided the discharges do not cause or contribute to a violation of applicable water quality standards. The Multi-sector General Permit for Mining requires monitoring of certain storm water discharges to assure that storm water best management practices are working as anticipated (see FR Volume 63, No. 152, August 7, 1998, pp. 42533-42548 for clarification of covered discharges and monitoring requirements. This clarification is also included in EPA's most recent issuance of the Multi-Sector General Permit for Storm Water associated with Industrial Activities which was issued on October 30, 2000). Storm water sampling guidance can be located at EPA's website.

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APPENDIX D

EFFLUENT QUALITY

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Hard rock mining operations can generate large quantities of effluent that are discharged to surface and ground water. The primary sources of effluent include drainage from mine workings, seepage and run-off from tailings impoundments or dry tailings piles, seepage and run-off from waste rock and spent ore dumps, and run-off from disturbed areas. The quantity and quality of effluent generated from each of these areas and facilities is a function of hydrological and geochemical factors as well as the engineering design for the facility. It is essential for mine operators and applicants to predict with a high degree of certainty the quality of all effluents from mine operations and waste disposal facilities that will or may be discharged to surface waters during all stages of a mine's life—development, operations, closure, and thereafter. This will enable the operator to predict and assure compliance with water quality standards, and to predict impacts to surface and ground water resources.

A detailed discussion of water quality standards and designated uses of receiving waters is provided in the main text and in Appendix B, *Receiving Waters*. This information is briefly summarized in Section 1.1 below. In addition, the main text presents a discussion of the regulatory classification of the various discharges to surface waters and of the water quality-based and technology-based standards that are incorporated into NPDES permits.

The principal goals of this appendix are to outline the methods and analytical procedures commonly used to characterize the quantity and quality of effluent generated at mine sites, and to identify the information related to effluent quality that must be provided to EPA under NEPA and the Clean Water Act. If predicted or tested effluent water quality does not meet applicable water quality- and technology-based effluent limitation standards, an applicant must demonstrate through its mine plan that appropriate management practices and/or water treatment systems will be employed to meet these standards prior to discharge. Accurate characterization of effluent water quality relies heavily on studies to characterize other resources such as site hydrology and meteorology, hydrogeology, water quality and waste and materials geochemistry. The fate and transport of effluent also is related to the design of the mine (either surface or subsurface) and its facilities, including tailings impoundments, dry tailings embankments, and waste rock dumps. The materials in this appendix complement discussions of resource characterization and waste management that are presented in Appendix A, *Hydrology,* Appendix B, *Receiving Waters*, Appendix C, *Characterization of Ore Waste Rock and Tailings,* Appendix E, *Wastewater Management,* and Appendix F, *Solid Waste Management.* The reader is referred to these appendices for more detailed discussions of these topics.

1.1 Water Quality Standards and Effluent Limitations

Water quality standards for receiving waters are discussed in Appendix B, *Receiving Waters.* Under the Clean Water Act, each State must classify all of the waters within its boundaries by their intended use. Once designated uses have been determined, the State must establish numeric and narrative water quality criteria to ensure the attainment and/or maintenance of the use. State water quality standards and implementing provisions are approved by EPA and are codified in State regulations.

The CWA provides that the discharge of any pollutant to Waters of the United States is unlawful except in accordance with a National Pollutant Discharge Elimination System (NPDES) permit. Section 402 of the Clean Water Act establishes the NPDES program which is designed to limit the discharge of pollutants into Waters of the U.S. from point sources through a combination of various requirements, including technology-based and water quality-based effluent limitations (40 CFR 122.1 (b)(1)). An NPDES permit must contain any requirements in addition to, or more stringent than, promulgated effluent limitation guidelines or standards necessary to achieve water quality standards, including State narrative criteria for water quality. NPDES permits are required to limit any pollutant or pollutant parameter that is or that may be discharged at a level that causes, has the reasonable potential to cause, or contributes to an excursion above any water quality criterion. See the main text for a more detailed discussion of the development of NPDES permit conditions, including effluent limitations.

It is important that applicants be able to predict effluent concentrations in light of the applicable water quality standards. A common problem encountered in many mining-related discharge permit applications is that metals are analyzed by methods with detection limits that are higher than the water quality criteria. It is important for any sampling and analysis program to ensure that:

- Appropriate methods and detection limits are used,
- All necessary constituents are measured,
- Data are obtained for total and dissolved phases of most metals, and
- The number of samples collected is adequate to accurately characterize expected variability in effluent quality (Sampling and Analysis Plans are described in more detail in Appendix B, *Receiving Waters*).

1.2 Considerations Regarding Predictive Modeling of Effluent Quality

Predictions of effluent quality often are based on modeling that uses water quality and hydrological data to calculate the geochemical species present at equilibrium, the geochemical reactions that are likely to occur under the physical conditions that prevail, and physical transport. They require a forward modeling approach in which assumptions regarding the initial state of a system and its boundary conditions are used to simulate the consequences of particular geochemical reactions (Alpers and Nordstrom, in press).

Alpers and Nordstrom (in press) discuss limitations to geochemical modeling and cite several cautionary measures that should be followed by those who create and interpret models of effluent quality. These measures apply to each of the modeling discussions below and are not repeated therein. Important considerations cited by Alpers and Nordstrom include:

- Modeling is an inexact science subject to numerous uncertainties and limitations.
- Models are not reality and may not be a reliable, correct, or valid representation of reality; they are only a tool to increase understanding.

- Geochemical models can never be proven as true in an absolute sense, their results are useful only insofar as they can be used to improve or disprove the original conceptual model.
- Analytical and thermodynamic data must be scrutinized for accuracy and internal consistency prior to their use.
- Chemical data used as input should be highly accurate and precise because errors can be exaggerated when propagated through model calculations.
- Standard errors should be clearly identified during sensitivity analyses.
- Model assumptions should be clearly identified, especially with regard to parameters such as redox potential.
- Speciation calculations indicate those reactions that are thermodynamically favored, not necessarily those that are likely to occur.
- Interpretations of ground water chemistry require knowledge of the flow system, aquifer mineralogy, and effects of sampling.
- Forward modeling places more responsibility on the user to make appropriate choices with regard to phase, components, and reaction equilibria.

Types of modeling applicable to different types of effluent is discussed in more detail in the following sections. Regardless of the specific model that is used, information such as the following should be submitted to EPA to substantiate modeling used for regulatory purposes:

- Description of the model, its basis, and why it is appropriate for the particular use
- Identification of all input parameters and assumptions, including discussion of how the parameters were derived (whether by measurement, calculation, or assumption), and whether they represent conservative conditions
- Discussion of uncertainties
- Sensitivity analysis of important input parameters.

Appendix A (Hydrology; Section 6.0) provides additional information related to the use of modeling for regulatory purposes. This appendix discusses a number of specific models that are commonly used to characterize effluents. Applicants should recognize that it is not the intent of this appendix to provide a comprehensive list of available models nor to suggest that these are the only models that can or should be used.

2.0 MINE DRAINAGE

Mine drainage includes waters that drain from or infiltrate into historical workings and that are pumped from active surface or subsurface mining operations. Although drainage can be sampled directly from active or historical workings, applicants for proposed mines will need to estimate the quantities and compositions of these waters. The NEPA review and CWA permitting processes will require applicants to provide accurate assessments of mine drainage volumes and quality during operations and after closure. (The main text describes the regulatory definition of "mine drainage").

2.1 Determining Mine Drainage Quantity and Discharge

Mine drainage from historical workings can be measured using techniques similar to those for measuring surface discharge. Typically this requires installing a stream gauge or other measuring device at the point of discharge. Some subsurface mines, particularly shallow adits and underground workings, may exhibit seasonal flow that occurs in response to snowmelt or other climatic factors. Where this occurs, applicants will need to characterize the magnitude of seasonal flow from all historic workings. For mines that are flooded and will be dewatered, maps of historic workings (if available) or records of mine production can provide some measure of the volume of drainage water that will require disposal.

Dewatering (e.g., pumping ground water from) mine workings, adits, or open pits is required when the mine elevation extends below the potentiometric surface in confined aquifers or below the water table in an unconfined aquifer. When an underground mine is excavated, the workings serve as a ground water sink that affects the natural ground water system. A mine can capture ground water recharge and stream flow and can drain ground water from storage. Underground and pit mines are typically dewatered using in-shaft or in-pit wells, perimeter wells, and/or sumps. Pumping ground water lowers the water table by creating a “cone of depression” in proximity to the mine. The quantity of water produced by pumping operations depends on the pumping rate, aquifer hydraulic conductivity, transmissivity and storage, and the homogeneity of the aquifer. Water produced from mine dewatering operations may be used for process operations, disposed via evaporation or infiltration ponds, and/or discharged to surface waters.

Applicants proposing operations in which a pit lake is expected to form after dewatering operations cease will be expected to estimate the rate at which the lake will form and its final elevation. A lake water balance must consider factors such as the rate of ground water inflow, contributions from surface run-off and precipitation, and losses from evaporation, seepage, or discharge. The water balance should lead to estimates of the equilibrium lake level and the amount of time it will take until this level is achieved. Applicants should also determine whether there will be a discharge from the pit lake, and the quantity and seasonality of any discharge.

Methods to characterize hydrogeology and ground water discharge at mine sites are discussed in Appendix A, *Hydrology*. Hydrogeologic characterization studies should include geological descriptions of the site, including descriptions of rock types, intensity and depth of weathering, and the abundance and orientation of faults, fractures, and joints. Although difficult to evaluate, the hydrologic effects of fractures, joints, and faults are especially important to distinguish and characterize. Water moves more easily through faults, fractures, and dissolution zones, collectively termed secondary permeability, than through rock matrices. Secondary permeability can present significant problems for a mining facility because it can result in a greater amount of ground water discharge to a mine than originally predicted.

Three methods are used to estimate ground water inflow to a mine; all are generally applicable to both open pit and underground mines:

- Analytical solutions for flow to a simplistic analog, such as a well or trench;
- Numerical ground water flow models based on a representative conceptual hydrogeologic model and a mine plan, and;
- Hydrologic control volumes to calculate inflows.

Applications of these general methods are briefly described below. Regardless of the methodology used, the quantity of ground water discharged to a mine and the resulting volume of mine water produced must be accurately characterized. This often requires applicants to determine whether mine development activities (e.g., blasting) would affect seasonal inflow or change recharge/discharge relationships, either of which could impact the amount of drainage. The discharge of water to a mine can potentially affect the effluent quality of both of the mine water and of ground water flowing down-gradient within an aquifer. Accurate determinations of the rate of inflow is specifically required to design water treatment systems. It is important, therefore, to couple studies conducted to determine the volume of water discharged to or from a mine with those to characterize water quality.

2.1.1 Analytical Solutions

A common method to analyze ground water in relation to a mine relies on a simple analytical solution in which the mine pit is approximated as a well. This method uses the constant-head Jacob-Lowman (1952) equation to calculate flow rates. Although not as accurate as a numerical (modeling) solution, this method gives a good approximation of the rate of water inflow to a proposed mine. It generally yields a conservative estimate of the pumping rates required to dewater a mine (Hanna et al., 1994). A second analytical method uses the technique of interfering wells, where each drift face of the proposed mine is considered to be a well. The cumulative production of the simulated wells is used to estimate the total influx into the mine and the extent of drawdown.

2.1.2 Numerical Models

Numerical ground water models can be used to simulate heterogeneous systems in which a variety of coupled processes describe the hydrology of near surface and deep aquifer systems. Available models vary in sophistication but incorporate either finite-difference or finite-element methods for solving the governing equations for ground water flow. A comparison of finite-difference and finite-element numerical methods is detailed by Pinder and Gray (1977). Both schemes are widely used to simulate transient flow in aquifers (Freeze and Cherry, 1979). Descriptions of commonly used numerical ground water models are given in Appendix A, *Hydrology* and Section 3.1.2. MODFLOW (McDonald and Harbaugh, 1988) is perhaps the most widely applied ground water flow model and its use is accepted by most regulatory agencies. In addition to simulating subsurface flow, this model has been used to simulate inflow to a mine pit and the development of a pit lake after dewatering operations cease (Bursey et al., 1997). Applicants preferring to use other software packages should check with regulatory agencies prior to beginning their modeling efforts.

The predictive capabilities of numerical models depend on the quality of input data. The accuracy and efficiency of the simulation depend on the applicability of the assumptions and simplifications used in the model, the accurate use of process information, the accuracy and completeness of site characterization data, and the subjective decisions made by the modeler. Where precise aquifer characteristics have been reasonably well established, ground water models may provide the most viable, if not the only, method to adequately predict inflow to a mine, evaluate dewatering operations, and assess mining operational variables.

Estimates of the fate and transport of potentially contaminated ground water discharging from an abandoned surface or underground mine down-gradient or to surface water bodies generally require numerical modeling. Estimates of the transport of dissolved constituents through porous media is highly dependent on accurate input data to characterize transport mechanisms such as convection, hydrodynamic dispersion, chemical sorption, and first-order decay.

2.1.3 Calculations Based On Hydrologic Control Volumes

This method estimates the volume of ground water recharge and discharge that would occur in a given control volume. For mine drainage determinations, the control volume would be defined as the volume of water-bearing rock that would be impacted by a mine. In general, the method applies water balance calculations to determine the volume and rate of water inflow to the exposed mine area (e.g., exposed aquifer) (Singh and Atkins, 1984). A water balance calculation is first applied to estimate the volume of ground water recharge that would be expected to enter a mine based on average or estimated values for precipitation, run-off, evapotranspiration and the surface area of the exposed aquifer. A second water balance is then applied to estimate the volume of ground water that would be expected to enter a mine from depletion of ground water storage. This estimate is based on measured or estimated factors for specific yield or drainable porosity, the surface area of the exposed aquifer, and the difference in the elevational head between the pre-mining water table and the lowest portion of the mine. These two calculations are then combined to estimate the total volume of ground water expected to enter the mine from recharge and subsurface sources.

The control volume method should only be applied when ground water data are insufficient to perform numerical or analytical analyses. The method is subject to errors associated with temporal variations in, and long-term measurements of precipitation run-off and stream flow. In addition, depending on hydrogeological conditions, the method potentially underestimates peak inflows during the early stages of mine development. After ground water has been drained from storage, most ground water discharge to a mine occurs from recharge by precipitation and stream infiltration.

2.2 Determining Mine Drainage Effluent Quality

Applicants will need to estimate the quality of mine drainage effluent produced by their operations. For sites with historical workings, mine drainage can be sampled and analyzed. Mine drainage may also be available for analysis from exploration activities. For new mine sites, mine drainage quality will need to be estimated using geochemical models and testing. In cases where pit lakes are expected to develop after mining ceases, applicants will be required to estimate the long-term quality of these waters.

2.2.1 Considerations Regarding Constituent Analyses

For NPDES permitting purposes, the constituents that should be analyzed/predicted in effluents that are to be discharged to surface waters are the parameters identified in applicable effluent limitation guidelines and any pollutant that the applicant knows or has reason to believe may be present in the effluent. The latter is in turn governed by mineralogy, mining activities (e.g., blasting agents that may be added) and site characteristics. The level of analysis (e.g., detection limits) depends on applicable water quality standards. Constituents not necessarily important for NPDES purposes (such as conductivity and major constituents) may be important for geochemical modeling, selecting wastewater treatment processes, etc.

Initially, it is usually important to evaluate a relatively large number of metal species in order to determine whether any exhibit concentration changes that vary with discharge or time. Analyses should be conducted for major constituents such as iron, aluminum, and magnesium, as well as for trace metals such as antimony, arsenic, boron, cadmium, chromium, copper, lead, manganese, mercury, nickel, selenium, silver, and zinc. Analyses of other trace metals may be appropriate when dictated by the mineralogy of the geologic units encountered and on the water quality standards designated for the receiving water. In general, analyses should be conducted to determine both dissolved and total metal concentrations (see Appendix B, *Receiving Waters*). Where static, kinetic, and leach testing are performed to indicate water quality (see Appendix C, *Characterization of Ore, Waste Rock, and Tailings*), data analysis should include evaluations of stable and expected species in relation to measured pH and Eh.

In determining mine drainage quality, applicants need to consider constituents that may be introduced through chemicals used in mine development and operation. Specifically, residual chemicals may be present in mine drainage due to use of explosives. For example, blasting operations that use ANFO can produce elevated levels of ammonia (NH_4) and nitrate (NO_3) in mine effluent. Similarly, applicants need to account for potential effects on mine drainage from any materials that will be backfilled to the mine (e.g., tailings)

Beyond individual constituent analyses, tests to determine whole effluent toxicity (WET) will need to be conducted for effluent discharges. As with chemical parameters, WET limits are required when WET test results show that the discharge has the “reasonable potential” to cause, or contribute to, an instream excursion of a numeric WET water quality standard or a narrative standard (e.g., “no toxics in toxic amounts”). Applicants should coordinate with EPA and State permitting authorities in determining the number and type of WET tests that should be performed.

2.2.2 Direct Measurement of Mine Drainage Quality

Direct measurement of mine drainage quality is possible at sites where historic workings are present. In these instances, applicants can use sampling and analysis procedures similar to those used to determine baseline surface and ground water quality (see Appendix B, *Receiving Waters*). Although direct measurements provide valuable data, applicants should exercise caution when extrapolating these values to a proposed project. For example, an operation proposed at a site with historic workings may extract ore that is mineralogically different from that which was mined previously. In cases where historic operations were conducted in oxide ore and proposed operations will operate in sulfide ore, historic water quality is likely to be a poor indicator of future water quality. Moreover, historic workings may contain multiple water sources with different water quality characteristics (e.g., Reisinger and Gusek, 1998), each of which may require evaluation in light of host rock and aquifer properties. Similarly, drainage from exploration activities may not be representative of full-scale mine development.

Studies and sampling designed to characterize the quality of ground water removed by dewatering operations should:

- Characterize the existing ground water quality in the vicinity of the proposed mine
- Determine the impacts to water quality from mine development (e.g., effects of blasting and the potential for acid generation from exposed surfaces)
- Define temporal differences in water quality that could occur seasonally or over the long-term. In general, natural ground water quality does not significantly change on a seasonal basis, but it may exhibit seasonality when acid generating mineralogy is exposed, near salt water intrusion areas, and near intermittent and influent streams (A. Brown, 1997).
- Characterize the ground water flow regime in all three dimensions.
- Characterize each lithologic unit the mine will intersect, and units at depths up to 1.5 times the depth of the proposed mine (A. Brown, 1997)
- Define water quality in both primary and secondary porosity systems, but focus on depths and lithologic units with the highest permeability, since these materials are the principal conduits for water and dissolved species (A. Brown, 1997).

There is no specific guidance for determining the number of samples that should be collected to characterize mine drainage quality. Because each mine site occurs in unique lithological and hydrological settings, the number of samples collected should be adequate to accurately define the average, median, and range of constituent concentrations, and to quantify the influence, if any, of seasonal changes in effluent quality.

The required sampling frequency depends on specific site conditions, lithology, and effects from temporal variations in recharge/discharge relationships. At a minimum, sampling should be conducted quarterly for at least one year to define potential temporal effects and sampling should continue throughout mine development and operation.

2.2.3 Predictive Modeling of Mine Drainage Quality

Predicting the quality of mine drainage is not a simple task (see Section 1.2). The following discussion considers three possible scenarios:

- Mine drainage that does not contact mine workings
- Mine drainage that contacts mine workings
- Mine pit lakes.

Mine drainage includes ground waters that are pumped from aquifers by dewatering operations. In areas where this water is removed from ground water storage without contacting mine workings or materials, mine drainage quality can be estimated using the measured baseline ground water quality, as discussed in section 2.2.1. Some mines may pump water from two or more aquifers and manage these waters together. In these cases, aqueous equilibrium geochemical models can be used to determine whether mixing will cause chemical effects such as mineral precipitation or desorption.

Dewatering operations may permit ground waters to contact mine workings prior to removal. In such cases, estimates of mine drainage quality will need to account for possible constituent contributions from the mine workings. The results of leach tests, kinetic tests, or minewall washing procedures can be used alone or in combination with computer models such as MINEWALL to estimate contributions from exposed, reactive rock surfaces (MEND, 1995; Morin and Hutt, 1995).

Open pit mines may flood and form pit lakes after dewatering operations cease. Applicants will be expected to estimate the quality of lake water and demonstrate a general understanding of how it may evolve with time. The process is complex, as illustrated in Figure D-1, which shows a conceptual model of the important components affecting pit-lake water quality, including:

- Lake water balance,
- Ground water composition,
- Geochemical reactions, and
- Wall rock contributions.

Of particular importance are any intermittent or permanent discharges, and applicants must predict the timing, quantity, and quality of any such discharges.

The lake water balance, described in Section 2.1, is a critical piece of information required to evaluate lake water quality (Kempton et al., 1998) and the potential for discharge. In addition to determining the rate of inflow and final lake volume, the water balance indicates the volumes of water and the constituent loads that would be contributed from different sources (Bursey et al., 1997). Importantly, different water sources are likely to have different water quality characteristics. For example, run-off from exposed pit walls will have characteristics that differ from seepage emanating from a waste rock pile. These compositions can be estimated from kinetic and leach tests of samples of materials that will be exposed in the pit walls. Ground water is likely to comprise yet another source. Waters contributed from each source can be mixed in the proportions in which they are expected to occur using an equilibrium geochemical model such as PHREEQC. This weighted mix can be used as an estimate of water quality (Bursey et al., 1997).

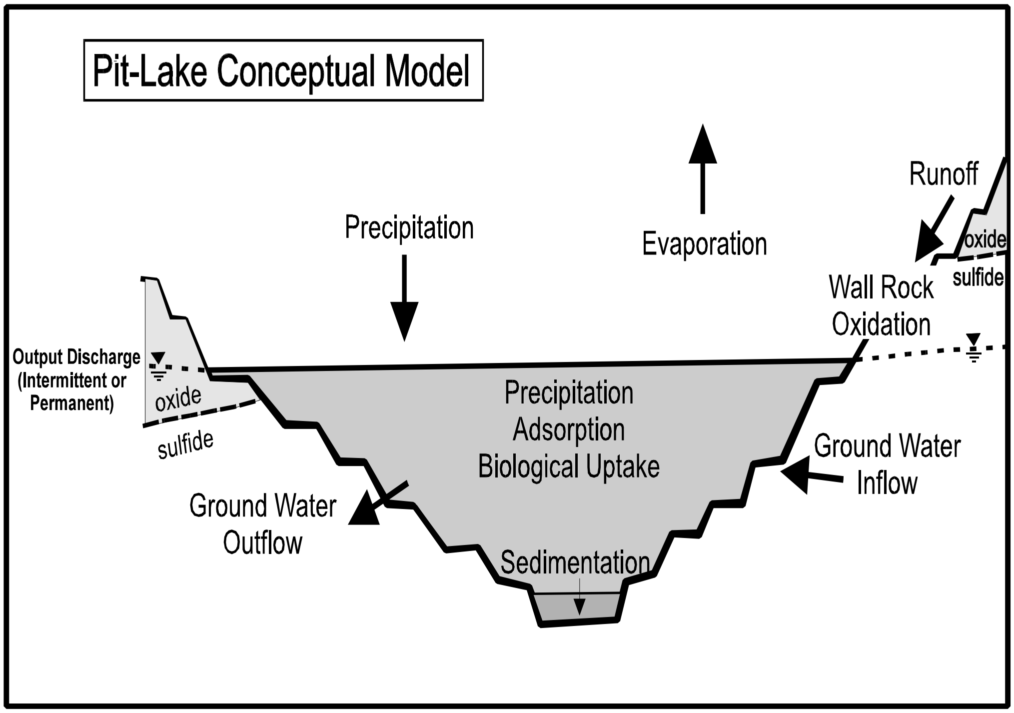

Figure D-1. Conceptual model of components that affect pit lake water quality (modified from Kempton et al., 1998)

Assigning source compositions will require applicants to use best professional judgement in the application of kinetic test results, leach test results, and surface and ground water quality analyses.

Equilibrium geochemical models can be used to evaluate how baseline water quality might evolve in light of the final physical character of the lake (e.g., outflow or terminal; volume; surface area, etc.). These calculations would determine how water quality would change in response to reactions between lake water and wall rock, through precipitation of mineral phases, as a result of adsorption reactions, and in response to biological activity (see Kempton et al. (1998) and Bursey et al. (1998) for a detailed discussion of the wide number of variables that applicants may need to consider). Final pit lake water quality will also require consideration of the physical limnology of the pit lake (Atkins et al., 1997; Doyle and Runnells, 1997) and the effects of long-term processes such as evapoconcentration (Bursey et al., 1997). Physical limnological considerations include chemical or physical stratification of the water column, seasonal overturn, and circulation.

3.0 WASTE ROCK AND SPENT ORE PILES

Seepage and run-off from waste rock dumps and spent ore (e.g., heap leach) piles[1] are sources of effluent. It is important that effluent from these units be predicted during both operations and closure. The materials in these units are composed of comparatively coarse-grained materials that are unsaturated to partly saturated. The potential for seepage is high in wet environments, but less certain in areas where annual precipitation is less than about 380 mm/yr (Swanson et al., 1998).

To accurately predict leachate and run-off water quantity and quality requires an understanding of both the hydrology and geochemistry of the pile. These characteristics are determined by the physical configuration of the pile, its engineering design and method of construction, the distribution of geologic materials within it (especially the acid producing and acid neutralizing materials), the addition of amendments or process chemicals to the pile, and the transport of water through it (SRK, 1992). The situation can be made more complex in cases where dumps have been fitted with engineered caps or soil covers during partial or complete closure. Such covers are likely to alter the flow of water and air through a pile that may have been exposed to the elements for many years. Consequently, pre-cap and post-cap configurations may need to be considered. According to SRK (1992), it is extremely difficult to predict the quality of water that will emanate from a waste rock or spent ore pile because there is no single analytical method or model that accurately combines algorithms for temperature, air and water transport, oxidation, neutralization reactions, and attentuation. Such models are presently being developed (e.g., Lin et al., 1997; Lopez et al., 1997; Newman et al., 1997). It is important for mining hydrologists and geochemists to combine programs for geochemical testing with hydrological studies to provide conservative estimates of effluent quality.

3.1 Determining Water Quantity and Discharge from Waste Rock and Spent Ore Piles

Precipitation that falls onto the surface of a waste rock dump or spent ore pile either infiltrates or flows laterally as run-off.

Swanson et al. (1998) describe a conceptual model of the hydrology of a pile of coarse waste materials that can be used as a basis for hydrological modeling. It contains three major components (see Figure D-2):

- Infiltration through the active surface zone,
- Percolation through the waste materials, and

[1] Spent ore is ore from which it is no longer economic to leach or otherwise remove valuable minerals. Spent ore can be in the heaps or dumps where leaching occurred or in repositories where leached ore is moved following detoxification. (Note that applicants should predict effluent quality during active operations for any discharges that may occur, including discharges under the NPDES "storm exemption." The latter is important when the predicted mine life amounts to a substantial proportion of the return interval of the facility's storm-surge capacity—a predicted 15-year mine with capacity to store all precipitation from a 25-year storm, for example.)

- Seepage at the base of the facility.

Under unsaturated conditions, water percolating through a disposal unit will gradually wet the materials and, depending on local conditions and material properties, will be stored in pores within the pile. For homogeneous piles of coarse rock, water is likely to be transmitted quickly to the base of the pile (Smith et al., 1995). Many waste rock dumps, however, are not homogeneous piles of coarse material, but instead are composed of a mix of coarse and fine materials that have undergone some degree of segregation through end-dumping or other construction practices. Particle segregation can create unit-specific hydrological characteristics that can lead to preferential flow through fine-grained waste rock layers as described by Newman et al. (1997) and Swanson et al. (1998). Seepage from the base of the pile may occur when storage is depleted or the hydraulic head is sufficient to force water through the toe of the dump. Depending on the nature of the foundation materials and the topographic setting of the dump, seepage may flow laterally from the base of the dump or percolate downward into the substrate. Flow through a heap could be somewhat different, since the materials, and the subsurface are likely to be somewhat different themselves. Although nominally homogenous, ore may have been agglomerated with cement or other materials, and there may be zones of low permeability throughout a heap or dump. Flow through heaps and dumps should have been modeled during site planning, and these data may be useful in predicting seepage and other flows through spent ore piles and dumps.

Aspects of engineering design influence the production of effluent from waste rock

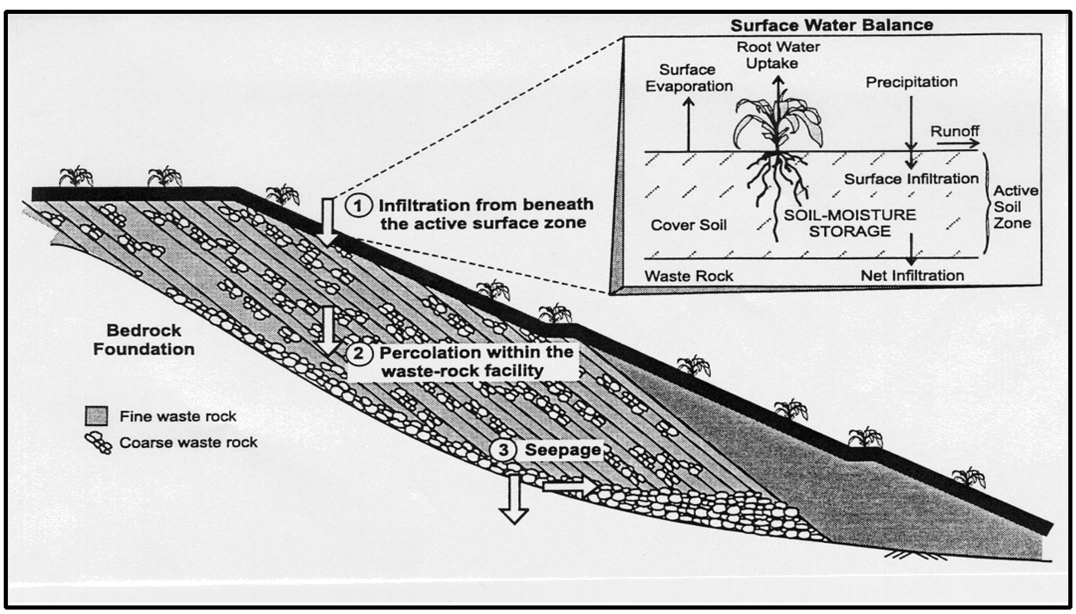

Figure D-2. Conceptual model of water flow through a reclaimed waste-rock facility (from Swanson et al., 1998) dumps and spent ore piles (see Kent, 1997 and Appendix F, *Solid Waste Management*). These include the:

- Range of geotechnical and hydrological properties of the waste materials;
- Topographical location of the dump (e.g., steep mountainous terrain versus valley fill sites);
- Mode of disposal and the expected particle size segregation that would occur from the dumping method;
- Lift construction and thickness;
- Loading rates;
- Pre-loading site preparation, such as placement of low-permeability clays or other soils and/or compaction of native soils or placed materials;
- Design of drainage systems, including internal drainage layers and foundation drains;
- Methods employed to isolate potentially acid or other contaminant generating materials;
- For spent ore, agglomeration or other means of treatment; and
- Physical and hydrological properties of the foundation.

In evaluating effluent production, applicants should consider factors in addition to engineering design. Certain operational practices, such as concurrent reclamation, use of daily or periodic covers, or seasonal operations, all would affect the quantity of effluent from dumps and piles. Similarly, actions taken at closure, such as topsoil replacement, design of the final cover, compaction of cover materials, or revegetation would affect effluent quantity. Applicants should consider and account for all variables that could affect the production of effluent through all mine life stages.

Most methods to characterize the hydrology and estimate the volumes and rates of run-off from and seepage through waste rock or spent ore piles use a water balance approach. In typical water balances, analytical methods to determine run-off and infiltration are combined with analytical or numerical solutions to estimate unsaturated and saturated flow through the embankment. The Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994) combines several analytical hydrological procedures and provides volume estimates of surface run-off, subsurface drainage, and leachate that are likely to result from different waste pile designs. Because of its widespread application, the HELP model is described in detail below. Other models that have been used to characterize waste pile hydrology include MODFLOW, SUTRA, SEEP/W, and FEMWATER/FEMWASTE; these models are briefly described in Section 3.1.2 (FEMWATER/FEMWASTE is described in Appendix A, *Hydrology*).

3.1.1 Hydrologic Evaluation of Landfill Performance (HELP) Model

The HELP computer program (Schroeder et al., 1994) is a quasi-two-dimensional model that can be used to compare effluent generation and run-off from various waste pile designs. The model uses meteorological, material, and design data to compute analytical solutions and estimate parameters such as surface storage, snowmelt, storm water run-off, infiltration, vegetative growth, evapotranspiration, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembranes or composite liners. HELP can be used to evaluate various combinations of reclaimed or unreclaimed surfaces and surface soil caps, waste cells, lateral drain layers, low permeability barrier layers, and synthetic geomembrane liners. Results are expressed as daily, monthly, annual, and long-term average water budgets.

HELP simulates precipitation and other meteorological conditions using the weather generation model (WGEN) developed by Richardson and Wright (1984). Daily rainfall data may be input by the user, generated stochastically, or taken from an historical data base contained in the model. Daily temperature and solar radiation data also can be input by the user or generated stochastically. Determinations of run-off are calculated using the United States Department of Agriculture Soil Conservation Service (SCS) curve number method (SCS, 1985), which is described in Appendix A, *Hydrology*. Potential evapotranspiration is calculated using the Penman method (Penman, 1963). The HELP model also incorporates routines for estimating interception (Horton, 1919), snowmelt (Anderson, 1973), and frozen soil (Knisel et al., 1985). Vertical drainage is modeled using saturated and unsaturated relationships described by Campbell (1974). Lateral drainage is determined using approximations of the steady-state solution of the Boussinesq equation and the Dupuit-Forchheimer assumptions for lateral flow. Each of these processes is linked sequentially by the HELP model, starting with determinations for run-off and a surface water balance. It then applies evapotranspiration from the soil profile and finally determines drainage and water routing, starting with infiltration at the surface and then calculating seepage through the pile.

3.1.2 Other Models

MODFLOW (McDonald and Harbaugh, 1988) is a block-centered finite difference program that can be used to simulate steady-state and transient flow in two or three dimensions. Simulations can be run for porous media in confined and unconfined aquifers above an impermeable base.

SEEP/W (Geo-Slope International, 1995) is a two-dimensional finite element program for ground water seepage analysis. The program permits analysis of saturated and unsaturated flow, seepage as a function of time, precipitation infiltration, migration of a wetting front, steady-state or transient flow, confined or unconfined flow, and excess pore pressure dissipation. The software was used by Newman et al. (1997) to model flow through columns constructed to simulate a structured waste rock pile composed of layers of coarse and fine waste rock materials.

SUTRA (Voss, 1984) uses a two-dimensional, hybrid finite element and integrated finite difference method to approximate the governing equations and simulate fluid movement and the transport of either energy or dissolved substances in the subsurface. The program calculates fluid pressures and either solute concentrations or temperatures as they vary with time. Flow simulation may be used for cross-sectional modeling of saturated and unsaturated flow and areal modeling of saturated flow.

3.1.3 Considerations for Model Selection

It will be difficult to accurately predict the hydrological behavior of a waste rock dump or spent heap leach pile prior to its construction. This is because the physical characteristics of the pile (development of layering, grain-size variability, lithological changes, etc.) cannot be known with any degree of certainty. Consequently, applicants may need to model a variety of scenarios that cover the range of expected structures. As discussed by Hutchinson and Ellison (1991), drainage through a waste pile should be estimated using unsaturated ground water flow models which can account for the upward movement of water caused by capillarity. However, once a mine has been brought on-line, operational monitoring of meteorological variables and of the hydraulic conductivity of different geotechnical layers within a waste pile can be used to refine pre-construction models of effluent quantity.

Most numerical ground water models require separate analyses or modeling to create input for precipitation, infiltration, evapotranspiration, and run-off. One advantage of the HELP model is that it combines analyses of surface and ground water components. HELP also allows meteorological data to be determined stochastically. However, a disadvantage of the HELP model is that it employs a less accurate method (SCS curve number) to estimate infiltration and run-off. Run-off can be determined more accurately using the Kinematic Wave Method (Linsley et al., 1975; COE, 1987; see Appendix A, *Hydrology*). Infiltration can be more accurately determined using mathematical methods such as Green and Ampt (1911) or the Richards equation (Philip, 1969), empirical models such as Horton (1940) and Holtan (1961), or by using variations of these methods (U.S. EPA, 1998a, 1998b; see Appendix A, *Hydrology*). However, the application of these alternative methods requires detailed knowledge of several physical variables that may be unknown or difficult to estimate prior to construction of the waste rock or spent ore pile. U.S. EPA (1998a; 1998b) evaluates the variety of available infiltration methods and provides recommendations on their application; readers should refer to these documents for more information.

3.2 Determining Effluent Quality from Waste Rock and Spent Ore Piles

The composition of effluent associated with an existing waste rock or spent ore pile can be determined by sampling seeps or pore waters. In contrast, predicting the quality of effluent that would be generated from a proposed waste rock dump or spent ore heap prior to its construction is difficult and presently cannot be accomplished with a high degree of certainty. This is because the processes that govern effluent quality operate at rates that are difficult to predict under field conditions. This is especially true for ARD chemical reaction kinetics, bacterial growth kinetics, and their interactions (Lin et al., 1997). The problem is made even more difficult when the disposed materials vary in grain size and/or mineralogy, when materials have been subjected to leaching by process chemicals, when construction methods produce preferential fluid pathways, and when chemical additives (e.g., limestone, chelating agents, bactericides) are used as amendments during construction or closure. Consequently, two approaches are used to predict leachate quality from proposed facilities. *Empirical* approaches use the results of geochemical testing to provide a measure of the future behavior of waste materials (Pettit et al., 1997). *Modeling* approaches use equilibrium geochemical models, mass transfer models, or coupled mass transfer-flow models to predict leachate quality (Lin et al., 1997; Perkins et al., 1997).

In general, the constituents of concern would be similar to those for mine drainage (see section 2.2.1). Of particular concern in gold heap leach facilities would be cyanide or other chemicals used as lixiviants, their breakdown products (in the case of cyanide, these would include ammonia and nitrate), and chemicals used to detoxify cyanide or other lixiviants. Applicants should ensure they conduct the proper cyanide analyses (weak acid dissociable or WAD versus total, for example), which would depend on applicable water quality standards.

3.2.1 Measuring Effluent Quality at Existing Facilities

The quality of effluent produced from an existing waste rock or spent ore pile should be determined from surface seeps and/or pore waters (for seepage) and run-off. In essence, the process is similar to that for sampling surface and ground waters described in Appendix B, *Receiving Waters*. Applicants should be certain to collect enough samples to permit an evaluation of seasonal changes in discharge quality and to determine whether pore water compositions vary with depth or position in a dump.

3.2.2 Empirical Predictions of Effluent Quality from Proposed Facilities

Appendix C, *Characterization of Ore, Waste Rock and Tailings,* describes the variety of geochemical and mineralogical tests that can be conducted on waste rock, ore, and heap leach residues. In general, the results of these tests provide only an indication of the chemical characteristics that an effluent may be expected to have and they cannot be used to provide an absolute measure of water quality. In part, this is because leach tests use (comparatively) short experimental times, simulated leach solutions, and materials with altered particle-size characteristics (most tests require crushing) that affect chemical and physical controls such as oxidation rates, mineral availability, and fluid flow.

Several factors influence the quality of run-off that is generated during a given storm event. They include the composition of the solid materials exposed on the surface of the waste dump, the contact time between run-off and waste rock materials (i.e, run-off flow path), the duration of the precipitation event, the length of time since the previous run-off event (i.e., oxidation time), and the climatic conditions. In general, these factors determine the composition and quantity of constituents present on the surface of the waste rock dump that potentially could be dissolved and transported by precipitation run-off. For example, a pyritic waste rock dump situated in a humid environment would undergo oxidative weathering between storm events that would result in a build-up of oxidation products on the surface of waste rock fragments. Precipitation run-off could dissolve and transport these products, leading to an initial “flush” of constituents as the most easily dissolved compounds are mobilized; continued run-off may show significantly lower constituent values.

Predicting run-off quality is a difficult undertaking for which a set methodology has not been established. In general, the results of leachate tests are used to estimate run-off quality. Most standard leach tests (e.g., TCLP, SPLP, ASTM) are thought to provide conservative estimates of leachate composition due to the comparatively long leachate-rock contact time (typically 18 to 24 hours), the exaggerated particle surface area (test samples are typically crushed to sizes substantially smaller than actual waste rock), and the aggressive character of the lixiviants used in some tests (pH values for some tests are lower than natural precipitation). Applicants should keep in mind that a disadvantage of standard leach tests is that they do not permit an evaluation of the potential effects of oxidative weathering. Kinetic tests (e.g., humidity cells or columns) can be used to constrain the potential importance of oxidation and "flushing".

Seepage quality will be partly a function of the methods by which a waste rock or spent ore pile is constructed. This will be especially true for mines that dispose of materials with widely different leaching and acid generating characteristics. Construction techniques dictate important factors such as the rate and path of water flow through the pile, the residence time of water in the pile, and the distribution of acid generating and acid neutralizing materials within the pile (e.g., Morin and Hutt, 1994). Moreover, dump design can play a major role in determining whether "hot spots" of acid generation form within a dump (e.g., Garvie et al., 1997) or whether a dump behaves in a chemically uniform manner because materials have been evenly distributed through layering or blending (Mehling et al., 1997). Operations and closure influence effluent quality as well, as was noted previously, and appropriate operational and closure aspects should be considered in predicting effluent quality during specific times of a mine's life.

In general, statistical analyses of geochemical test results are used to assess the characteristics of waste rock materials and the quality of effluent that would be generated from waste rock piles. Pettit et al. (1997) describe applications of multi-variate techniques such as cluster analysis and discriminant analysis. These analyses can indicate waste rock types that have similar behavior.

An empirical approach described by Morin and Hutt (1994) predicts seepage quality from kinetic leach test results. Geochemical production rates (mg of constituent/kg of rock/week) are estimated from test results using "best-fit lines" through test data points. Estimated long-term production rates are combined with assumed precipitation volumes and total waste rock volume to yield predicted constituent concentrations. Constituent concentrations determined using this method depend heavily on the estimate of long-term production rate, which requires careful long-term kinetic testing. Because this model ignores many of the hydrological and chemical complexities associated with waste rock piles, it should be used only to approximate seepage quality.

3.2.3 Predictive Modeling of Effluent Quality from Proposed Facilities

Perkins et al. (1997) review the applicability of numerous types of computer models to predictions of water quality from waste rock dumps or from leach heaps or dumps. They describe four general model classes that can be used to predict water quality:

- Aqueous Geochemical Equilibrium Models,
- Geochemical Mass Transfer Models,
- Coupled Geochemical Mass Transfer-Flow (Reaction-Transport) Models, and
- Applied Engineering Models.

From an environmental perspective, every waste rock or spent ore pile is unique. Consequently, there is no standardized approach for modeling effluent quality from these facilities. The choice of a predictive model depends on the conceptual model developed for the site (see Section 1.2). In all cases, it is important for applicants to select tools capable of addressing the task at hand and to clearly state the assumptions used to generate model simulations. At most sites, the modeling process will require an iterative approach in which the results of early numerical models are used to refine the conceptual site model. Several models that have been used are described below.

A mathematical model of pyrite oxidation and oxygen diffusion through a waste rock dump was developed by Davis et al. (1986). The Davis-Ritchey model views oxidation as a moving front that proceeds inward from the edges of pyrite grains to their cores (the “shrinking core” model). The approach has been incorporated into numerical models such as PYROX (Wunderly et al., 1996). The shrinking core model has recently been criticized as underestimating the decrease of oxidation rate that occurs as grain size increases (Otwinowski, 1997).

Aqueous geochemical equilibrium models are static models that use water composition, temperature, and pressure to compute equilibria among aqueous species. They are widely used in studies of acid rock drainage and background stream composition to estimate the precipitation and dissolution of mineral phases and identify the maximum solute concentrations that can occur. Geochemical equilibrium models utilize thermodynamic data to compute equilibria; the quality of these data and the number of species contained in the dataset govern the quality of the computed results. Shortcomings of this class of models are that they do not consider flow and they cannot be used to provide a 2- or 3-dimensional picture of chemical equilibrium (e.g., in a waste rock dump). Examples of this model class include MINTEQA2 and PHREEQC, which are described in more detail in Appendix B, *Receiving Waters.*

Geochemical mass transfer models are dynamic models that use initial fluid composition, mineral composition, and mineral mass and surface area to compute a final fluid composition following fluid-mineral reactions in a closed system. Mass transfer models compute how fluid composition changes as host minerals dissolve and new minerals precipitate until equilibrium is achieved. These models have not been widely applied to predictions of effluent quality from waste rock or spent ore piles. Deficiencies of this class of models are that they cannot accommodate flow and that important mineral reactions may be overlooked if the computational reaction step size is too large. Use of an appropriately small reaction step has the negative effect of greatly increasing computing time. Examples of this model class include React!, which is available commercially.

Coupled geochemical mass transfer-flow models (also termed reaction-transport models) are similar to mass transfer models, but have been expanded to accommodate open systems. Consequently, they are capable of handling fluid composition changes that occur due to dilution by infiltrating precipitation, and concentration by evaporation. These models are complex but hold the most promise for producing accurate predictions. At present, Perkins et al. (1997) do not recommend use of most coupled mass transfer-flow models, because they generally do not combine sufficiently rigorous geochemical and flow analyses. However, Lin et al. (1997) presently are developing a new mass transfer-flow model (ARD-UU) specifically for predicting acid rock drainage from waste rock dumps under unsaturated conditions. In addition, Wunderly et al. (1996) have combined the PYROX and MINTRAN codes to produce the program MINTOX, which is a 3-dimensional coupled mass transfer-flow model that simulates pyrite oxidation, gas diffusion, and the formation of oxidation products in mining wastes.

Empirical models do not compute equilibrium geochemical relations, but instead use a limited set of geochemical and physical processes to simulate the observed geochemistry. These models, which can be applied only to the site of interest, are best used for comparing different management options because they have limited predictive applications. An empirical approach described by Morin and Hutt (1994) was described in the Section 3.2.2.

4.0 TAILINGS FACILITIES

Effluent from tailings impoundments and dry tailings facilities can include process waters that are either discharged directly or through seepage and run-off from the facility area. Discharges may be continuous or they may occur only under high precipitation conditions. Tailings impoundments often are used to manage other waters from the site (e.g., mine drainage, sanitary wastes, wastewater treatment plant sludge). Consequently, flows from other sources need to be addressed when determining tailings unit effluent quantity and quality.

It is extremely important that effluent quality be characterized during all stages in a tailings facility's life. Even if a facility is designed not to discharge during its active life, there may be a need to discharge during and after closure. The quantity and quality of that effluent should be predicted. In addition, applicants should take note of the relationship between the reasonably anticipated life of the mine and the return interval of the design storm. If the life is a significant proportion of the return interval, then it is likely there will be a storm-related discharge during the mine's life (see the main text for a discussion of the so-called "storm exemption" to the NPDES effluent limits). Applicants should predict the quality of discharges under various storm scenarios, including the probable maximum flood.

4.1 Determining Water Quantity and Discharge from Tailings Facilities

Every tailings impoundment will behave in a slightly different hydrological manner that reflects the impoundment design, construction and management; its physical, hydrological and climatological setting; and the physical and chemical characteristics of the materials contained within it. In general, tailings solids are retained by an embankment or perimeter dike and are maintained under a partial to complete water cover. Most facilities are unlined; some have embankments with impermeable cores or grout curtains to preclude seepage (Vick, 1990; see Appendix F, *Solid Waste Management*). It is assumed that the catchment area contributing run-off to the impoundment will be minimized by designing and constructing appropriate stream and/or run-off diversion structures around the impoundment. This is important for minimizing the amount of effluent that may need to be discharged. Although filled with generally fine-grained materials, the method of tailings disposal can create particle size differences that affect permeability and transmissivity. Moreover, facilities that contain pyritic tailings under partially saturated conditions may develop hardpan layers that complicate lateral and vertical flow paths (Blowes et al., 1991).

In dry tailings facilities, tailings are dewatered prior to placement and maintained under unsaturated conditions (see Appendix F, *Solid Waste Management*). They are typically reclaimed concurrent with operation. The materials comprising these facilities contain moisture only in the form of residual process water or precipitation that falls onto exposed tailings materials.

Estimating effluent volumes from a tailings facility (wet or dry) begins with the need for an accurate site water balance throughout the predicted life of the unit. The water balance must include both process water inputs and outputs including run-on/run-off, evaporation, and seepage. In addition, applicants should predict estimated discharges during and after closure.

Seepage from tailings facilities can be predicted using empirical, analytical, or numerical methods like those described in Section 3.1. Similar to predictions of drainage from waste rock dumps, predictions of seepage from tailings facilities require knowledge of the proposed engineering design of the facility. In addition to the engineering factors cited in Section 3.1, tailings seepage predictions require knowledge of the permeability, transmissivity, and storage capacity of the substrate; local and regional ground water hydrogeology; and embankment permeability.

Programs such as SEEP/W and MODFLOW (Section 3.1.2) can be used to analyze seepage from impoundments. These models can be used to simulate the migration of a wetting front into the underlying substrate, the development of a ground water mound beneath the impoundment, and seepage through an embankment (e.g., Vick, 1990). For dry tailings facilities, the HELP model (Section 3.1.1) can be used to determine parameters such as infiltration, storage, and drainage.

Besides estimating the quantity of seepage that may emerge from a tailings facility, applicants also should estimate quantities of run-off under various storm conditions, and any discharges of process wastewater in net precipitation zones that are allowed under the regulations (see Section 2.2 in the main text).

A detailed description of methods used to quantify volumes of ***surface run-off*** is provided in Appendix A, *Hydrology.* In general, the most appropriate methods for developing and analyzing run-off from sub-basins or facilities at mine sites, including areas with tailings impoundments, use a unit hydrograph approach (see Appendix A, *Hydrology*). A unit hydrograph is a hydrograph of run-off resulting from a unit of rainfall excess that is distributed uniformly over a watershed, sub-basin or mine facility in a specified duration of time (Barfield et al., 1981). The unit hydrograph represents the run-off characteristics for the specific facility or sub-basin for which it was developed and is used to quantify the volume and timing of run-off . Common methods to develop and use unit hydrographs are described by Snyder (1938), Clark (1945), Chow (1964), Linsley et al. (1975) and SCS (1972).

Estimating the volume and timing of discharges from mine facilities in regions with net precipitation requires an accurate understanding of the site water balance. A detailed description of methods and approaches used to develop a site water balance are provided in Appendix A, *Hydrology*. In general, an accurate site water balance is required to successfully manage storm run-off, stream flows, and point and non-point source pollutant discharges; and to design control and discharge structures. M.L. Brown (1997) describes methods to determine a site water balance using both deterministic and probabilistic approaches. To provide insight into the range of conditions that could be expected to occur, deterministic water balances should be computed for average, wet, and dry conditions. In contrast, the input values used in probabilistic approaches are sampled from probability distributions (e.g., annual precipitation probability). Computer spreadsheets are used to iteratively calculate inflow and outflow probabilities. According to M.L. Brown (1997), probabilistic approaches result in better facility designs because they can indicate which parameters have the most effect on model results and may reveal potential design weaknesses.

4.2 Determining Effluent Quality from Tailings Facilities

Determining the quality of effluent from tailings management facilities requires an understanding of ore mineralogy, beneficiation processes, tailings facility design, mine site water flow, closure plans, and surface and ground water quality. Consequently, the process used to estimate tailings effluent quality will vary from site to site. Tailings management plays a pivotal role in determining the potential for water quality impacts. For example, sites may treat process chemicals (e.g., cyanide) contained in tailings water prior to discharge or they may maintain a water cover over reactive tailings to prevent oxidation of pyritic materials. In general, the metals leaching potential of tailings depends on the mill process, ore mineralogy, and particle size (Price et al., 1997).

Constituents of concern should be identified as described in section 2.2.1. In addition, applicants should monitor for residual process chemicals (cyanide, xanthates, etc.) as well as for pollutants in other wastes that may be disposed with tailings (for example, fecal coliform and BOD if sanitary wastes are disposed).

4.2.1 Measuring Effluent Quality at Existing Facilities

Tailings effluent quality can be measured at existing facilities by collecting and analyzing impoundment water quality, pore water samples, and samples collected from seepage ponds and surface seeps. In essence, the process is similar to that for sampling surface and ground waters described in Appendix B, *Receiving Waters*. Applicants should be certain to collect sufficient samples to permit an evaluation of seasonal changes in discharge quality and to determine whether pore water compositions vary with depth or position in an impoundment.

4.2.2 Predicting Effluent Quality from Proposed Facilities

From an environmental perspective, every tailings impoundment is unique. Consequently, there is no standardized approach for modeling effluent quality from these facilities. The caveats stated with regard to predictive modeling of waste rock and spent ore piles (Section 3.2.3) apply to models of tailings effluent as well (also see Section 1.2).

Tailings management is a critical issue, particularly for sites that would produce tailings containing pyrite or residual cyanide. Studies of active impoundments show that water quality can vary throughout an impoundment due to differences in the rate of pyrite oxidation (e.g., Robertson et al., 1997). For example, subaerially exposed tailings that occur on a beach near the discharge point may contain pore waters with significantly lower pH and higher (by an order of magnitude) sulfate and metals concentrations than tailings that remain saturated. For cyanidation tailings, impoundment design, water balance, and climate can influence the rate of natural cyanide degradation (Botz and Mudder, 1999).

Predictions of effluent quality need to consider the range of environments (e.g., subaerial, unsaturated vs. subaqueous, saturated) that would be present throughout the life of the facility and the volumes and compositions of materials that would be stored under the different environmental conditions. Assumptions regarding the behavior of these environments (steady-state or transient) are a necessary part of these considerations (Alpers and Nordstrom, in press). However, broad assumptions regarding the behavior of pyritic or cyanidation tailings should be avoided. For example, Li et al. (1997) showed that water covers may not preclude sulfide oxidation as is often assumed. Instead, their work indicated that sulfide oxidation rates, although low, vary as a function of water depth, wave action, and particle resuspension (Figure D-3). Studies such as this illustrate the importance of developing a conceptual model that incorporates aspects of engineering design, facility water balance, climate, and materials properties and compositions when predicting effluent quality. The conceptual model serves as the basis for developing numerical models of water quality (see Section 3.2.3 for model descriptions; Botz and Mudder (1999) describe a model for natural cyanide degradation that presently is being calibrated and tested).

In general, the models described for waste rock and spent ore piles in Section 3.2.3 also can be applied to predictions of effluent quality from tailings facilities. These include equilibrium models such as MINTEQA2 and PHREEQC and coupled mass transfer-flow models such as MINTOX. Similarly, the methods described in section 3.2.2 should be suitable for predicting run-off quality; besides considering constituent additions from native minerals, however, applicants should consider how constituents in process water quality will affect run-off quality from tailings facilities.

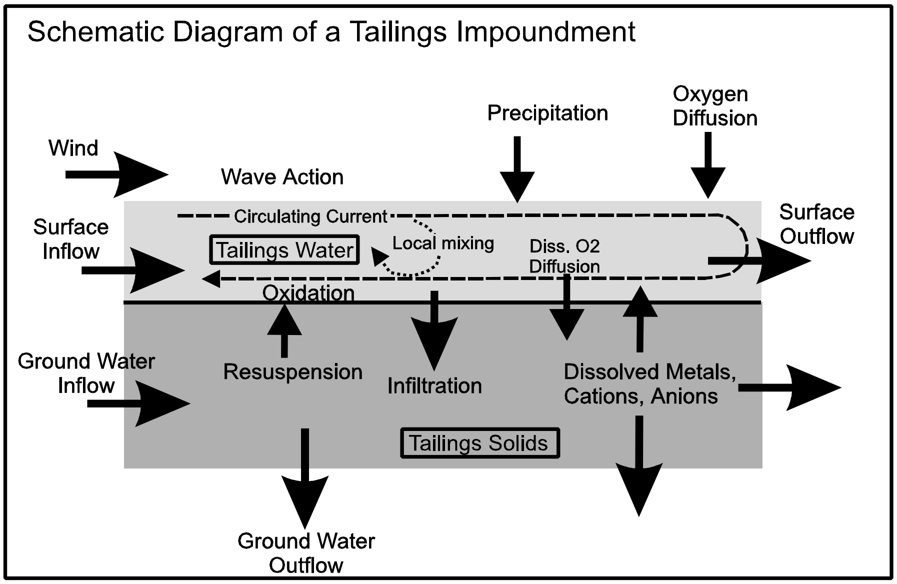

Figure D-3. Processes that affect subaqueous sulfide oxidation in tailings impoundments and the quality of tailings impoundment water (modified from Li et al., 1997).

It is assumed that applicants will perform pilot-scale testing for beneficiation operations to determine/optimize metals recovery. It is important that these tests be conducted with representative ore feeds with the reagent chemicals expected to be used at the mine. Tailings solids generated from these tests should be used for geochemical analyses (i.e., static acid-base accounts, kinetic humidity cell tests, leach tests, and mineralogical tests; see Appendix C, *Characterization of Ore, Waste Rock and Tailings*). Water produced during pilot-scale tests should be analyzed to indicate the general composition of water to be discharged to tailings management units, including residuals from any chemicals used in the process. Geochemical analyses and pilot-scale test results can be used to predict effluent quality directly or as input to predictive models.

Price et al. (1997) cite several factors that should be considered in predictions of tailings effluent quality:

- Tailings composition may change with time due to processes such as pyrite oxidation or the formation of ferricrete hardpan layers;
- The particle-size characteristics of tailings influences the surface areas of minerals susceptible to weathering;
- The particle-size characteristics of tailings determines the permeability of tailings to water and oxygen; and
- The method by which tailings are deposited can segregate particles by size and mineral type which, in turn, can create zones with different metal leaching potential.

Other questions that may need to be addressed for long-term predictions of effluent quality include:

- Will the impoundment be used to store storm water run-off?
- Will facility closure permit oxidation (e.g., through dewatering)?
- Will residual process chemicals (e.g., cyanide) remain in the tailings?
- What is the mineralogy of the residual tailings solids?
- What is the alkalinity of the residual tailings solids?

5.0 FLOW ROUTING AND EFFLUENT QUALITY FROM A MINE SITE

The preceding sections describe methods to estimate effluent quality from different types of mine facilities. At many mine sites, water management plans may dictate that multiple effluent streams be combined. In such cases, applicants will initially need to determine the quantity and quality of effluent from each source. An accurate site water balance is required to demonstrate how each contributing flow will vary with time, site conditions, and facility operations. Appendix E (*Wastewater Management*) discusses the importance of performing detailed water balance calculations, and describes wastewater management in some detail. Based on the water balance, applicants should then determine the quantity and quality of the combined effluents.

Expected variations in flow and water quality from each source can be combined using mass balance calculations or modeling. For example, equilibrium geochemical models such as MINTEQA2 or PHREEQC may be used to compute flow-weighted effluent quality. Such calculations should determine the average effluent quality and the range of possible effluent compositions that could occur. If the effluent is to be discharged, the maximum values of effluent parameters are important. The estimated quality of the combined effluent can then serve as the basis for determining management practices and/or treatment requirements. Treatment may be required for individual effluent streams only or for the combined effluent stream. Where treatment prior to discharge is a component of wastewater management, effluent quality and quantity (average and maximum, variability, etc.). following treatment must be predicted. Treatability studies may be required to make such predictions. This is discussed in Appendix E.

6.0 STORM WATER

Storm water discharges from active and inactive mining areas and reclaimed areas, that are not combined with mine drainage or process water, may be authorized under individual or general NPDES storm water permits (e.g., the Multi-sector General Storm Water Permit, Sector G for Mining; see Section 2.4 of the *Source Book* main text) provided the discharges do not cause or contribute to a violation of applicable water quality standards. The Multi-sector General Permit for Mining requires monitoring of certain storm water discharges to assure that storm water best management practices are working as anticipated (see FR Volume 63, No. 152, August 7, 1998, pp. 42533-42548 for clarification of covered discharges and monitoring requirements. This clarification is also included in EPA's most recent issuance of the Multi-Sector General Permit for Storm Water associated with Industrial Activities which was issued on October 30, 2000). Storm water sampling guidance can be located at EPA's website.

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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 impoundments 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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APPENDIX F

SOLID WASTE MANAGEMENT

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Mining operations produce a variety of solid materials that require permanent management. In order to prevent or minimize environmental impacts, applicants must pay careful attention to the methods by which these materials will be disposed, the locations of the disposal facilities, and the engineering designs of the disposal facilities. The largest mines may generate over a billion tons of solid wastes that cover areas exceeding a thousand acres, and even smaller operations must handle and dispose of formidable quantities of materials that can affect large areas. The environmental behavior of these materials ranges from benign to deleterious, with specific areas of concern arising from sediment loading, metals contamination, cyanide release, and acidification. This appendix provides a brief overview of the issues related to the disposal of solid wastes which applicants may be expected to address during the NEPA and associated Clean Water Act permit application processes. It is not intended to provide a comprehensive review of solid waste disposal practices. Related information is provided in Appendix C, *Characterization of Ore, Waste Rock, and Tailings* and Appendix H, *Erosion and Sedimentation.*

2.0 TYPES OF SOLID WASTES AND MATERIALS

This appendix is concerned with the disposal of the four types of mining wastes and materials that are generated and managed in the highest volumes:

- Overburden
- Waste rock
- Tailings
- Heap and dump leach residues.

Other types of solid mining wastes that may require disposal include smelter slag, trash, construction debris, incinerator ash, wastewater treatment sludge, and sewage sludge. The management of sludge from wastewater treatment is discussed in Appendix E.

2.1 Overburden

Overburden consists of unconsolidated to poorly consolidated materials such as soils, alluvium, colluvium, or glacial tills that must be removed to access the ore body that will be mined and processed (Hutchinson and Ellison, 1991). In most cases, overburden materials will not contain significant quantities of leachable metals or acid-generating minerals. However, geochemical tests similar to those described in Appendix C, *Characterization of Ore, Waste Rock, and Tailings,* may need to be conducted to ensure the benign character of these materials. Humus-rich forest soils may be slightly acidic and should be tested if they would be used as cover materials or growth media atop metal-bearing wastes. Soils and unconsolidated deposits may require proper handling and disposal to prevent erosion and sediment loading to streams and other surface waters. Management of overburden is discussed in Section 3 below.

2.2 Waste Rock

Waste rock is removed from above or within the ore during mining activities. 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. Waste rock consists of non-mineralized and low-grade mineralized rock. Materials may be 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 the existing technology. Materials that are disposed as waste at one point in a mine's life may become ore at another stage, depending on commodity prices, changes in and costs of technology, and other factors.

Waste rock may be acid generating and may contain metals that can be mobilized and transported into the environment. These materials generally will require extensive geochemical testing (Appendix C, *Characterization of Ore, Waste Rock, and Tailings*) to determine if they will impact the environment over the short or long term. Special engineering designs, waste handling and disposal procedures, or closure and reclamation plans may be required for those materials whose characteristics may pose significant risks. Waste rock management is discussed in Section 3 of this Appendix.

2.3 Tailings

Tailings are produced by beneficiation activities that separate the target minerals or metals from the remaining host rock. Beneficiation begins when primary ore is crushed and ground to particle sizes ranging from sand- to silt-sized. Target minerals are separated from the ground ore using density or magnetic separation, froth flotation, or other concentration techniques. The target metal is then separated from the mineral by leaching, electrowinning, or other metallurgical techniques. Residues (tailings) from these processes may make up to ninety percent of the original ore mined. Although lower in the target minerals, the tailings can have a wide range of composition that depends on the mineralogy of the primary ore material, the type of separation process employed, and the efficiency of the separation process. Based on the original constituents, the tailings may contain acid-generating minerals and a variety of metals. The small grain size of most tailings makes them an important potential sedimentation source that is susceptible to erosion and downstream transport. Characterization of tailings are discussed in Appendix C. Section 4 below discusses tailings management.

2.4 Spent Ore, Heap and Dump Leach Residues

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, to extract the valuable metal(s) 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. Characterization of spent ore is discussed in Appendix C. Section 5 below discusses the management of spent ore.

3.0 WASTE ROCK AND OVERBURDEN MANAGEMENT

Waste rock and overburden materials are managed according to specific site conditions, regulatory requirements, and materials composition. Management practices that are suitable at one site may be unsuitable at another due to factors as diverse as regulatory requirements, material properties, climate, and cultural values. The disposition of these materials can vary greatly depending on their mineralogical and chemical compositions and numerous economic factors. Some materials may be suitable for beneficial uses such as road surfacing, aggregate, structural rock, or decorative rock, whereas other materials possess characteristics that require their permanent disposal in an engineered management facility. Recent contaminant releases associated with waste rock materials or disposal practices at several mines emphasize the importance of comprehensive geochemical testing programs and sound geotechnical studies and engineering designs. This section briefly describes four widely used waste rock management techniques, highlighting the issues and information needs that should be addressed for NEPA and other analyses

3.1 Piles and Dumps

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 is accomplished using a variety of techniques that may include end-, sidehill-, or random-dumping, and dozing. Dump design may vary markedly depending on the nature of the mining operation and the terrain in which materials are being placed. In steep, mountainous areas, dumps may have faces of a few hundred meters height. For these dumps, the buildup of pore water pressures with time is an important variable that is difficult to evaluate quantitatively, but that may lead eventually to partial slope failure (Kent, 1997). Dump designs of this type may require some level of risk analysis to determine potential impacts should failure occur (Kent, 1997). Dumps placed as valley-fill deposits may require the construction of rock underdrains to permit the flow of water through the drainage. The materials used to construct these drains needs to be thoroughly tested to ensure that they will not contribute metals, acid, or other constituents to surface (EPA, 1993a; 1993b). Dump underdrains may need to be tied into the mine drainage or storm water drainage systems that convey seepage to treatment facilities (see Appendix E, *Wastewater Management*).

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, 1992a; 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). These features may include:

- Waste segregation and encapsulation (i.e., cellular construction; SRK et al., 1989),
- Blending and interlayering with materials that neutralize acidity and metals release (i.e., base amendments; e.g., SRK et al., 1989; Mehling et al., 1997).
- Waste conditioning to remove acid generating minerals (SRK et al., 1989).
- Incorporating low permeability materials to slow the migration of poor-quality drainage through a waste rock dump (SRK et al., 1989).
- Designing and preparing substrates that would minimize infiltration and route seepage to collection and treatment points.
- Incorporating bactericides to slow the rate of pyrite oxidation (SRK et al., 1989; Environment Australia, 1997).

Mines that produce a mix of acid-generating and acid-neutralizing waste rock must be careful to design and construct dumps in a manner that does not create local "hot spots" of acid generation from which seepage could escape. Section 7 of this appendix discusses acid drainage considerations in more detail. It is important that mine operators keep accurate and easily interpretable records of the source, amount, and location of all waste placed in waste storage facilities, and for ore material placed on heap leach pads. Reclamation design can then be facilitated, especially if it is shown that the original geochemical characterization of the waste (or the altered state of leached ore) is different than predicted.

Table F-1 lists the type of data needed to select a suitable site for a waste rock dump and some critical design factors of dump construction. Table F-2 identifies monitoring that may be conducted during dump construction and operations. In order for regulatory agencies to perform NEPA analyses and permitting, it is critical that mine applicants supply the following information related to waste rock dump management:

- Describe the criteria that were used to determine whether proposed sites are technically and economically feasible (e.g., Table F-1). Evaluate the importance of critical factors such as foundation stability, substrate bearing capacity, ground water conditions, and surface water hydrology. Compare to any applicable regulatory requirements.
- Provide the rate and total volume of waste rock to be disposed. Characterize the physical and chemical properties of the waste rock and how they relate to dump stability and leachability. Characterization of waste rock is discussed in Appendix C.

- Develop a water balance (see Figure F-1) and predict the potential for seepage and run-off from waste rock dumps during dump construction, operations, and closure in order to design appropriate wastewater management (e.g., containment and/or treatment, need for discharge permit, etc.). Various models are available to facilitate this. For example, the HELP (Hydrologic Evaluation of Landfill Performance) model may be used to predict leachate quantities. Where modeling is used, all model assumptions, input parameters, and uncertainties should be disclosed and a sensitivity analysis may be necessary (see Section 6 of Appendix A, *Hydrology* for general considerations related to modeling). Methods for estimating a water balance for waste piles, modeling of waste rock dumps, and techniques to estimate seepage quality are provided in Hutchinson and Ellison (1991), MEND (1995), SRK (1992b), MEND (1996), and Price (1997). Water balances are discussed in Appendix A. Wastewater management is discussed in Appendix E.

- Describe how the dump will be constructed and managed during operations and closure in terms of maintaining dump stability and reducing impacts to the environment. Develop performance standards and compare to any applicable regulatory requirements (e.g., standards for containment, stability, etc.).

- Develop and describe operational and environmental monitoring plans to ensure dump stability, adherence to performance standards, and to identify impacts to surface and ground water quality. Table F-2 identifies types of monitoring that may be required. Monitoring plans should include action levels and contingency plans. Monitoring plans should incorporate quality assurance (QA) and quality control (QC) (see Section 5 of Appendix B, *Receiving Waters* for a description of quality assurance and quality control plans).

See Section 6 of this appendix for additional considerations related to waste rock dump closure and Section 7 for considerations related to acid drainage.

Table F-1. Data Needs for Waste Rock Disposal Facilities

Critical Design Factor	*Data Needs*	*Data Source/Methodologies*
Facility Site Selection	Topography	Topographical maps, Aerial photos
	Geology and Soils, including fault mapping	Geological maps, Engineering tests of site samples.
	Seismicity (natural and blasting-induced)	Geological maps, Seismic zone maps, Uniform Building Code (U.S. ACE, 1995), Mine Plan of Operation, Engineering tests of site samples.
	Surface Water Hydrology	See Appendix A
	Ground Water Hydrogeology	See Appendix A

Table F-1. Data Needs for Waste Rock Disposal Facilities

Critical Design Factor	*Data Needs*	*Data Source/Methodologies*
	Baseline Water Quality	See Appendix B
	Operational Considerations	Mine Plan of Operation
Waste Rock Characteristics	Physical Properties	See Appendix C
	Chemical Properties	See Appendix C
Pile/Dump Construction	Foundation Stability	Geotechnical and engineering tests of site soil samples.
	Pile Stability	Geotechnical and engineering tests of waste rock materials.
	Surface Water Diversion	See Appendix H
	Seepage/Run-off Collection and Treatment	See Appendix D

Table F-2. Operational Monitoring of Waste Rock Dumps and Heap Leach Facilities

Type of Monitoring	*Methods Used*	*Purpose*
Geotechnical	Visual inspection; Extensiometer; Leveling surveys; Soil strength testing; Soil borings.	Detect changes in slope stability, compaction, and settling that may identify structural weaknesses or signal potential failure of the facility.
Surface Water	Flow/Runoff monitoring; Upstream and downstream water quality analyses	Detect impacts to surface water quality.
Ground Water	Water table monitoring; Upgradient and downgradient water quality analyses	Detect impacts to ground water quality.
Hydraulic	Precipitation/Infiltration measurements; Piezometers; Water quality analyses.	Detect development of water table within pile, identify fluid pathways, monitor internal pore water pressures.
Thermal	Temperature Probes	Detect temperature increases within the pile that may indicate sulfide oxidation.
Pore Water	Water quality analyses	Determine quality of leachate, Early detection of acidification

3.2 Mine Backfill

Mine backfilling is the act of transporting and placing overburden, waste rock, or tailings materials in surface or underground mines. Tailings are more often used as backfill than waste rock or overburden. The technique is being used increasingly as a remediation measure (e.g., to minimize the potential for acid generation in mine walls and/or the backfilled material) and to minimize the amount of surface disturbance required to store waste materials. Coarse-grained materials such as waste rock and overburden typically are hauled to backfill locations using vehicles or conveyors. Due to the increase in rock volume that occurs through blasting and excavation, mine voids can accommodate a maximum of approximately 70 percent of the original material that was excavated and, in practice, the amount is likely to be significantly less. The remaining waste rock and overburden still must be put to beneficial use or disposed of in surface facilities. Coarse backfill materials will have comparatively high porosity and permeability. Their larger surface areas (compared to solid rock) increase the availability of metals and make these materials more susceptible to leaching and acidification. Materials that would be stored in locations above the water table may be subject to periodic flushing by infiltrating meteoric waters which could remove accumulated soluble oxidation products and transport them to surface or ground waters.

Examples of the use of waste rock as mine backfill follow. The Goldbug Waste Rock Repository at Landusky Mine in Montana is material that has been backfilled into the old Goldbug Pit. The waste is placed atop 2-3 feet of crushed dolomite/ limestone which, in turn, sits on a compacted clay liner that is engineered to drain to a collection area. Waste is segregated within the dump to encapsulate acid-generating waste rock within non-acid generating waste. Similarly, at the Castle Mountain Mine in California, waste rock has been used to backfill the initial pit; there, no special handling was required or needed.

If waste rock and overburden are to be used as backfill, mine applicants should provide information of the following types to allow regulatory agencies to conduct full NEPA analyses and make permitting decisions.

- Describe backfill operations and closure, including: timing and amounts of material proposed for backfilling; means of transporting the material to the backfill site; types and timing of storage, if any; if material is to be stabilized or otherwise treated, full description of additives and treatment processes.

- Describe physical characteristics (e.g., size distribution, including percent fines, moisture content) and chemical characteristics of backfill materials and any additives (see Appendix C) .

- Predict the structural stability and leachability of backfill material and enclosing mine rock.

- Description of mine hydrology, including post-closure (see Appendix A). Prediction of water quality in the mine, both with and without backfilling in order to determine potential for impacts to groundwater and surface water and to design appropriate controls.

- Description of monitoring program to be used to verify predictions and allow detection of the need for changes.

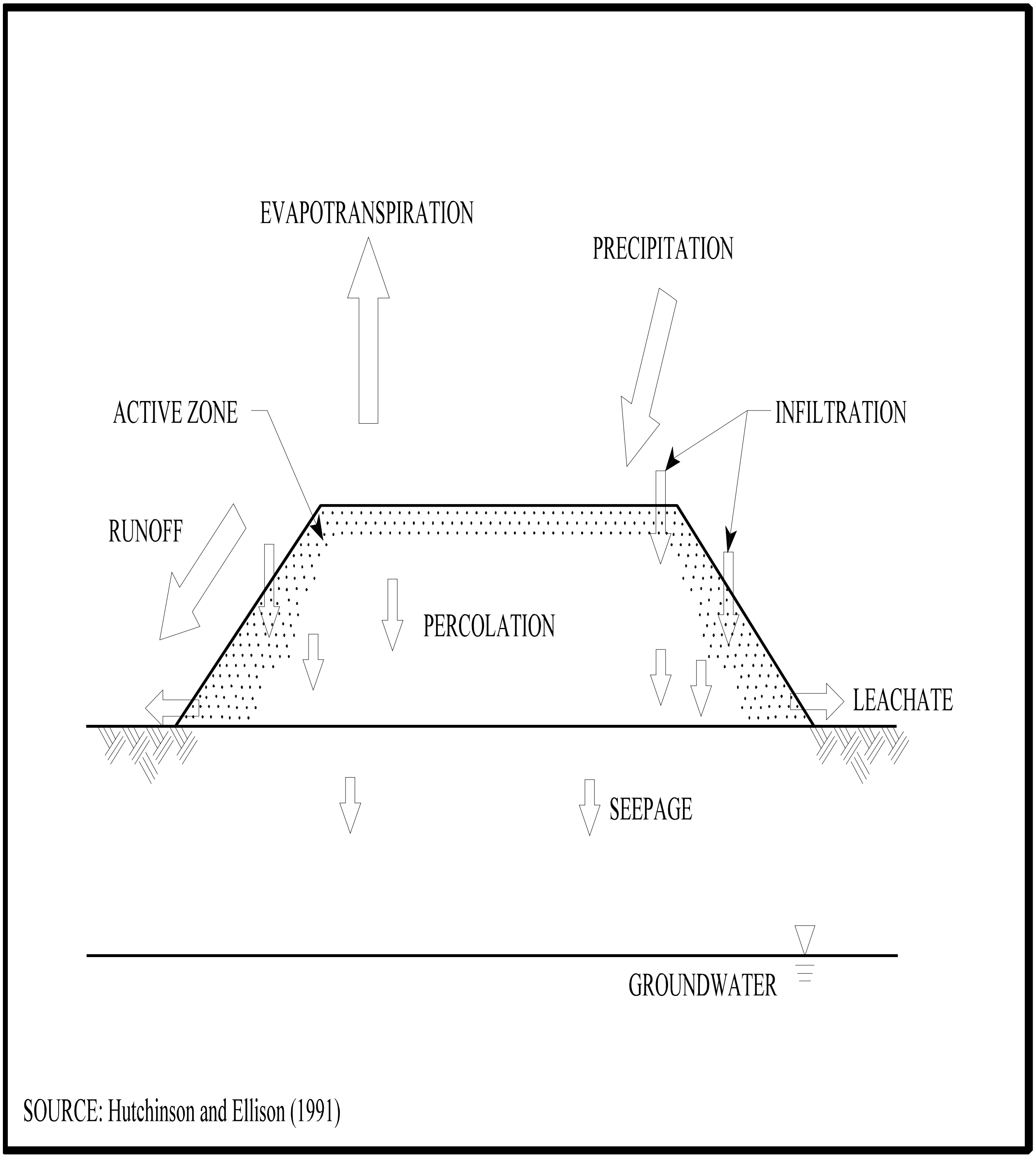


Figure F-1. Hydrologic Cycle for A Typical Waste Pile.

3.3 Use in Facility Construction

Waste rock and overburden materials can be beneficially used as construction materials at many mine sites. Applicants proposing to use waste rock to construct roads, impoundments, buttresses, underdrains, or other facilities or as rip-rap to line channels or stabilize embankments, will need to conduct geochemical tests similar to those described in Appendix C, *Characterization of Ore, Waste Rock, and Tailings.* Testing programs should be designed to ensure that these materials will not themselves generate acid or otherwise cause negative environmental impacts.

If waste rock and overburden are to be used in facility construction, mine applicants should provide information of the following types to allow regulatory agencies to conduct full NEPA analyses and make permitting decisions.

- Describe how the waste rock or overburden will be used for facility construction, including: timing and amounts of material proposed for use, and the purpose for which they will be used; means of transporting the material from the mine to storage and/or construction sites; types and timing of storage, if any.

- Physical (e.g., size distribution, including percent fines, moisture content) and chemical characteristics (e.g., acid generation potential, metals concentrations) and how they relate to stability and leachability.

- Prediction of water quality in situations where the materials will be in contact with wastewater/seepage (e.g,. when used as drains) and of any best management practices (BMPs) or other controls necessary to meet standards.

- Description of alternate sources of construction materials, including the same types of information provided for waste rock/overburden.

- Description of monitoring program(s) to be used to verify predictions and allow detection of the need for changes.

3.4 Use as Cover Materials

Waste rock may be used to cover and stabilize fine-grained tailings. The intent is to reduce or prevent fluvial or aeolian erosion, transport, and redeposition of the fine-grained materials (e.g., Woodward-Clyde, 1998).

If applicants propose to use waste rock as cover material, they should provide the following types of information to support the NEPA analyses and permitting decisions:

- Timing and amounts of material proposed for use, and the means of transporting the material from the mine to the storage and/or tailings areas.

- Types and timing of storage, if any. This should include any storage site preparation (e.g., run-on/run-off controls, temporary vegetation)
- Geotechnical evaluation of the stability of the underlying tailings materials, with and without the waste rock cover.
- Geochemical evaluation of the waste rock/overburden that allows prediction of changes in water quality of infiltrating run-on and precipitation, and of any run-off.
- Description of alternate sources of cover materials, if any, including the same types of information provided for waste rock/overburden.
- Description of the ability of the cover material to support vegetation or other long-term closure solution
- Demonstration that the cover will meet performance standards and regulatory requirements during operations and following closure.
- Description of monitoring program(s) to be used to verify predictions and allow detection of the need for changes.

4.0 TAILINGS MANAGEMENT

Tailings materials are typically disposed of in impoundments. Other management practices that are becoming more common include disposal in dry tailing facilities, disposal under water covers (subaqeous disposal), and disposal in mine voids (mine backfill). This section briefly describes these tailings management techniques. More detailed descriptions are provided in Vick (1990) and Johnson (1997); an overview of tailings disposal in impoundment settings in given in EPA (1994a). As discussed in Section 2.3 and Appendix C, characterization of the tailings materials is critical to predicting environmental impacts and designing appropriate management. As this section will discuss, extensive studies are necessary to evaluate potential tailings management sites and to design and operate the sites.

4.1 Tailings Impoundments

Most mines dispose of tailings in engineered impoundments that cover areas ranging from a few acres to more than a thousand acres. Thickened tailings solids typically are sluiced to the impoundment and deposited by spigotting or through single-point discharges or cyclones. As solid particles settle out of suspension, clarified water from the top of the impoundment is generally recycled to the milling process circuit for reuse. In some cases (e.g., in areas of net precipitation or following mine closure), water may be discharged from the impoundment, in which case an NPDES or land application permit is required. Tailings impoundments may also be used as emergency containment for excess storm water run-off from other areas of the mine site and for disposal of sludges from on-site mine wastewater or sewage treatment plants.

Critical issues related to the design and management of tailings impoundments are discussed in the following subsections. Issues related to closure and reclamation of tailings impoundments are discussed in Section 6.

4.1.1 Site Characterization.

The choice of a tailings impoundment site is based on the need to maximize desirable features and minimize undesirable features. Criteria typically used to determine an appropriate tailings impoundment site are presented in Table F-3. Site characterization studies need to include comprehensive geological, geotechnical, and engineering evaluations to ensure the long-term stability of the impoundment. As recently demonstrated at a Spanish zinc mine, failure to conduct adequate site foundation studies can lead to tailings spills, leaks, and partial dam collapse (Mining Engineering, 1998).

Table F-3. Example Siting Criteria for Tailings Impoundments and Dry Tailings Facilities

Criteria to Determine Initial Site Feasibility	
Anticipated tailings volume Tailings grain size and composition Hydrological conditions Proximity to milling/processing operations	Climate, including type and magnitude of storms Topography Geology and mineralization, including seismic activity Hydrogeological conditions, including foundation permeability
Criteria to Determine Final Site Suitability	
Visual impact Land use of site and surrounding area Ecological resources Site access Run-on control feasibility	Seepage release potential Surface water discharge potential Airborne release potential Development and operating costs Wetland impacts
Source: Vick (1990); Johnson (1997)	

4.1.2 Impoundment and Embankments

Vick (1990) and others discuss the different types of tailings impoundments and embankments. The choice of impoundment type is determined primarily by site topography (Vick, 1990). Cross-valley impoundments are used where drainages are incised into hilly terrain. Sidehill impoundments are three-sided embankments arranged in stair-step fashion on broad areas of sloping terrain. Valley bottom impoundments are constructed in stream valleys that are wide enough to route streams between the embankment and opposite valley wall. Fully enclosed ring dike impoundments are used on flat terrain.

Surface embankments can be classified into two general categories: water-retention type dams and raised embankments (Vick, 1990). Water-retention type dams normally are placed in valley bottoms, but occasionally are used on hillsides. They commonly are used for finely ground materials such as flotation tails and to construct impoundments with high water storage requirements. Water-retention type dams are constructed of earthen materials or concrete to their full height prior to tailings placement. Because they are intended to prohibit horizontal fluid flow, most are designed with impervious cores, filter material, drains, and rip-rap (Figure F-2a) (Vick, 1990).

Raised embankments begin with starter dikes that are designed to contain the amount of tailings expected during the first few years of production. Starter dikes are constructed using a wide variety of materials that range from natural borrow soils to waste rock to tailings (Vick, 1990). The embankment is raised periodically as dictated by mine operations. Embankment height is increased using upstream, downstream, or centerline construction methods (Figure F-2b, -2c, and -2d) (Vick, 1990). Upstream construction is generally the least costly because it requires the least amount of dike fill material; however, it is susceptible to liquefaction and requires careful control of tailings discharge (Vick, 1990). As a result, upstream construction is rarely used now due to the risk of seismic failure. In contrast, downstream construction offers good seismic resistance and can be used for water storage; this method is the most costly and requires the largest amount of fill material (Vick, 1990). Centerline construction shares advantages and disadvantages of the other methods. The raised embankment method is popular because embankment designs are comparatively simple and it provides the economic benefit of spreading construction costs over a longer period (Vick, 1990).

Stream diversions may be incorporated into each category of 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. Especially in areas of high stream flow or high precipitation, diverting water around impoundments can be necessary to maintain proper water balances and to promote quiescent conditions in the impoundment for settling. They can also be particularly useful for minimizing tailings erosion during storm events (see Appendix H, *Erosion and Sedimentation*). Diversions can be constructed either as conduits located below the impoundment or as ditches that skirt the perimeter of the impoundment. The feasibility of diversions depends on the particular site conditions.

Seepage control may be used to protect the structures associated with a tailings facility and to provide barriers to contain fluids originating from the facility. It can be used to partly or completely contain the lateral flow of tailings waters through the subsurface. Types of commonly used seepage barriers, which restrict flow, include cutoff trenches, grout curtains, and slurry walls (Vick, 1990). Seepage collection devices include collection wells, ditches, and ponds. For so-called "zero discharge" impoundments where seepage is collected and returned to the impoundment or otherwise used, long-term plans for seepage control/management have to be considered during design, not just at the time of closure.

For the NEPA process, applicants should provide at least the following information related to tailings impoundment and embankment design and operation:

- Describe the criteria that was used to determine whether proposed tailings impoundment sites and designs are technically and economically feasible (see Table F-3). Evaluate the importance of critical factors such as foundation stability, substrate bearing capacity, and ground water and surface water hydrology. Compare predicted impoundment performance to applicable regulatory requirements.

- Specify the sources (and their acquisition), types and volumes of construction materials required for the dam.

- Investigate naturally occurring hazards at the dam site or within the impoundment area and assess the risks that these hazards pose.

- Perform stability and liquefaction analyses consistent with State and other regulatory requirement.

- Provide the rate and volume of tailings to be disposed. Characterize the physical and chemical properties of the tailings and how they relate to impoundment/embankment stability and leachability. Characterization of tailings is discussed in Appendix C.

- Develop a water balance and predict effluent quantity and quality (including seepage) under normal conditions and under storm scenarios, and describe how seepage, if any, will be collected and managed. See Section 4.1.4. below.

- Describe impoundment construction and management, including construction QA/QC, and performance standards necessary to meet applicable regulatory requirements.

Information needs related to impoundment liners and monitoring is discussed below. Closure issues related to impoundments and embankments and discussed in Section 6 below. Issues related to acid drainage are discussed in Section 7.

4.1.3 Liners

At sites where mill effluents containing toxic constituents (e.g., cyanide or radioactive isotopes, or metals if there is a risk to ground water) will be discharged to a tailings impoundment, tailings facilities may need to be fitted with a liner system. The decision to choose a liner can be made after determining if the substances contained in the tailings are toxic, if sufficient quantities of the substances exist, and if sufficient quantities of those substance can reach ground water and degrade it. In addition, State regulations may require liners. Tailings pond liners can be composed of compacted clay, synthetic materials, or tailings slimes. Each has advantages and disadvantages. Compacted clay liners provide good containment for relatively low material and placement costs. However, not

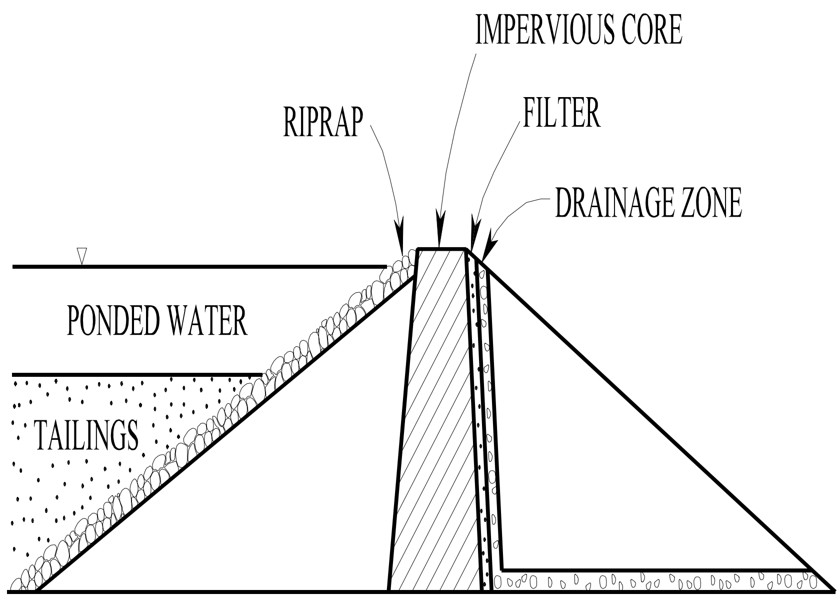


Figure F-2a. Water-Retention Type Dam for Tailings Storage

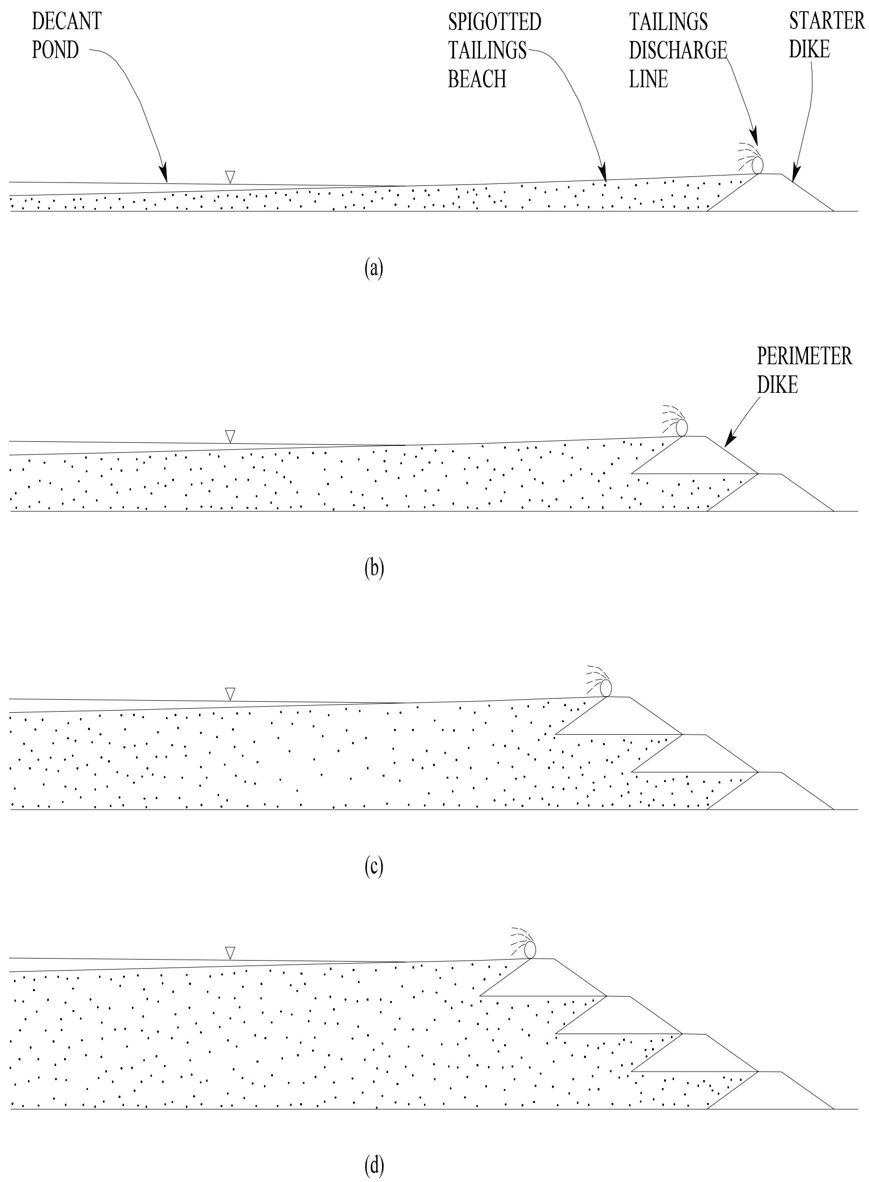


Figure F-2b. Sequential Raising, Upstream Embankment

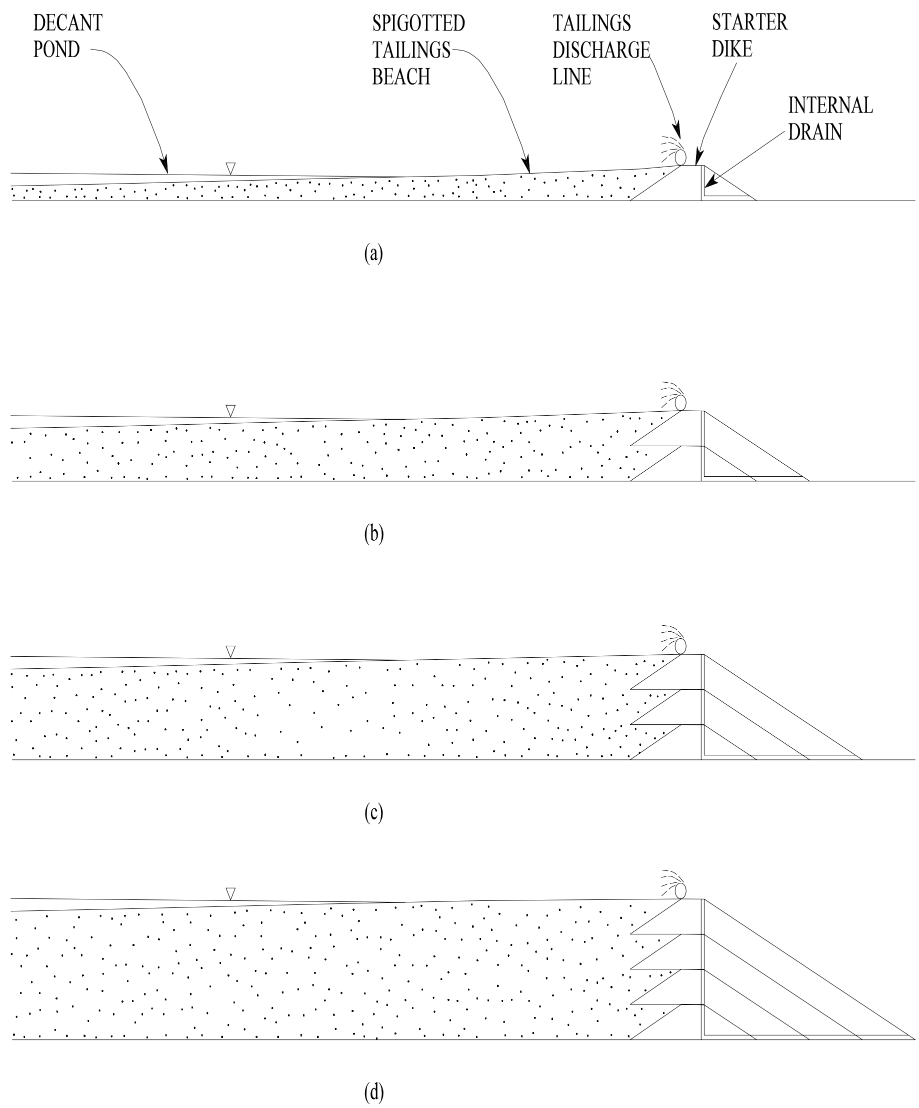


Figure F-2c. Sequential Raising, Centerline Embankment

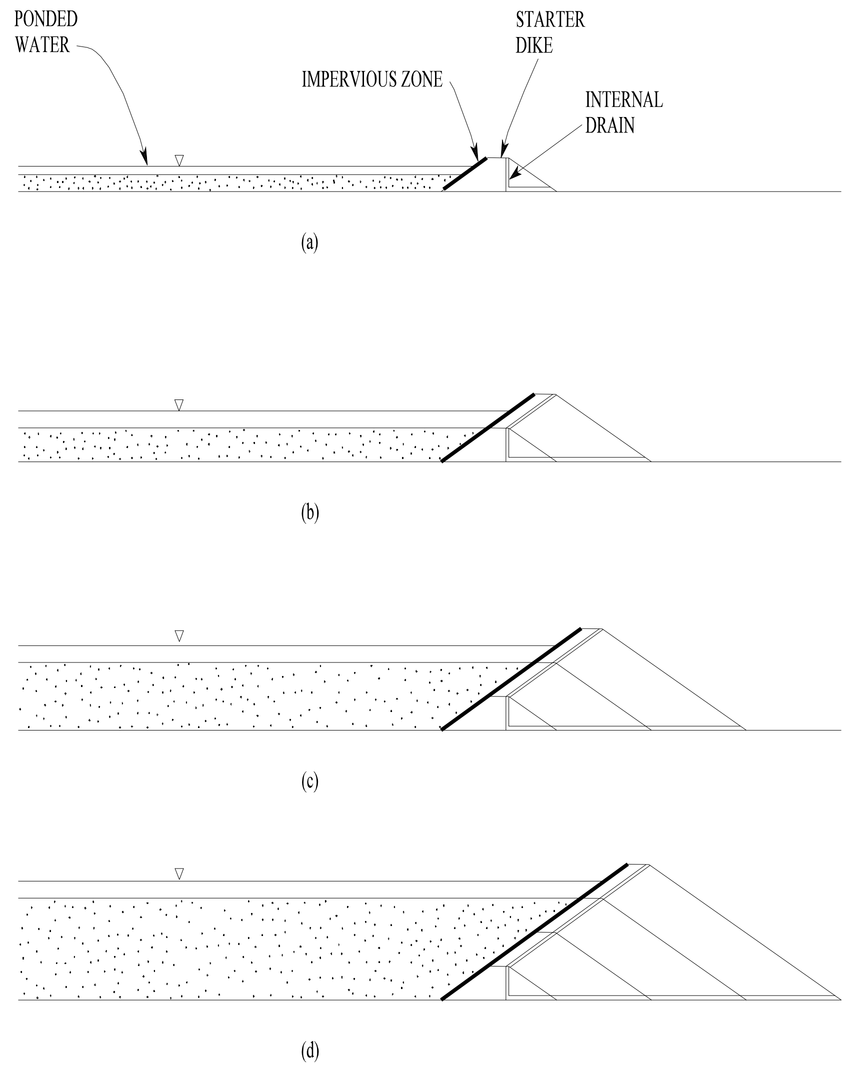


Figure F-2d. Sequential Raising, Downstream Embankment.

all sites contain sufficient suitable material. Synthetic liners have the advantages of low permeability and consistent quality, but disadvantages that include high product cost, high placement cost, and substantial foundation preparation requirements. Both clay and synthetic liners can be subject to damage by settling. Mill slimes offer an inexpensive source of low permeability material that is used in a similar manner to a clay liner. Careful placement of slimes can provide good containment. A slime liner also can provide a superior seal in case of foundation settling or geologic movement due to its plasticity. Disadvantages of slime liners include the necessity of careful material placement, the requirement that the material not contain toxic materials that could escape the containment area, and the difficulty in predicting long-term effectiveness of containment.

If a tailings impoundment is to be lined, or if a liner is to be used over part of an embankment, mine applicants should provide information of the following types to allow regulatory agencies to conduct full NEPA analyses and make permitting decisions.

- Delineation of the initial area to be lined, anticipated expansions, and the maximum area that might be lined, and the approximate schedule for expansions (including the likely maximum amount of exposed liner at any one time under various scenarios– this is crucial for estimating run-on/run-off).
- Description of liner site preparation activities (compaction, etc.).
- Description of the type and characteristics of liner proposed (type of synthetic material, sources of clays, physical characteristics).
- Information on compatibility of tailings and liner materials, including long-term compatibility.
- Description of leak detection, if any, and contingency plans for detected leakage.
- Analysis of liner effectiveness, such as a demonstration of how liner will meet applicable performance standards for containment over the long term.

4.1.4 Tailings Water

Tailings waters may contain elevated concentrations of metals, process chemicals, acidity, and other constituents that have the potential to impact surface and ground water quality. Applicants must provide water balance information that describes the flow and composition of waters into and out of the tailings impoundment. Modeling may be required. Water balances are discussed in more detail in Appendix A (*Hydrology*) and Appendix E (*Wastewater Management*). Applicants who request an NPDES permitted discharge from the tailings impoundment should provide information on flow and composition and treatment of such discharge. NPDES permitting needs are discussed in the main text of the source book and in Appendix D (*Effluent Characterization*)

4.1.5 Operational Monitoring.

Monitoring of active tailings impoundments should focus on detecting changes in embankment stability, surface and ground water quality, and ground water flow (Table F-4) (see Sengupta, 1993). Embankment stability can be monitored using various geotechnical methods and visual observation. Surface and ground water quality can be monitored by routinely collecting and analyzing samples from upstream and downstream stations. Downstream surface water stations should be located such that they would receive direct discharge from retention ponds, seepage collection sumps, and diversion ditches and at selected downstream confluences. Ground water stations should be located around the perimeter of an impoundment in order to detect changes to ground water flow that might occur as a result of a recharge mound that would form beneath the impoundment (Vick, 1990). All water quality monitoring stations should be sampled on a regular basis and analyzed for a suite of constituents as specified in an approved Sampling and Analysis Plan (see Appendix B, *Receiving Waters*, and Appendix C, *Characterization of Ore, Waste Rock and Tailings)*.

Table F-4. Operational Monitoring of Tailings Impoundments

Type of Monitoring	***Methods Used***	***Purpose***
Geotechnical	Visual inspection; Soil strength testing; Soil borings; Degree of saturation; Pore water pressure.	Detect changes in slope stability, compaction, and settling that may identify structural weaknesses or signal potential failure of the embankment.
Surface Water	Flow monitoring; Upstream and downstream water quality analyses.	Detect impacts to surface water quality.
Ground Water	Water table monitoring; Upgradient and downgradient water quality analyses	Detect impacts to ground water quality; determine influence of recharge mound on ground water flow.
Ambient air	Visual (opacity), PM-10 monitoring	Detect blowing dust, detect high particulate (particularly important if high arsenic in tailings)
Tailings water and seepage	Flow monitoring, Water quality analysis	Early detection of water quantity and quality changes, potential for acid drainage, detection of process chemicals

Applicants should submit information of the following types to allow full NEPA analyses and informed permitting decisions.

- Description of all monitoring plans, both for operational components as well as potentially affected environments, including frequency, the components to be monitored, the parameters to be monitored, and quality assurance/quality control. Table F-4 identifies the types of monitoring.

- Description of strategy and schedule for updating and refining monitoring plans,

- Description of how monitoring data will be used during the active life of the facility,

- Description of contingency plan for responding to various monitoring results, including identification of action levels for each monitored component and parameter (i.e., the level that will trigger further monitoring or some type of other action, including corrective action).

4.2 Dry Tailings Facilities

Dry tailings disposal is a relatively new method of placing tailings that have been dewatered to less than saturation using thickeners, belt filters, and filter presses (Johnson, 1997). Although best suited to dry climates and is most productive where water shortages exist, dry tailings facilities also have been approved in wet climates (e.g., Greens Creek Mine and the Kensington Project in Alaska). Dewatered tailings are transported to the disposal facility via haul trucks, conveyors, or special pumps. The materials are then placed, compacted, and covered. Dry tailings facilities typically are reclaimed concurrent with placement, resulting in less disturbed area at any given time (Johnson, 1997).

In addition, "paste" tailings, which are used extensively to backfill underground mines (see Section 4.4), may be disposed on the surface. According to Norman and Raforth (1998), paste materials have an initial moisture content of approximately 20 weight percent, most of which is held by surface tension in the material matrix. This amount of water is sufficient to permit the material to be pumped, but insufficient to create free-draining water or particle segregation. A few percent of portland cement or fly ash can be added to increase material strength and durability.

A significant advantage to dry tailings management is that the technique reduces the potential for surface and ground water contamination since it eliminates free process water from the pile. Other advantages include the ability to reclaim more process water, the ability to place dry material at locations where wet placement is difficult or impossible. Dry tailings management also may result in less water to treat and discharge, which can be a significant advantage in light of the zero discharge provisions of the NPDES New Source Performance Standards. A disadvantage to this type of management is that the unsaturated and moist condition of the tailings would permit any iron sulfide minerals that are present to oxidize and, potentially, form acidic leachate. Other disadvantages include high unit costs and difficulty in placing materials in wet climates. Saturation of a dry tailings pile by precipitation potentially can lead to slope failures if a facility is not properly designed to accommodate storm events.

As with tailings impoundments, the choice of a dry tailings disposal site is important. General siting criteria are shown in Table F-3. Facilities are most easily located along valley bottoms, on flat plains, or on gently sloping surfaces. Placing dry tailings on hillsides with steep slopes requires larger facility footprints and higher pile heights, and it presents challenges for access and foundation stability.

The decision to use dry tailings management depends partly on the volume of water required by the process system and the site water balance. For some zero discharge facilities, the use of dry tailings disposal may return too much water continuously to the process system. For example, the water storage and/or evaporative loss components of a tailings impoundment may be important elements of the facility water balance.

If applicants plan to use dry tailings management techniques, they should provide information of the following types to support NEPA analyses and permitting.

- Describe the criteria that was used to determine whether proposed tailings facility sites are technically and economically feasible (see Table F-3). Evaluate the importance of critical factors such as foundation stability, substrate bearing capacity, and groundwater and surface water hydrology. Compare impoundment performance to applicable regulatory requirements.

- Perform stability and liquefaction analyses consistent with State and other regulatory requirements.

- Characterize the physical and chemical properties of the tailings and how they relate to impoundment stability and leachability.

- Describe the rate and total volume of tailings to be dried and managed, means of dewatering the tailings, and wastewater management.

- Description of dry tailings facility—location and topography, site preparation and containment (compaction, berms, liners), long-term configuration, and means of transporting dry tailings to the facility.

- Develop a water balance and predict effluent quantity and quality (including seepage) under normal conditions and under storm scenarios. Describe how seepage, if any, will be collected and managed. See Appendix E.

- Describe facility construction and management, including construction QA/QC, and performance standards necessary to meet applicable regulatory requirements.

- Develop and describe operational and environmental monitoring plans, including contingency plans and action levels. Monitoring similar to that described in Table F-4.

Closure issues are discussed in Section 6, below. Issues related to acid drainage are discussed in Section 7.

4.3 Subaqueous Tailings Disposal

The objective of subaqueous tailings disposal is to maintain a water cover over the tailings to control oxidation of sulfides, bacterial action, and subsequent acid generation (see Appendix C for discussion on the geochemistry of acid generation). This objective can be accomplished by depositing mine tailings directly into a body of water such as a constructed impoundment, a flooded mine, a freshwater lake, or a marine environment such as a fjord or deep marine channel. Although practiced in other countries, disposal of tailings into lakes and marine environments is not allowed in the United States. For most industry sectors, NPDES effluent limitation guidelines prohibit process water discharges to waters of the U.S., including both fresh and marine waters. Effluent limitation guidelines also limit the discharge of total suspended solids. For these reasons, disposal of tailings into lakes or the marine environment is not discussed in this Appendix. Instead, the Appendix focuses on the use of water covers in engineered impoundments and disposal into flooded mine workings.

Subaqueous tailings disposal controls acid generation by limiting available oxygen for the oxidation process, thereby controlling acid generation; eliminating surface erosion and dust problems caused by wind and water action on tailings placed in a depositional basin, and; creating a reducing environment, suitable for supporting sulphate and nitrate reducing micro-organisms in sediments, in which soluble metals are precipitated as sulfides and ammonia is generated by the reduction of nitrates. The physical and chemical stability of the tailings materials are controlled by the oxidation, reduction, and diffusion kinetics in sediments; interactions with the overlying water column; and tailings transport related to wave induced turbulent motion.

4.3.1 Water Covers over Constructed Impoundments.

Disposal of tailings into engineered impoundments where a permanent water cover is maintained is a relatively new concept that presents a number of practical difficulties. These facilities would require some sort of perpetual maintenance to ensure a permanent water cover and continued structural integrity of embankments and dikes. In addition, these facilities would require a permanent and regular water supply and a minimum water depth to maintain anaerobic conditions at the bottom.

The advantages of using underwater disposal in a constructed impoundment include the ability to mitigate the production and release of acid drainage and lower implementation costs compared to the costs of a soil cover. Disadvantages include heightened potential for embankment failure due to seismic events or erosion due to additional liquid in the impoundment compared to conventional tailings impoundments; the displacement of resources (e.g., habitat, vegetation, etc.) at the location of the tailings impoundment; the potential inability to keep tailings flooded and maintain anaerobic conditions; and the potential release of metals present in pore water solutions or in soluble mineral phases. Many of these disadvantages may be more difficult to overcome in impoundments that are not designed for permanent water retention (i.e., whose design is modified after initial construction).

Subaqueous tailings disposal in constructed impoundments has been evaluated at two mines in Canada. At the Highland Copper Mine, British Columbia., a tailings impoundment was flooded and monitored to evaluate the efficiency of the subaqueous disposal technique (Scott and Lo, 1992). At the Fault Lake Mine, Falconbridge, Ontario, test plots of saturated tailings were developed and evaluated to determine the effectiveness of various test scenarios.

Design and operational issues that should be analyzed for NEPA disclosure and permitting relating to water covers include:

The issues discussed in Section 4.1 for the siting, design, operations, and monitoring of tailings impoundments also apply to constructed underwater disposal impoundments (e.g., characterization of tailings, stability evaluation, water balance, monitoring plans, etc.). Additional issues specific to water covers include:

- Designs must demonstrate that the tailings will be maintained in an anaerobic state to prevent sulfide oxidation and that the tailings will be placed below the level of wave action to prevent redistribution.

- Impacts to the aquatic environment must be evaluated

- Operating and monitoring plan, including monitoring to ensure that tailings remain saturated.

- Issues associated with the long-term maintenance need to continue saturation after closure.

4.3.2 Disposal into Flooded Mine Workings.

Tailings can be disposed of in the subaqueous environment provided by flooded underground and surface mine workings. Placement is accomplished through sluicing to fill mine stopes, adits, shafts, and pits. Tailings may be mixed with inert materials, such as cement or sand or fly ash, to add structural integrity.

The U.S. Bureau of Mines studied metal dissolution from mine tailings that were placed underground as backfill in a flooded mine shaft (Levens and Boldt, 1993). Computer simulations based on sample data collected during these studies indicated that metals release from the backfill after flooding was expected to be low due to reduced rates of sulfide oxidation and to buffering capacity provided by carbonate minerals.

The disposal of tailings in flooded mine workings offers advantages over standard tailings impoundments that include placing mine wastes into a comparatively stable environment; eliminating the potential for tailings dam failure and the need to maintain a facility during post-closure; and reducing visual impacts and land surface disturbance. Disadvantages include the potential for chemical transformations to create less stable minerals after placement and the hydraulic conductivity of uncemented tailings which is likely to be higher than that of the surrounding rock. The latter may result in the formation of preferential ground water pathways that enhance the potential for leaching of backfilled material (Levens and Boldt, 1993). It is also important to coordinate backfilling with mine planning.

Issues associated with disposal in flooded pits or underground workings that should be evaluated for NEPA analyses include:

- Describe the disposal operations and closure, including: timing and amounts of tailings proposed for disposal; means of transporting the tailings to the backfill site; if material is to be stabilized or otherwise treated, description of additives and treatment process.

- Characterization of the backfill tailings and any additives.

- Demonstrating the structural integrity and physical consistency of the backfill material.

- Characterizing geochemical effects of tailings solids and fluids on the quality of ground water or pit lakes, including results from any necessary modeling.

- Characterizing any predicted discharges to ground water or surface water.

- Conducting rigorous hydrogeological and limnological studies to ensure that workings will remain continuously flooded.

- Developing a monitoring plan for operational and post-closure periods to verify predictions and allow detection of the need for changes or corrective actions.

4.4 Mine Backfill

Tailings materials can be used to backfill underground mines. In this setting, they are used to provide a working floor, provide wall and roof support and stability, maximize ore recovery, minimize surface subsidence, and aid ventilation control (Vick, 1990; Johnson, 1997). Because most backfill applications require material with high permeability (to permit dewatering) and low compressibility, generally only the sand fraction of tailings are used in these operations and slimes still require an alternative disposal method (Vick, 1990). Tailings are delivered underground using hydraulic systems or, if the tailings have been dewatered to "paste," using positive displacement pumps (Johnson, 1997). Slurried tailings (60 to 75 percent solids) dewater underground and require drainage control to ensure that fluids are handled in a manner that is environmentally acceptable. Paste backfills (80 percent solids) offer lower permeability and can be used to restrict underground water flow (Johnson, 1997). Although paste backfills introduce less water underground, water extracted during the filtering operation requires environmentally acceptable disposal (Johnson, 1997). In some cases, tailings may be augmented with cement or fly ash to provide additional stability and/or alkalinity.

Issues associated with the disposal of tailings as backfill that should be analyzed for NEPA disclosure include:

- Describe the backfill operations and closure, including: timing and amounts of material proposed for backfilling; means of transporting the material to the backfill site; if material is to be stabilized or otherwise treated, description of additives and treatment process.
- Characterization of the backfill tailings (e.g., particle size, chemical and physical characteristics), including the effects of additives such as cement or fly ash.
- Predict the structural stability of backfill material and enclosing mine rock.
- Determine/predict the potential reactivity (particularly acid generation potential) of backfill material (tailings and any additives) and enclosing mine rock. This would involve laboratory testing, modeling, and other methods, as described in Appendix C.
- Prediction of water quality in the mine and whether a discharge is needed in order to determine potential impacts to ground water and surface water and to design appropriate controls.
- Description of monitoring program to be used to verify predictions and allow detection of the need for changes.

Issues associated with acid generation is discussed further in Section 7 of this Appendix and in Appendix C.

5.0 SPENT ORE/HEAP AND DUMP LEACH MANAGEMENT

Although the purpose of heap leach pads and dumps is to recover metals, these facilities cross into the realm of waste management upon closure (Hutchinson and Ellison, 1991). Mines presently use three types of heap leach facilities (Hutchinson and Ellison, 1991). Reusable pads (also termed "on-off" pads) are designed for continual reuse, with spent ore materials removed and transported to a separate disposal facility at the end of the leach cycle; fresh ore is replaced on the pad for a new leach cycle. Dedicated or permanent expanding pads are engineered facilities designed for a single use, with spent ore remaining in place at the end of the leach cycle; fresh ore is placed on newly constructed portions of the pad. Valley leach facilities are constructed in a natural stream valley, with ore contained on the downstream side by an embankment; they are operated in a manner generally similar to dedicated pads. In part, the choice of a facility type is dictated by site topography, geotechnical considerations, and the mineralogy and metallurgical characteristics of the ore materials. In some cases, ore is leached in vats or tanks rather than in open heaps; in such cases, the spent ore is generally disposed in a manner similar to that used by on-off pads or in a manner similar to that used for conventional tailings (see Section 4 above).

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 will 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. Wastewater management issues are discussed in more detail in Appendix E.

Many of the criteria for choosing the locations of waste rock dumps and tailings impoundments also apply to the locations of heap leach facilities. Primary among these are economic factors such as haulage distance and geotechnical concerns such as foundation stability and liner integrity. The types of technical data that may be required for locating a suitable site are summarized in Table F-5.

Table F-5. Data Needs for Heap Leach Facilities

Critical Design Factor	***Data Needs***	***Data Source/Methodologies***
Facility Site Selection	Topography	Topographical maps, Aerial photos
	Geology and Soils, including fault mapping	Geological maps, Engineering tests of site samples.
	Seismicity (natural and blasting-induced)	Geological maps, Seismic zone maps, Uniform Building Code (U.S. ACE, 1995), Mine Plan of Operation, Engineering tests of site samples.
	Surface Water Hydrology	See Appendix A
	Ground Water Hydrogeology	See Appendix A
	Baseline Water Quality	See Appendix B
	Operational Considerations	Mine Plan of Operation
Process Solution System	Leaching and Processing Operations	Mine Plan of Operation
	Facility Water Balance	See Appendix A
Pile/Dump Construction	Foundation and Embankment Stability	Geotechnical and engineering tests of site soil samples.
	Pile Stability	Geotechnical and engineering tests of ore materials.
	Surface Water Diversion	See Appendix H
	Seepage/run-off Collection and/or Liner	Model results, Meteorological data; See Sections 4.1.4, 4.1.5, 6.5

Spent ore that is removed from a reusable pad, or spent ore removed from vats or tanks, will require disposal in a separate facility. The manner of disposal will be governed by the likelihood that these materials could impact surface or ground water quality by releasing metals, acidity, process chemicals, or other constituents. Consequently, the potential for water quality impacts is expected to be a function primarily of the mineralogy of the spent materials and the completeness of rinsing and process chemical neutralization actions (see Section 6.6). Spent materials that are unlikely to have deleterious effects could be disposed of with other waste rock materials; those expected to contribute to poor water quality may require special handling or disposal (e.g., encapsulation).

Issues associated with heap management that should be analyzed for NEPA disclosure and permitting include:

- Describe the criteria used to determine whether proposed heap sites and designs are technically and economically feasible and how they fulfill regulatory requirements. Many of the criteria will be similar to that discussed for siting waste rock dumps and tailings impoundments. Table F-5 lists some of the critical criteria.

- Characterize the physical and chemical properties of the heap material and how they relate to heap stability and leachability (see Appendix C).

- Prepare a water balance and predict the potential for seepage and run-off from the heap in order to design appropriate wastewater management. Various models are available to facilitate this. Where modeling is used, all model assumptions, input parameters, and uncertainties should be disclosed and a sensitivity analysis may be necessary. Wastewater management is discussed in Appendix E.

- Describe how the heap will be constructed and managed during operations and closure in terms of maintaining heap stability and reducing impacts to the environment. Develop performance standards and compare to any applicable regulatory requirements (e.g., predict liner performance). Additional closure considerations are discussed in Section 6 of this appendix.

- Develop and describe operational and environmental monitoring plans to ensure heap stability and predict impacts to surface and ground water quality. Table F-2 identifies types of monitoring that may be required. Monitoring plans should include action levels and contingency plans.

- For disposal units for spent ore from on-off pads and from vats and tanks, provide similar information on unit design and performance, including performance following closure and abandonment.

6.0 ISSUES RELATED TO CLOSURE AND RECLAMATION

Closure and reclamation of permanent waste disposal facilities should be directed toward preventing future impacts from these sites. Primary considerations center on creating physically and chemically stable facilities that will not impact surface and ground water resources through erosion, runoff, seepage, or windblown dust (Hutchinson and Ellison, 1991). Over the long-term, the stability of facilities such as waste rock dumps and spent leach piles depends on factors such as the build-up of pore water pressure within the pile, erosion during high intensity precipitation events, slope angle, and the presence of internal weaknesses (e.g., inclined layering) within the pile. In addition to those produced by sluicing practices, internal weaknesses may be produced in tailings piles by sulfide oxidation, which creates hardpan layers that restrict precipitation infiltration (Blowes et al., 1991).

This section briefly describes aspects of closure and reclamation and associated analyses that should be performed for permitting and NEPA analyses. The reader is referred to Section 7.0 for more detailed descriptions of techniques to control the formation and migration of acidic drainage. Appendix H, *Erosion and Sedimentation* provides a more complete discussion of runoff and sediment transport control.

6.1 Soils Placement and Revegetation

An understanding of soil resources can help applicants to establish realistic goals for revegetation success and increase the likelihood of achieving those goals. Most mining activities directly impact soils. The actions of stripping and replacing topsoil and overburden disrupt the horizons that produce a soil's physical and chemical characteristics and often inverts them in the process of creating stockpiles. These actions also lead to soil compaction. However, even where soils are not stripped, the operation of heavy equipment causes compaction that can significantly reduce soil productivity (Ellis and Mellor, 1995). Compaction reduces pore space within a soil which decreases the infiltration of water and air. Soil porosity is critical to maintaining the types of biological activity that produce a healthy soil.

If there is a single key to reclamation success, it is the need to maintain or reestablish biological activity within the soils or the growth material serving as soil. Soil structure, moisture holding capacity, nutrients/pH, and stability are all critical to reclamation success.
The biological activities occurring within soils are key contributors to plant-soil interactions. Micro- and macroorganisms within the soil conduct all of the important soil-building processes, such as the decomposition of organic material and nutrient cycling (Ellis and Mellor, 1995). Biological activity typically is lost when soils are stockpiled for a period of time. One handling technique that maintains biological activity is to directly haul topsoil from an area to be stripped to an area undergoing reclamation (Sengupta, 1993). This approach, also termed 'live hauling', can enhance revegetation efforts by maintaining a viable seed bank of indigenous species. Live hauling is only practical where concurrent reclamation is being employed; in settings where live hauling is not possible, islands of native plant material and soil can be transplanted into newly reclaimed areas to serve as propagule sources for important soil organisms. Windblown

propagules can be collected using snow fences (Reeves and Redente, 1991).

A number of reclamation options are available to operators, including directly seeding waste piles or covering them with topsoil or growth media prior to seeding. Where soil resources are limited, waste materials should be analyzed for their suitability as plant growth media. Based on analytical results, amendments may be incorporated to improve fertility or texture (e.g., Munshower, 1997). In such cases, amendments can be either chemical fertilizers or organic mulches such as paper, wood chips, straw, hay, manure or compost which are tilled into the upper portion of the soil. Many soils, particularly in the western U.S., have limited phosphorus contents and require fertilization. However, the addition of a nitrogen-rich fertilizer requires thorough consideration because the addition of nitrogen to native soils has been shown to influence the species composition at reclamation sites and may predispose a site to invasion by weedy species adapted to such a nutrient-rich regime. In some cases, successful nitrogen additions have been made after plants have had two to three years to become established (Peterson et al., 1991). Seed mixtures should be developed based on the type of soil being placed on the site. While the long-term reclamation goals may reflect a later successional stage, reclamation plans should acknowledge the limitations that 'new' soils may impose on the establishment of new vegetation.

Reclaiming a large facility (e.g., a tailings impoundment) typically requires that a site have significant soil resources so that a suitable growth medium can be placed. For mines that are situated in arid or mountainous terrains with limited soil resources, this may be problematic. In these areas and in others where soils may need supplements, operators have used biosolids (i.e., sanitary sewage sludge), wood chips, and other means of increasing organic matter in soil. Recent studies have shown that cattle grazing can provide an innovative, effective, and cost-competitive option for reclaiming fine-grained materials (i.e., tailings). In Miami, Arizona, penned cattle helped to establish growth media on abandoned tailings by trampling hay mulch, urine, and manure into the upper tailings layer (Norman and Raforth, 1998). In addition, cattle helped to minimize erosion by creating sidehill terraces and pathways and to establish seed germination areas in hoof depressions.

6.2 Runoff and Erosion Control

The long-term control of sediment erosion and redeposition is an important aspect of protecting water quality and aquatic resources. Runoff and erosion control typically is achieved through grading, surface diversion, revegetation, and armoring in accordance with Best Management Practices (BMPs) established by the operator. Predicting and controlling runoff and erosion is discussed in detail in Appendix H, *Erosion and Sedimentation*.

Grading and recontouring waste rock dumps and decommissioned heap leach piles typically is intended to provide stable slopes that will not avalanche or erode. Grading and recontouring techniques can be used to create benches or other features that reduce gully and rill formation on sloping surfaces and to guide precipitation runoff to engineered swales or other conveyance structures. In general, tailings are not regraded (although embankment faces may be). More often, long-term diversions or conveyance structures are constructed around or even across tailings facilities to control erosion

In most cases, runoff from a disposal facility (whether from dumps, piles, tailings embankments, or flow around or over impoundments) is routed to a sediment control structure as described in Appendix H, *Erosion and Sedimentation*. Surface water diversions are used to direct up-gradient flows around or across a facility in order to prevent erosion of waste materials and the embankments that contain them. Storm event planning is key in designing diversion structures. Runoff control structures, including conveyance structures and detention basins, that were initially sized and constructed to meet design life guidelines, may require reconstruction to convey or detain flows that result from low probability precipitation events (e.g., 100 or 500 year events). This may require measures to stabilize the beds and banks of ditches (e.g., with rip-rap), increase the size of diversion structures and sediment detention ponds, or raise the height of tailings embankments to prevent storm water overflow. Closure requirements will likely be site-specific and intended to promote long-term drainage control.

As described in Section 6.1, revegetation typically requires the addition of soil amendments or the placement of topsoil or other growth media to provide a suitable substrate for plant growth. Establishing vegetation on waste facilities lessens infiltration and decreases the potential for erosion by diminishing rainwater impact and providing soil cohesion. Surface armoring is intended to cover fine-grained, easily eroded materials such as tailings with more resistant, coarse-grained rock.

6.3 Infiltration Control

Infiltration control is used to minimize the amount of meteoric water that enters a waste disposal facility. These measures can help to stabilize facilities by maintaining low pore water pressures and decreasing the potential for water quality impacts by reducing seepage quantities and limiting oxygen diffusion. Requirements for infiltration control depend on climatic conditions and the characteristics of the materials contained in a given disposal facility. Facilities situated in arid climates or that contain non-reactive materials may not require infiltration controls at closure.

Infiltration control typically is achieved through the use of impermeable caps, seals, and capillary barriers, by establishing vegetation, and by recontouring facility surfaces. Caps and seals may be composed of clay or other natural materials that are compacted to an acceptably low permeability or a variety of synthetic materials such as PVC, HDPE, or asphalt and concrete mixes. Compacted natural soils are effective at controlling water infiltration and are unlikely to suffer long-term degradation. Similarly, clay caps can control water infiltration. Although synthetic membrane covers may offer superior short-term performance, they can suffer long-term degradation through the loss of plasticity, cracking, or tearing under differential settling (Sengupta, 1993). Surface sealants such as shotcrete or asphalt provide more robust alternatives to membrane covers. Capillary barriers can have a variety of designs (Hutchinson and Ellison, 1991). In general, they consist of a vegetated soil layer that overlies a coarse drainage layer that is, in turn, underlain by a low permeability cover or low permeability wastes (Figure F-3) (Hutchinson and Ellison, 1991). They are designed to intercept infiltration penetrating the soil layer and divert it from the surface of the waste disposal facility. Vegetation will take up moisture that falls onto the surface of a disposal facility and minimize that which will infiltrate (see Section 6.1). Infiltration also can be decreased by grading facility surfaces to eliminate ponding and promote runoff (see Section 6.2).

6.4 Seepage Control

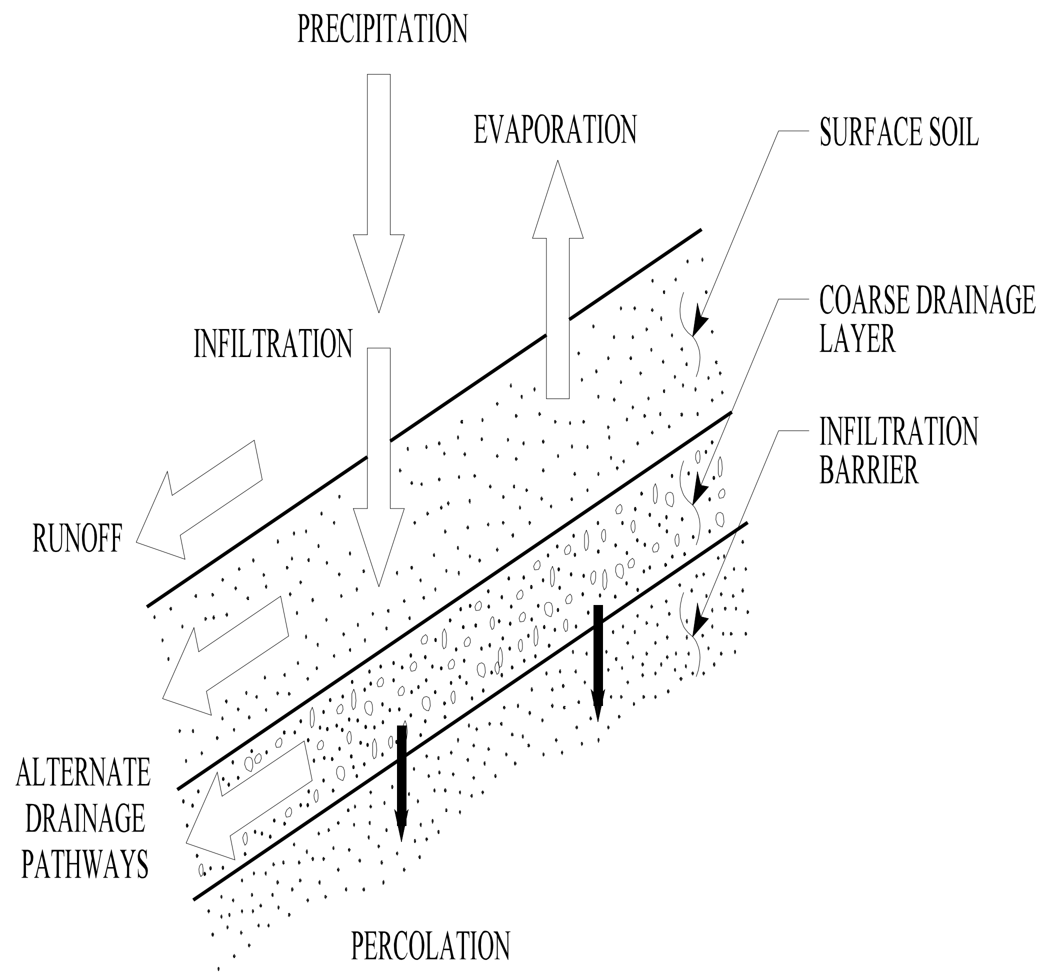
Seepage control may be needed for certain facilities upon closure. Requirements for seepage control are likely to differ significantly for waste management facilities in arid and humid climates (Hutchinson and Ellison, 1991). In general, seepage can result from infiltrating precipitation or snowmelt that percolates through a facility, the flow of surface or ground waters through a facility, or from the release of pore waters upon dewatering and consolidation of tailings.

Seepage control from waste disposal facilities can be achieved through the use of impermeable liners and systems that are engineered to collect seepage and route it to treatment facilities. Typically, these systems are designed to work in concert with runoff and infiltration control systems. Types of seepage collection systems include sumps, ditches, drains, and ground water interception wells (Hutchinson and Ellison, 1991). Seepage conveyance systems at closure may need to be designed to accommodate increased seepage and runoff that could result from low probability storm events. Poor quality seepage may need to be routed to a treatment facility prior to its discharge to surface waters. These facilities can be in the form of active or passive treatment systems (see Appendix E, *Wastewater Treatment*).

6.5 Other Considerations

The potential deleterious effects of highly reactive wastes (for example, materials with a net acid generating potential) can be lessened by installing covers materials that limit oxygen diffusion into waste facilities (e.g., Sengupta, 1993). Water covers are effective oxygen barriers, but require maintenance to assure they remain intact. In addition, the use of water covers require that the original impoundment structure be designed to maintain such covers. Synthetic membranes such as PVC and HDPE provide effective oxygen control but may suffer puncture or long-term degradation. While compacted soil covers offer limited oxygen control, saturated soils may preclude significant oxygen diffusion (Sengupta, 1993).

The control of windblown dust may be an issue for tailings and other fine-grained waste materials. Dust can be suppressed by maintaining a water cover over tailings materials, placing natural or synthetic covers, or promoting vegetative growth. The use of waste rock as a cover for tailings should be thoroughly investigated to ensure that the tailings materials possess sufficient strength to support the waste rock load (see Section 3.4).



SOURCE: Hutchinson and Ellison (1991)

Figure F-3. Layered Waste System.

In some cases, facilities may be recontoured to blend with existing topography and reduce visual impact. While coal mining regulations require that spoil piles and pits be regraded to approximate original topography, there is no such requirement for non-coal mines. However, permits may require that any facilities remaining upon closure be consistent with the surrounding topography and support the approved post mining land use(s).

6.6 Spent Ore Treatment and Neutralization

Spent ore materials may occur in the form of processed heap and leach facilities or tailings materials. Pore waters and soluble metal compounds that remain in closed acid and cyanide heap leach facilities or in tailings from cyanide leaching can be mobilized by infiltrating rainwater. To prevent chemical releases to the environment, leached materials may require rinsing and neutralization to remove potentially deleterious compounds prior to facility closure. In general, this can be accomplished by:

- Applying a neutral rinse solution to remove constituents from the processed material, then collecting and treating the solution; piles are rinsed until effluent concentrations reach pre-determined acceptable levels.

- Applying a rinse solution containing chemical or biological agents that neutralize or chemically decompose constituents of concern *in situ.*

In situ heap rinsing requires that piles have sufficient permeability to permit neutralizing fluids to penetrate through and contact all materials within them. Piles with insufficient permeability or with highly variable permeability or fluid flow pathways may need to be dismantled and treated in smaller batches (EPA, 1994b). Climate can play a significant role in determining the length of time required for complete neutralization. For example, cold weather may slow or halt biological breakdown of cyanide. Experience has shown that initial treatment may produce effluent that meets constituent guidelines, but that effluent quality may degrade after treatment stops (EPA, 1994b). Thus, some facilities may require repeated treatment until effluent quality remains at acceptable levels.

Li et al. (1996) describe lab and pilot-scale experiments designed to determine the appropriate methods to rinse and neutralize an acid leach pile. Their results demonstrated that decommissioning tests should use large diameter columns or field-scale test piles to determine rinsing times, solution application rates, and decommissioning costs. These experiments also showed that precipitation and dissolution of secondary minerals controls the metals content of the rinse effluent. Rinsing duration depends on the volume of the leached materials in the pile, their mineralogical and chemical characteristics, and physical factors such as permeability, porosity, and precipitation. Accelerated artificial rinsing, in which neutralizing solutions (e.g., calcium hydroxide) are applied using the leach solution system, can effectively remove acidity and soluble metals from a large heap leach pile in a reasonable period of time.

There are a variety of techniques that can be used to chemically or biologically breakdown residual cyanide and metal-cyanide complexes in heap leach and tailings facilities

(EPA, 1994b summarizes these techniques; see also Appendix E, *Wastewater Treatment*). Some of these methods produce by-product ammonia or nitrate that may require additional treatment in effluent waters. In general, chemical or biological agents can be applied to leach piles using the leach solution system. Rinsing continues until the cyanide content of seepage from the pile reaches an acceptable level. Processed tailings from circuits using agitation leaching typically are treated prior to discharge to a tailings impoundment.

It should be noted that rinsing heaps, while effective in reducing cyanide, can mobilize other metals (notably, selenium, mercury, and arsenic) to the point that rinsate or leachate will not meet regulatory standards for discharge without treatment of the rinsate as well as future leachate from infiltration. It also is important to note that other closure issues discussed in this section (run-off and erosion control, infiltration and seepage control, soils placement and vegetation, and post-closure monitoring, are important considerations following neutralization of spent heaps.

6.7 Post-Closure Monitoring

Post-closure monitoring is conducted to ensure long-term protection of the environment and to identify any problems in the early stages of their development. Depending on the facilities and methods of closure employed, post-closure monitoring may include visual inspections of site conditions, evaluations of embankment integrity, surface and ground water quality monitoring, determinations of available capacity in sediment retention structures, assessments of the performance of stream diversions, seepage collection, and seepage treatment systems, and the success and progress of reclamation activities. For each type of monitoring conducted, there should be clear action levels that trigger specific responses (which could include such things as heightened monitoring, notification of authorities, correction action). These responses should be clearly laid out in contingency plans that describe the actions that have to take place when an action level is reached or exceeded. The types of monitoring that are required, the schedule by which they are conducted, and the parties that are responsible for conducting monitoring activities will depend on site-specific conditions and requirements.

6.8 Information and Analytical Needs

Issues associated with closure and reclamation that should be analyzed for NEPA disclosure and permitting include:

- Describe closure and reclamation techniques and timing. Develop performance standards for reclamation measures. The performance standards should be consistent with regulatory requirements and also provide for long-term stability (chemical and physical).

- Describe any performance bonds or other financial assurance that may be provided to authorities as potential mitigation for impacts, the means of calculating the amount provided, and the conditions and timing of release.

- Develop a long-term water balance, including prediction of run-off and seepage under low probability conditions.

- Predict the short- and long-term effectiveness of infiltration controls, seepage controls, revegetation, and other stability and water controls. Lab tests and field test plots may be used to evaluate cover effectiveness and revegetation. Modeling may be required to predict long-term impacts of weathering.

- Describe any treatment and neutralization of wastewater, spent ore, or tailings prior to site abandonment, including verification testing.

- Describe all monitoring that is proposed at various stages of reclamation and closure and afterward, including QA/QC, action levels and contingency plans. Section 6.7 describes the types of monitoring that may be needed.

7.0 ACID MINE DRAINAGE

Acid mine drainage (AMD) may often represent the greatest environmental concern at mining sites. All of the mining solid wastes discussed in this appendix may be potential sources of AMD. Measures to control and mitigate AMD production from solid mining wastes are briefly discussed in this section. Management and treatment of AMD wastewaters is discussed in Appendix E. The chemistry of AMD production is described briefly here and is described in detail in many of the references provided in this section.

AMD occurs when sulfide-bearing mine wastes and materials react with meteoric water and atmospheric oxygen to produce sulfuric acid. The most reactive sulfide phases are the iron sulfide minerals pyrite, marcasite, and pyrrhotite. Nordstrom et al. (1979) summarize the pyrite oxidation process. In the initial stages of acid formation, pyrite reacts with water and oxygen to form ferrous iron and sulfuric acid. Ferrous iron is slowly oxidized to ferric iron by oxygen. As pH decreases below 4.5, ferric iron also begins to oxidize pyrite and it becomes the primary oxidant at pH values below 3.0. Iron oxidizing bacteria (e.g., *T. ferrooxidans*) greatly accelerate the oxidation of ferrous iron to ferric iron and serve to catalyze pyrite oxidation at low pH. When this occurs, the presence of oxygen has little effect on the rate at which pyrite oxidizes to form acid. Acid generation at low pH is controlled by bacterially mediated ferric iron oxidation (Singer and Stumm, 1970; Nordstrom et al., 1979).

AMD can be initiated from any pyrite-bearing mine material that is exposed to air and water. This includes ore piles, overburden and waste rock dumps, tailings impoundments, pit walls, underground workings, and spent ore heaps. Appendix C describes tests that can be performed on tailings, waste rock, etc. to determine their acid generating potential. To the greatest extent possible, new facilities should seek to prevent acid drainage rather than treat or abate AMD after it forms.

7.1 Controlling the Acid Generation Process

Acid generation can be controlled by regulating one or more of the primary reaction components (pyrite, oxygen, water) or the catalyst (bacteria). Control can be achieved by removing pyrite from materials and wastes or precluding interactions between the solid materials and oxygen, water, or bacteria. The process can be slowed by using bactericides or eliminating the environmental conditions that sustain bacterial populations.

Pyrite can be removed from mining wastes and materials by processing. The most common procedure produces a sulfide-rich metal concentrate through flotation, which then can be handled separately (SRK et al., 1989). Although flotation can be utilized at mines where it is part of the beneficiation scheme, it is neither a practical nor cost-effective solution for treating pyritic overburden or waste materials, subeconomic underground workings, or pit walls that contain pyrite.

At any stage of the acid generation process, water (or moisture) and air are required for acid production. Removing either or both of these reactants from the site of acid generation will diminish acid production (SRK et al., 1989; Environment Australia, 1997). Low permeability covers and seals are widely used to accomplish this task. *Capillary soil barriers* are engineered covers that have a compacted, low permeability layer (generally clay) that is interlayered with more permeable materials (typically sand) which serve as evaporation barriers. Erosion control is achieved by covering the soil barrier with gravel. Capillary soil barriers have proven effective in excluding oxygen and precipitation from mine wastes and materials (greater than 90 percent exclusion) and are an effective AMD control agent (Groupe de Recherche, 1991; Robertson and Barton-Bridges, 1992; Bell et al., 1994; Yanful et al., 1994; Ziemkiewicz and Skousen, 1996a). *Synthetic barriers* also are effective control agents, but are less widely used because of their high cost. Synthetic barriers typically are PVC or HDPE liners placed over acid-generating materials and protected with a cover of soil or rock (SRK et al., 1989; Ziemkiewicz and Skousen, 1996a).

Oxygen can be excluded from mine materials and wastes by submerging them under water (SRK et al., 1989). Although water contains a small amount of dissolved oxygen, it is present in amounts insufficient to oxidize pyrite. Mine materials can be submerged by depositing them in a constructed water body, depositing them in a flooded mine pit or underground working, or depositing them on a specially prepared surface where they are naturally saturated by perched water (Broughton and Robertson, 1992). Subaqueous tailings disposal, which has been used successfully at several mine sites (Dave, 1993; Dave and Vivyurka, 1994; Fraser and Robertson, 1994; ; Environment Australia, 1997), is discussed in greater detail in Section 4.3.

At advanced stages of the acid-generation process, bacterial oxidation of ferrous iron catalyzes acid generation. Consequently, controlling bacterial populations can provide immediate control of acid generation. Anionic surfactants (e.g., sodium lauryl sulfate; Kleinmann et al., 1981), which typically have liquid formulations, can be sprayed onto potentially acid-generating materials prior to or during disposal (Parisi et al., 1994). Because these compounds eventually decompose or leach from treated materials, they must be reapplied periodically and are not a permanent solution to the AMD problem (Ziemkiewicz and Skousen, 1996a). However, slow-release formulations (sorbates and benzoates; Erickson et al., 1985) are available and have proven useful (Splittorf and Rastogi, 1995). Bactericides are most effective when applied to fresh, unoxidized pyritic materials and can be a useful tool when used in combination with other control methods (Ziemkiewicz and Skousen, 1996a).

7.2 Moderating the Effects of Acid Generation

The effects of acid generation can be moderated by neutralizing any acid that is generated before it can migrate from a disposal site. Neutralization can occur as a result of natural conditions, but commonly it is spurred by chemical amendments applied directly to the wastes and materials prior to or during disposal or added to the cover materials that are placed following disposal. When amendments are added to the waste materials, neutralization occurs within the pile near the site of acid generation. In contrast, amendments added to cover materials supply alkalinity to meteoric water that infiltrates the material pile and neutralizes acidity. Where mine materials include both acid-generating and net neutralizing solids, special handling and construction practices can be used to mitigate acid generation. Acid migration from underground workings can be reduced or prevented by backfilling and sealing mine portals.

Several types of alkaline amendments can be used at mine sites (SRK et al., 1989; Ziemkiewicz and Skousen, 1996a, b; Environment Australia, 1997). *Limestone* (calcium carbonate), which lacks cementing capability, is inexpensive, readily available, safe, effective, and easy to handle. *Fluidized bed combustion ash* is a mix of coal ash, lime (calcium oxide), and gypsum (hydrous calcium sulfate) that reacts quickly and hardens into a cement upon wetting. *Kiln dust* from cement and lime kilns is a mix of unreacted limestone, lime, and ash that is highly reactive, absorbs moisture, and has cementing abilities. *Steel slags* also have high calcium oxide contents but also may have high concentrations of trace metals which make them less suitable for widespread use. *Phosphate rock*, which will react with ferrous iron to form insoluble coatings on pyrite, is more expensive than the other amendments listed above.

The amount of alkaline material that must be added to wastes and materials prior to their disposal can be estimated from acid-base accounting tests of the disposed materials (see Appendix C) and of the amendment. A cost-effective control strategy can be determined during pre-mining planning when different disposal options can be tested. In theory, amendments should be thoroughly admixed with mining materials prior to disposal to maximize their chemical effectiveness. In practice, however, this may require repeated handling of the materials which may not be cost effective. Consequently, it is common for amendments to be interlayered with mine materials (termed *layered base amendments*). As described below, the construction of piles that include heterogeneously distributed, layered base amendments is critical to their success.

The construction of waste and material piles plays a significant role in determining whether mixed acid-forming and acid-neutralizing materials will generate acid mine drainage. The formation, storage, and flushing of acid products in a rock or tailings pile depends on flow paths within the pile, flushing rates through different parts of the pile, the distribution of acid-generating and acid-neutralizing materials, and localized physical and chemical conditions (Robertson and Barton-Bridges, 1992). Consequently, it is possible for rock piles with net neutralizing character to develop areas of acid generation. Regardless of the amount of neutralizing material contained within a rock pile, acid generated within the pile will not be neutralized if it percolates along a flow path that does not encounter alkaline materials (Ziemkiewicz and Skousen, 1996b). Although hydrologic modeling of waste rock piles is still a developing science (Robertson and Barton-Bridges, 1992), it is possible to design and construct waste piles with internal drainage characteristics that route leachate to locations where it will be neutralized.

Acid generation from underground mine workings can be moderated by several methods. In cases where workings extend below the water table, sealing mine portals allow the workings to flood, excluding oxygen and prohibiting acid generation (Kim et al., 1982). Alternatively, workings can be backfilled with alkaline materials (e.g., as slurries) that will neutralize acid generated underground (Ziemkiewicz and Skousen, 1996a).

7.3 Controlling the Migration of Acid Mine Drainage

In cases where acid generation is not prevented, then AMD must be controlled by preventing its migration to the environment. Because water is the dominant transport medium, controlling water exit pays few dividends. Consequently, control technology focuses on preventing water entry to the AMD source (SRK et al., 1989). Surface water entry can be controlled using diversion ditches and berms and locating disposal facilities in areas with low runoff. Ground water entry can be controlled using grout curtains or other seepage control devices, avoiding areas of ground water discharge, and installing synthetic or compacted soil liners. Infiltration can be controlled using surface covers and drainage control features. These features are described in Sections 6.2 to 6.5.

7.4 Collecting and Treating Acid Mine Drainage

Acid mine drainage that discharges to surface waters or infiltrates to ground waters from waste piles, tailings impoundments, underground workings, or mine pits must be collected and treated. Collection typically is accomplished using ditches, trenches, shallow wells, cut-off walls, and pumps (SRK et al., 1989). Treatment is accomplished by several methods that fall into the general categories of active and passive treatment. Treatment methods are described in more detail in Appendix E, *Wastewater Treatment*.

7.5 Information Needs

Issues associated with acid drainage that should be analyzed and presented for NEPA disclosure and permitting include:

- Describe existing and proposed predictive testing that will be used to determine the potential for and neutralization of AMD (see Appendix C). Testing proposed throughout the mine's life should be described.

- Describe and predict the effectiveness of AMD prevention, moderation, or control measures. Present results of geochemical testing and treatability testing as well as modeling results.

- Describe QA/QC procedures during operations to ensure that acid-generating material is handled according to mine plan.

- Describe monitoring programs to confirm that AMD preventive and control measures are working and/or to provide early warning of any problems, including development of action levels and contingency plans.

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APPENDIX G

AQUATIC RESOURCES

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1.0 PURPOSE AND GOALS OF THE APPENDIX

In the Pacific Northwest and Alaska, freshwater aquatic resources often represent an important component of the environment that must be considered in impact assessments for mining projects. Freshwater aquatic resources that typically are addressed in a NEPA document and baseline studies include fish, benthic macroinvertebrates, and physical parameters that define habitat for these communities. These aquatic resources, especially fish, often represent significant issues for the proposed action being evaluated during the NEPA process.

The purpose of this appendix is to provide a summary of the types of information needed to characterize freshwater aquatic resources within the project study area and describe methods that can be used in analyzing impacts of mining projects on freshwater aquatic communities and their habitat. The remaining portions of this Appendix provide information on Issues and Terminology (Section 2.0), Affected Environment Description (Section 3.0), Impact Assessment (Section 4.0), and Literature Cited (Section 5.0). Contacts and other information sources for the topics discussed in this Appendix are included in Section 6.0.

When conducting NEPA impact assessments for mining projects, considerable overlap exists between aquatic resources and surface water and ground water quality and hydrology. Descriptions of methods for conducting NEPA impact assessments on hydrology, sedimentation, and surface and ground water quality are provided in Appendix A, *Hydrology,* Appendix B, *Receiving Waters*, and Appendix H, *Erosion and Sedimentation.*

This appendix addresses only freshwater aquatic resources. Most of the direct impacts of mining operations in EPA Region 10 are to freshwater resources, simply because most mines and mineral deposits are inland, and discharges to marine environments are generally prohibited. In some cases, including cases where there are effects on anadromous fish, there would be indirect effects on marine resources. Although not covered in this appendix, NEPA analyses should address any such impacts to the marine environment and marine aquatic resources, whether direct or indirect.

2.0 ISSUES AND TERMINOLOGY

Resident and anadromous fisheries that are located within a mining project study area represent a concern to the public and governmental agencies such as the National Marine Fisheries Service (NMFS), the Bureau of Land Management (BLM), the U.S. Fish and Wildlife Service (USFWS), the U.S. Forest Service (USFS), the U.S. Army Corps of Engineers (USACE), Tribal Commissions, Tribes, and appropriate state organizations. Fish species, particularly salmonids (trout and salmon), are important because of their recreational, commercial, and/or cultural fishery value. Numerous species also are listed as threatened or endangered (T&E) under the Federal Endangered Species Act or related state statutes. The USFWS, NMFS, and appropriate state agencies should be contacted as part of the scoping and issue identification for a particular project to obtain a list of Federal and state listed species. The

USFS also uses important fish species (usually salmonids) as Management Indicator Species. These species should be included in the NEPA analysis for projects that are located on USFS land.

In addition, the Magnuson-Stevens Act requires Federal lead agencies to consult on Essential Fish Habitat[1] (EFH) that is established by the appropriate fisheries management council and NMFS, as identified in their fishery management plans. The Act is a mandate to conserve marine habitat, but it also includes freshwater habitat for anadromous fish species. In a regulatory context for conserving fish habitat, the Act requires Federal agencies to consult with NMFS when any activity proposed to be permitted, funded, or undertaken by a Federal agency may have adverse impacts on designated EFH. If a project may have adverse effects on EFH, NMFS is required to develop EFH Conservation Recommendations, which will include measures to avoid, minimize, mitigate, or otherwise offset adverse effects on EFH. The consultation process for EFH will be incorporated into interagency procedures previously established under NEPA, ESA, Clean Water Act, Fish and Wildlife Coordination Act, and any other applicable statutes.

Benthic macroinvertebrate communities represent an important biological component of the aquatic environment, since they provide food sources for fish and are indicators of water quality and habitat conditions.

The Clean Water Act (CWA) directs the EPA and states to develop and implement programs that evaluate, restore, and maintain the chemical, physical, and biological integrity[2]. States adopt water quality standards to protect public health and welfare, enhance the quality of water, and protect biological integrity. In general terms, a water quality standard defines the goals of a water body by designating the use or uses to be made of the water, establishing criteria necessary to protect those uses, and preventing degradation of water quality through antidegradation provisions. The fish, macroinvertebrate, and periphyton (attached algae) assemblages are all direct measures of the beneficial use under the CWA. The CWA applies to all species of aquatic life including, but not limited to, “important” fish species.

After reviewing the proposed mining plan for a particular project, the potentially disturbed or impacted areas should be related to the presence of fish species, macroinvertebrate communities, and habitat conditions (including riparian and hyporheic zones) within the project study area. Potential aquatic resource issues for mining projects include:

- Potential adverse effects on water quality and aquatic communities and habitat due to sedimentation, metals, acid generating materials, and other toxic chemical loadings.

[1] Essential Fish Habitat is defined as ". . . those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity."

[2] Biological integrity is "a balanced, integrated, adaptive community of organisms having species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr and Dudley 1981).

- Potential effects of transporting and storing fuel and other toxic chemicals that could pose risk of spills and adversely affect aquatic communities and their habitat.
- Potential water use by mining operations that may affect flows in project area water bodies, which could adversely affect habitat for important fish species and macroinvertebrate communities.
- Potential direct disturbance to habitat used by important fish species during life history events such as spawning, rearing, and adult movements.

These issues are discussed in more detail in Section 4.0.

3.0 AFFECTED ENVIRONMENT DESCRIPTION

The initial steps in describing an affected environment include: (1) define the study area and (2) collect and review available information on aquatic resources that are located within the project study area. Information in this appendix focuses on specific aspects of the data collection and review task for aquatic resources and a summary of methods that can be used in conducting additional baseline studies.

The affected environment description should characterize important information on fish communities, macroinvertebrate communities, amphibians and other aquatic and semi-aquatic vertebrates, and aquatic habitat, including the adjacent riparian[3] zone, within the project study area. Fish and macroinvertebrate assemblages are defined as an associations of organisms in a given water body (EPA 1996). The study area for aquatic resources should include potentially affected watersheds. The study area should encompass on-site (project area boundary) and off-site (both upstream and downstream) water bodies and adjacent riparian zones that receive both direct and indirect impacts. The level of detail and analyses need to be commensurate with the importance of the impact (Council on Environmental Quality, 1986). The following types of information are typically needed to characterize aquatic resource topics for the Affected Environment Section of a NEPA document:

<u>Fish (Aquatic Vertebrates) Assemblage Information</u>

- Species list (all species included). This includes any other aquatic vertebrate species (e.g., amphibians) that might be collected in conjunction with the fish.
- Distribution, abundance, and composition of game fish and T&E and candidate species.
- Distribution, abundance, and composition of amphibians and other aquatic and semi-aquatic vertebrates (including aquatic mammals and reptiles)
- List of any critical habitat designations for T&E species, as established by the

[3]*Riparian* is a term that refers to "plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: 1) distinctly different vegetative species than adjacent areas, and 2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland" (USFWS, 1997). Riparian areas also often include wetlands.

USFWS and/or state agencies.

- List of any Essential Fish Habitat established by regional fisheries management council.
- Seasonal timing of spawning for game and T&E and candidate species.
- Habitat requirements of game and T&E and candidate species.

Fish Tissue Contamination Information

- Species, type of sample (i.e. whole fish, fillet), and number of samples; and
- Metal concentration in sample.

Macroinvertebrate Assemblages Information

- Enumeration and identification of benthic invertebrates to the lowest taxonomic level (Plotnikoff and White 1996).
- Community metric data (e.g., total number of taxa, percent dominance, number of Plecoptera taxa, number of Ephemeroptera taxa, and number of Trichoptera taxa.).

Information on Other Aquatic Organisms (Amphibians and Aquatic/Semi-Aquatic Mammals)

- Species composition and abundance.
- Habitat requirements and seasonal timing of breeding.

Habitat Information

- Streams - Gradient, widths and depths, pool frequency, substrate composition, streambank erosion, existing barriers and/or road crossings, culvert characteristics, large woody debris, percent undercut banks, surface fins, flow characteristics, temperature, and dissolved oxygen.
- Lakes and Reservoirs - Depth, surface area, littoral zone area, presence of aquatic vegetation, and substrate composition.
- Riparian Zone - Width, percent cover and composition of vegetation by strata, and estimated shaded area by seasons.

Project scoping and discussions with Federal and state agency biologists should be used to define the specific list of topics to be covered as part of the Affected Environment Description. Sources of information for the aquatic resource topics can be obtained by searching published literature, unpublished agency file information, and contacts with relevant Federal and state agencies.

Summaries of recommended methodologies to collect baseline data, if needed, are provided below. The summaries focus on field studies for fish, benthic macroinvertebrates, and habitat characterization. For topics such as the life history and habitat requirements of fish, sufficient information is usually available in published literature. Prior to initiating any baseline studies, the proposed methods should be discussed and approved by appropriate Federal and state agency fishery biologists and/or aquatic ecologists.

3.1 Fish

3.1.1 Distribution, Abundance, and Composition

The timing and frequency of fish surveys largely depend upon the extent of migration or movements exhibited by the important fish species. If the important species are resident (i.e., minimal movement or migrations), one sampling effort in the summer or fall should be adequate to characterize composition and abundance. Additional sampling efforts may be needed to characterize composition and abundance information for more mobile species. If spawning information is needed, one survey should be scheduled to coincide with the peak spawning period for the important species. It also is important to note that surveys of downstream, and in some instances upstream, areas may be appropriate. This is true even if no fish reside within or migrate through the project boundary. Final decisions on the timing and frequency of surveys should be made through discussions with the appropriate agency biologists.

The selection of a sampling method to collect data on the distribution, abundance, and composition of fish communities depends mainly upon the type of water body. Each sampling technique has limitations in terms of its effectiveness in particular types of habitat and behavior and life stages of fish species. In streams and shallow rivers, sampling methods include backpack or shoreline electrofishing, snorkeling, weirs, minnow traps, and seining. Of these methods, electrofishing is the most commonly used technique due to the time efficiency in completing the survey. However, electrofishing has been restricted in some watersheds within the Pacific Northwest that contain federally threatened or endangered salmon or trout species. In deeper rivers, boat electrofishing and hoop nets can be used to collect fish. Possible types of collecting methods for lakes or reservoirs include boat electrofishing, gill nets, fyke nets, and seine nets. Collection permits are required from the USFWS, NMFS, and/or state fish and wildlife agencies for all of these methods except snorkeling. Applications of the various fish sampling methods in terms of general type of habitat and life stage are listed in Table G-1. Brief summaries of these sampling methods are provided below; refer to literature citations in Table G-1 for more detailed descriptions of the sampling methods.

Backpack Electrofishing. In streams and rivers with depths less than about 3 feet, backpack electrofishing is a common method used to collect adult and juvenile fish by producing an electrical field in the water. In addition, some amphibians may be collected along with the fish; they should be enumerated and identified as well. The method is not effective in capturing small-sized fish (i.e. young-of-the-year) because of their relatively small surface area. Prior to initiating the survey, the sampling effort is quantified in terms of linear distance, stream area sampled, or duration of sampling in minutes. The crew moves in an upstream direction and electrofishes all habitat within the reach. All fish species are netted and then processed in the field by identifying and enumerating each fish by species. Species identifications should be made by a qualified fisheries biologist and/or voucher specimens checked by a fish taxonomist at a university, college, or museum. If population studies are required, the upper and lower ends of the sampling reach are blocked off with nets. Multiple passes through the reach are usually required for estimating fish population numbers.

Shoreline Electrofishing. Shore-based electrofishing can be used in larger wadeable streams and rivers, where backpack electrofishing produces an electrical field that is too small and weak to be effective. In shore-based electrofishing, all equipment (electrical unit and generator) is located on land, except for the lead electrode. A two or three-person crew electrofishes the sampling reach in the manner as described above for backpack electrofishing.

Boat Electrofishing. A flat-bottomed boat equipped with electrofishing equipment can be used to collect fish in slow-moving rivers and standing water environments. The boat design consists of a forward deck that can accommodate two standing adults as dip-netters and one or two booms that extend forward from the bow with an electrode. The sampling procedure involves slow operation of the boat in an upstream direction along shoreline areas with depths less than approximately five feet. Fish are netted as they are stunned and then placed in collecting containers. Field processing is similar to backpack electrofishing.

Snorkeling. As part of the R1/R4 Fish Habitat Inventory procedures that are used on USFS land in the Pacific Northwest, direct counts of game and T&E fish are made by snorkeling (Overton et al., 1997). This technique is not recommended for fish assemblage characterization since some of the small non-game species can be difficult to observe. Typically, one or two snorkelers count all fish in a single pass within the study reach. Sampling criteria required for this technique include: (1) stable flow periods between late June and September; (2) direct sunlight conditions between late morning and early afternoon; (3) water temperatures should exceed 9 °C; and (4) visibility should be greater than 3 to 4 meters. All fish are counted in the entire habitat unit or a portion of the unit using one of the following approaches: (1) proceed up the center of the unit and count fish by zigzagging outward to both banks; (2) proceed up one bank and count all fish towards the other bank if the water is too deep or turbulent to zigzag; or (3) float downstream along the center of the stream in deep water.

Weir. This technique involves the construction of a temporary or permanent barrier across the entire width of the stream to divert fish into a trap. Weirs are best suited for capturing migratory adult and juvenile fish as they move up or down streams. The use of weirs is limited to streams and small rivers because of construction expense, formation of navigation barriers, and tendency to clog with debris and ice.

Minnow Traps. This portable trap captures juvenile fish as they enter through a conical-shaped funnel at both ends. The traps are usually baited with fish eggs when they are used to collect juvenile salmon. Typically, the traps are scattered along a stream or river segment and fished for at least 12 to 24 hours.

Seining. Appropriate-sized seine nets also can be used in slow-moving sections of streams or shallow rivers to collect young-of-the-year and juvenile fish, if bottom substrate is relatively smooth and free of debris and other snags. Beach or haul seines are constructed of mesh panels hung from a float line with a weighted leadline attached to the lower edge. A mesh bag is often attached to the middle of the net, which collects fish as the seine is dragged along the bottom by two people.

Hoop Nets. This entrapment device is a cylindrical or conical net distended by a series of hoops or frames. The net has one or more internal funnel-shaped throats whose tapered ends are directed inward from the mouth. In riverine habitats, hoop nets are set with the mouth opening downstream and sufficient depths to cover the net. Hoop nets are usually baited and fished for at least 24 hours. This method is selective for bottom-feeding species such as carp, catfish, and suckers.

Fyke Nets. This entrapment device is a modified hoop net with one or two wings or leaders of webbing attached to the mouth to guide fish into the enclosure. Generally, fyke nets are set in shallow areas of ponds, lakes, or reservoirs, with sufficient depths to cover the top f the net. Fyke nets are selective for certain mobile, cover-seeking species such as sunfishes and pike.

Gill Nets. This entanglement gear consists of vertical walls of netting that are typically set out in a straight line in lakes, reservoirs, and ponds. Fish are captured as they swim into the netting and become entangled in the mesh. Gill nets can be set in many different ways, depending on the species desired and types of habitats in the water body. A variety of species can be captured by gill nets, but the gear is most effective for species that exhibit substantial daily movements. This collecting method usually targets adult fish, although juveniles can be captured if smaller mesh sizes are used.

3.1.2 Adult Spawning Counts

The number of spawning salmon that return to freshwater streams or rivers can be estimated by ground counts or aerial helicopter flyovers. These methods are applicable in clear streams with depths less than about six to eight feet. Helicopter surveys are conducted by flying just above tree height along the stream. An observer records the number and location of salmon. A sufficient number of surveys should be conducted to cover the peak spawning period for each of the salmon species. For effective counting, weather conditions should be mostly sunny and clear. Ground counts of spawning salmon can be used to census the number of salmon that reach their spawning areas in a drainage. One or more observers walk along the stream and count the number of spawning salmon. The survey needs to occur during the peak spawning period when most of the salmon have returned to their spawning areas.

3.1.3 Fish Tissue

Definition of metal concentrations in fish tissue can provide important baseline information concerning the background levels in the project study area. If metal contamination in fish tissue is identified as an impact issue, it is important to determine concentrations in the study area prior to the initiation of a new or modified monitoring activity. Numerous problems are typically

Table G-1. Summary of Fish Sampling Techniques

General Type of Water Body/ Sampling Gear	Types of Information					Salmonid Life Stages			References - Descriptions of Sampling Methods
	Species List	Distribution	Abundance/Composition	Population	Adult Spawning Counts	Adults	Juvenile	Young of the Year	
Streams/Shallow Rivers									
Backpack electroshocker, shore-based electroshocker	x	x	x	x		x	x		Nielsen and Johnson (1983); Klemm et al. (1993)
Snorkeling						x	x		Overton et al. (1997)
Seine net	x	x	x	x			x	x	Nielsen and Johnson (1983); Klemm et al. (1993)
Minnow trap	x	x	x				x	x	Nielsen and Johnson (1983); Klemm et al. (1993)
Weir	x	x	x			x	x		Nielsen and Johnson(1983); Klemm et al. (1993)
Ground survey					x	x			See Section 3.1.2
Aerial (helicopter) flyover					x	x			See Section 3.1.2
Deep Rivers (Moderate Velocities)									
Hoop net	x	x	x			x	x		Nielsen and Johnson (1983)
Deep Rivers (Low Velocities)									
Boat or raft electroshocker	x	x	x			x	x		Nielsen and Johnson (1983)
Lakes, Reservoirs, and Ponds									
Boat electroshocker	x	x	x			x	x		Nielsen and Johnson (1983); Klemm et al. (1993)
Fyke net	x	x	x			x	x		Nielsen and Johnson (1983); Klemm et al. (1993)
Gill net	x	x	x			x	x		Nielsen and Johnson (1983); Klemm et al. (1993)
Seine net							x	x	Nielsen and Johnson (1983); Klemm et al. (1993)

encountered during the design and implementation of a baseline sampling program for fish tissue analyses. Problem areas include definition of the most meaningful tissue(s) and metals for study, difficulties in collecting the desired samples (i.e., species, numbers, and sizes), proper handling and preparation of samples without contamination, and the interpretation of results. Metals are not evenly distributed among different specimens or within different organs or tissues. Natural variation in metal concentrations also typically exists in fish populations due to a variety of reasons such as movements, feeding habits, and physiological differences. Therefore, a relatively large number of replicates should be collected, if possible, to statistically differentiate various fish populations inhabiting the study area.

The final design for a fish tissue sampling study should be determined through discussions with the appropriate Federal and state agencies. Decisions need to be made regarding the sampling locations, target species, number of replicate samples, composite or individual samples, and tissues or organs to be analyzed. The types of tissues that are typically analyzed for metals include liver, gills, muscle, and whole body. Fish can be collected using any of the methods discussed above. Hook-and line method also is sometimes used to collect fish for tissue analyses.

Specific field and laboratory procedures have been developed to analyze metal concentrations in fish tissue. Field processing techniques, which are described in EPA (1980), involve decontamination of the sampling equipment, double wrapping the fish or tissue in 5 percent nitric acid-rinsed aluminum foil, and then placing the samples on ice during the time of sampling. At a minimum, samples should be kept on ice for no more than 24 hours. Fish or tissues should be frozen prior to shipment to a commercial laboratory for chemical analyses. The procedure for decontaminating sampling equipment consists of the following steps: (1) initial rinse with tap water; (2) wash with biodegradable detergent; (3) rinse with deionized water; (4) rinse with 5 percent nitric acid; and (5) final rinse with analyte-free water. Tissue can be removed from the whole fish in the field or in the laboratory. Latex gloves should be used for each decontamination procedure and field processing of each sample and then discarded.

Additional field data that are recommended for each fish sample include measurements of weight (in grams), length (in millimeters), and the removal of scales for age determination. It is important that the laboratory selected to perform the tissue analyses follows these procedures, including Quality Control/Quality Assurance measures.

3.2 Benthic Macroinvertebrates

Both quantitative and semi-quantitative methods are used to obtain abundance and composition data for macroinvertebrates. Sampling methods should be selected based on the scope and purpose of the overall study. Methods and data should be reviewed for accuracy and their appropriateness for meeting the study's specific objectives. The design of any additional or new studies must decide on whether semi-quantitative or quantitative methods are appropriate, given the purpose of the study and the nature of data from previous investigations (for example, to identify any trends, it might be appropriate to use the same methods as earlier studies even if other methods would provide more complete information).

Semi-quantitative methods typically consist of kick net samplers in streams. After placing the net in a riffle or run, the substrate material in front of the net is rubbed or agitated to remove any macroinvertebrates. The organisms in the sampled area drift into the net. The sampled area is estimated rather than measured. Data analyses usually consist of relative abundance of the various macroinvertebrate taxa present in the sample. Many state environmental agencies and the U.S. Geological Survey use this method in their National Water Quality Assessment Program. The existence of semi-quantitative data from previous surveys make the use of such methods more appropriate than would otherwise be the case.

Quantitative methods are used to provide abundance and composition data per unit area sampled. The sampling methodology depends upon the type of water body. In riffle areas of streams or rivers with depths less than about 18 inches, sieve-type samplers (either Surber or Hess) are the most common devices used to collect macroinvertebrates. The Surber sampler consists of a 1 square foot frame (0.09 square meter) with an attached net and bucket (0.5 millimeter mesh). The Hess sampler is a circular frame with an attached net (0.5 millimeter mesh) that encloses a surface area of approximately 1 square foot or 0.1 square meter. Both methods involve the removal of macroinvertebrates on substrate surfaces by hand. All collected material then is washed and concentrated into the bucket and placed into a labeled sample jar and preserved with formalin and ethanol. Field collection techniques for these methods are described by the following authors: Surber sampler (Surber, 1937; Hughes, 1975, Klemm et al., 1990) and Hess sampler (Hess, 1941; Waters and Knapp, 1961; Jacobi, 1978).

Quantitative sampling in deeper rivers, lakes, reservoirs, or ponds is accomplished using a grab-type device such as a petite Ponar, Peterson, or Eckman. These grab samplers are designed to penetrate the substrate and then enclose bottom substrate material with either spring- or gravity-operated mechanisms. The Eckman grab is relatively light and designed for soft bottoms consisting of sand, clay, silt, and organic material. For clay hardpan and coarse sands, heavier grabs such as the petite Ponar or Petersen are used. The most important criterion in effective grab sampling is to penetrate the bottom material and obtain complete closure of the sides of the sampler. The surface area sampled ranges from 0.25 square foot (0.02 square meter) with the petite Ponar to approximately 1 square foot (0.09 square meter) with the Peterson sampler. Descriptions of sampling techniques for these grab samplers are provided by Weber (1973), Elliott and Drake (1981), Lewis et al. (1982), and Klemm et al. (1990).

The design of a macroinvertebrate sampling program needs to select sampling sites that encompass areas potentially affected by past or future mining operations. If possible, a reference site, which is located outside the influence of the mining activities, should be selected that exhibits similar habitat conditions compared to downstream sites. By comparing sites with similar habitat conditions, the identification of possible causes for differences in macroinvertebrate communities often focuses on water quality. Two to four replicate samples also should be collected at each sampling site to provide sufficient data for statistical analyses, if required. At a minimum, one sampling effort should be conducted in the summer or early fall. Two sampling efforts (spring, summer, or fall) would account for seasonal changes in macroinvertebrate communities that result from developing young and adult hatching. If previous sampling has been conducted, additional sampling should be scheduled to coincide with the dates as much as possible.

Laboratory processing for all samples consists of sorting and picking all macro-invertebrates into a vial, followed by identification and enumeration of all organisms. If the sample contains a large number of macroinvertebrates, subsampling of 500 organisms can be used (Hayslip, 1993). Identifications should be taken to the lowest possible taxonomic level to provide information on the composition and diversity of macroinvertebrates inhabiting the water body.

Data analyses recommended for a baseline study of macroinvertebrates varies depending upon whether issues were identified during scoping. At a minimum, the number of taxa, abundance, and composition data should be analyzed. However, data analyses are recommended only if at least 50 organisms are present in the sample. Densities are presented as the number of individuals of each taxon per square foot or square meter; composition is presented as percent of each taxon total macroinvertebrate densities at a sampling location. If a more detailed evaluation of sedimentation or metal toxicity are required, the following additional metrics can be analyzed.

- Number of Ephemeroptera (mayflies) taxa.
- Number of Plecoptera (stoneflies) taxa.
- Number of Trichoptera (caddisflies) taxa, whose absence may indicate metals contamination.
- Percent Dominant Taxon - Percent composition of the most abundant taxon in the macroinvertebrate community at a sampling location.
- Percent Baetidae - Percent composition of baetid mayflies (metal sensitive group).
- Species Diversity - Index that indicates taxonomic richness and abundance among the various taxa.
- Metal Tolerance Index - Rating system representing relative sensitivity or tolerance to metals developed by McGuire (1994) for western montane streams.

Information on how to use metric data in evaluating the impacts of mining or other stresses within a water body are discussed in Section 4.0 (Impact Assessment). For the purposes of including these metrics in baseline characterizations of macroinvertebrate communities, procedures are discussed in Plafkin et al. (1989), (Klemm et al. (1990), Wisseman (1996), and Barbour et al. (1997).

3.3 Amphibians

Amphibians are another group of organisms that inhabit aquatic environments. Due to widespread declines of amphibian populations, conservation planning and monitoring efforts have been implemented by Pacific Northwest Federal and state agencies. In the Pacific Northwest, numerous native amphibian species are listed as state "sensitive" or "special concern" species. Federal agencies such as the Forest Service also have targeted certain amphibian species as Forest "sensitive" species.

In general, two groups of amphibian assemblages are associated with aquatic habitats in the Pacific Northwest: (1) stream-dependent species which live in or adjacent to water during all or part of their life cycle (e.g., tailed frogs, *Ascaphus truei*, and giant salamanders, *Dicamptodon* spp.); and (2) pond-breeders which require standing water or lentic habitats for egg-laying and larval development (Olson et al., 1997). The following information describes the more common methods that can be used to collect data on species presence and relative abundance for stream and lentic environments. Detailed descriptions of these and other sampling methods can be found in Heyer et al. (1994) and Olson et al. (1997).

<u>Visual Observations and Dipnetting</u>. The most common method in determining the presence and relative abundance of amphibians in both stream and lentic environments involve visual observations and dipnetting. Species presence and relative abundance can be made by walking and counting amphibians within defined sections of the study area. If relatively large numbers of amphibians are encountered, subsampling can be used. Dipnetting can be used to collect egg masses, larvae, and adults in shallow aquatic areas by making sweeps in front and to the sides at designated stops. Each scoop should include the upper 2 to 3 centimeters of bottom from a sweep approximately 1 meter (3 feet) in length. After each scoop, water and fine sediment should be strained from the net by gently sloshing it back and forth in the surface water. The contents should be examined for adult and larval amphibians. If relative abundance is a study objective, it is important to standardize the distance between stops, as well as the number and length of sweeps. In this situation, abundance data are presented as the number of amphibians per area sampled.

A systematic approach in obtaining relative abundance data can be achieved by using quadrate or transect sampling methods. Quadrate sampling consists of laying out a series of small squares at randomly selected sites within a habitat type and thoroughly searching those squares for amphibians. In the transect method, narrow strip transects are randomly layed out and surveyed for amphibians. Patch sampling, which is a modified form of quadrate sampling, can be used to determine the presence and abundance of amphibians in discrete subunits of an area (i.e, logs, debris jams, etc.). Detailed descriptions of these methods are provided by Heyer et al. (1994).

<u>Funnel Traps</u>. For nocturnal or cryptic species, and habitats that are difficult to sample due to depth or abundance of vegetation, funnel trapping is a useful method. Funnel traps consist of a holding chamber with one or two tapered mouths that channel organisms toward a small entrance to the trap interior. One type of funnel trap that can be used is the commercially available minnow trap, which is constructed of 0.25-inch plastic or galvanized hardware cloth. Other commercial traps are available that are constructed of nylon webbing wrapped around a wire-frame. Traps are sometimes baited to attract amphibians.

<u>Night Surveys</u>. Since some amphibians are more active at night, visual surveys can be conducted using a flashlight. The reflective shine of amphibian eyes are used to record larvae and adults (Olson et al. 1997).

Snorkeling. Visual surveys conducted by snorkeling are useful in deep portions of lakes and wetlands. Visual counts are made along snorkeled transects or defined areas. The number of amphibians also can be recorded per unit of time surveyed.

Electrofishing. Generally, this method is used for fish surveys, but incidental observations of amphibians can be included as part of the fish survey. Pools and backwater areas represent the areas where amphibians may be encountered.

The design and selection of study sites for amphibian surveys are discussed in detail by Olson et al. (1997). Surveys should consider all aquatic habitats within a study area that could be inhabited by amphibians such as streams, rivers, ponds, lakes, meadows, and other wetland areas. If larvae and egg surveys are required, the surveys must be timed to coincide with the breeding and early development of the species (spring and summer).

3.4 Aquatic Habitat and Riparian Zone

The level of detail required for characterizing aquatic habitat within water bodies depends upon numerous factors such as the presence of game fish or T&E fish species, presence of critical habitat for Federally listed fish species, management goals for aquatic resources established by Federal and state agencies, types of potential impacts that could result from the mining project, and the level of concern for habitat impacts as identified during the scoping process. In some instances, existing habitat information may be available for watersheds that support game or T&E fish species. The data should be reviewed and determined whether it would be sufficient to characterize aquatic habitat for the NEPA document. If additional field surveys are required, methods should be used to allow comparisons to future monitoring programs or other watersheds. Examples of methods that are currently being used in the Pacific Northwest are summarized below.

Mining projects that are located on USFS land should use their preferred methods. The USFS Columbia Basin Anadromous Fish Policy and Implementation guidelines directed Columbia Basin Forests to have comparable data within basins to identify existing habitat conditions. The Salmon Conservation Strategy (PACFISH) use habitat variables for monitoring goals and objectives that help protect, maintain, and restore important fish habitat. As a result of these requirements, the R1/R4 habitat procedures were developed by Overton et al. (1997). The following parameters are covered in the R1/R4 manual: general type of habitat designation, discharge, gradient, stream width, stream depth, type and frequency of pools, percent surface fines, substrate composition, percent undercut bank, number of large woody debris, bank stability, vegetative cover, and Rosgen channel classification. The riparian zone provides important habitat values for the aquatic environment. Riparian surveys should include information on width of the zone, percent cover and composition of vegetation, and estimated shaded area. Methods for collecting these data are described by Platts et al. (1983), MacDonald (1991), and Hansen et al. (1995). When designing baseline habitat surveys for a mining project, these parameters should be considered. The final study design should be developed through discussions with the USFS and state agency biologists or habitat specialists.

Specific habitat procedures also may be recommended by state agencies. The appropriate state agency should be contacted prior to designing aquatic habitat studies to determine whether specific procedures are required. Standardized methods for characterizing habitat in western U.S. streams/rivers also are described by Binns (1982), Platts et al. (1983), Hamilton and Bergen (1984), and Rosgen (1985).

4.0 IMPACT ASSESSMENT

Numerous reviews of the effects of mining on aquatic resources are useful in identifying potential issues for a mining project (e.g., Martin and Platts, 1981; Meehan, 1991; Ripley et al., 1995; Waters, 1995; and Starnes and Gasper, 1996). Environmental impact statements (EIS) or environmental assessments (EA) that have been completed for similar mining projects also should be used in the issue identification task. This type of information available from published literature sources in conjunction with the scoping process are used in identifying specific impact issues for a project. Potential aquatic resource issues for a mining project may include the following topics:

- Potential effects of water quality changes on aquatic and semi-aquatic (mammals, amphibians, birds) communities and their habitat that may result from mine operation. Parameters of concern may include heavy metals, pH, and acid-generation materials.
- Potential effects of sedimentation on aquatic and semi-aquatic communities and their habitat due to construction and operation activities.
- Potential effects of physical disturbance or removal of habitat on aquatic and semi-aquatic biota.
- Potential effects of spills on aquatic and semi-aquatic biota that may result from fuel transportation and use (i.e., leaking equipment and refueling) and use of other hazardous materials.
- Potential effects of flow changes on aquatic habitat and riparian zones and their respective biota due to water withdrawals.
- Potential effects of physical blockages or barriers created by mining construction or operation activities on fish movements.

The analysis should encompass potential effects on riparian areas, which can in turn affect aquatic ecosystem health, and on aquatic and semi-aquatic organisms and ecosystems. As required under NEPA regulations, the impact assessment must analyze both direct and indirect impacts (Council on Environmental Quality, 1986). The analyses used in the environmental impact assessment must be scientifically accurate and exhibit scientific integrity. Specific methods used in analyzing impacts and making conclusions must be referenced in the NEPA document. The following information describes methods that can be used in analyzing impacts for the various issues listed above.

4.1 Water Quality Impacts

4.1.1 Comparisons to Aquatic Life Water Quality Criteria

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 from waste rock, spent ore, and mine workings. If these pollutants reach surface waters, toxic conditions could affect important aquatic species. Potential analytes of concern for mining projects generally include pH, cyanide and associated chemical species, and metals.

Actions and/or measures that can be taken to avoid or reduce water quality impacts from mining activities are discussed in Appendix B, *Receiving Waters*; Appendix C, *Characterization of Ore, Waste Rock, and Tailings*; Appendix D, *Effluent Quality*; Appendix E*, Wastewater Treatment*; and Appendix F, *Solid Waste Management*.

The most common approach used to analyze the effects of water quality changes on aquatic communities is to compare projected post-mining water quality to applicable standards intended to protect aquatic life. Water quality standards are based on three components:

(1) designated beneficial use or uses of water (i.e., aquatic life use)
(2) criteria designed to protect those uses (e.g., pH)
(3) an antidegradation provision.

The fish, macroinvertebrate, and/or periphyton assemblages are all direct measures of the aquatic life beneficial use under the CWA. For many metals, criteria are used to protect aquatic organisms from both acute[4] and chronic[5] toxicity. Standards for metals such as cadmium, chromium III, copper, lead, nickel, and zinc are dependent upon hardness (mg/L as $CaCO_3$), which is reflected in equations that are used to calculate the criterion for each metal. Toxicity is inversely related to hardness and EPA typically uses a conservative hardness (5th or 10th percentile) in determining applicable criteria. It is essential to have representative hardness data for the receiving water. The standards for metals also are based on either total recoverable or dissolved concentrations. The standards used (i.e., total recoverable or dissolved) should be incorporated into a baseline surface water sampling program.

The analysis requires close coordination between the surface water and aquatic resource analyses. The first step in the analysis is to characterize natural background concentrations using available data. Second, water quality conditions during mining and post-closure are projected. The final step in the analysis is to compare the pre-mining and post-mining water quality

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[3]Acute toxicity is defined as concentrations that cause mortality or immobilization during a short-term period (usually 48 to 96 hours) of exposure.

[4]Chronic toxicity is defined as concentrations that cause reproductive impairment or other sublethal effects during a long-term period (seven days to greater than one year) of exposure.

concentrations to state water quality standards. It is important to estimate water quality during and after mining for both the proposed operation and alternatives; this would involve analyses both qualitative and quantitative) including various combinations of best management practices and other mitigation measures.

If analytes of concern are identified for the project study area, a qualitative discussion of impacts can be made using available published literature. The discussion should describe the types of effects that the analytes of concern may have on fish and macroinvertebrate communities. If possible, affected water bodies that may exhibit toxic conditions should be identified in terms of their length or surface area.

The issue of sediment water quality effects on aquatic biota is more difficult to evaluate, since standards are not available. The best approach in analyzing this issue is to compare natural background and post-mining sediment quality to benchmark values available in the published literature. These comparisons help identify whether the sediment quality is within background levels reported for areas with no known metal contamination. Examples of information sources for metal concentrations in sediment include Washington State Department of Ecology (1991); EPA (1994a; 1995); and Jones et al. (1996).

4.1.2 Toxicity Studies

Additional site-specific information can be obtained by conducting toxicity studies using surface water or sediment from the project study area. These tests can be used to confirm potential water quality concerns identified as part of the water quality comparisons between post-mining conditions and applicable water quality standards. Typically, microcrustaceans (*Dapnia* or *Ceriodaphnia* species) and fish species are used as test organisms, although test procedures exist for a variety of macroinvertebrates such as midges, mayflies, annelid worms, and amphipods. If additional testing is required, decisions need to be made concerning the test organisms, type of test (acute or chronic), static or flow-through conditions, test medium (surface water or sediment), and concentrations to be tested. Mining companies (or their representatives) are strongly encouraged to consult with the EPA and the appropriate state agency before designing and conducting toxicity tests. The following test procedures should be followed for designing and conducting the tests:

- Acute Toxicity - Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms (Weber, 1993).
- Chronic Toxicity - Short-Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms (Lewis et al., 1994).
- Sediment Toxicity and Bioaccumulation - Methods for Measuring the Toxicity and Bioaccumulation of Sediment-Associated Contaminants with Freshwater Invertebrates (EPA, 1994b) and Standard Test Methods for Measuring the Toxicity of Sediment-Associated Contaminants with Freshwater Invertebrates (American Society for Testing Materials, 1998).

Additional guidance in designing and conducting toxicity testing is provided in *Standard*

Methods for the Examination of Water and Wastewater (American Public Health Association et al., 1989).

4.1.3 Macroinvertebrate Metric Analysis

Macroinvertebrate communities are useful indicators for assessing the effects of various types of environmental stress, as reflected in degraded water quality conditions or habitat. Many benthic macroinvertebrates have limited migration patterns or a sessile mode of life, which makes them well-suited to assess site-specific impacts. Macroinvertebrate assemblages are comprised of a broad range or organisms that exhibit varying levels of tolerance to pollution sources such as sedimentation and metals (Barbour et al., 1997).

The evaluation of impacts on macroinvertebrates typically uses relevant literature pertaining to the effects of sedimentation and metals contamination on macroinvertebrate communities. Previous studies have found that macroinvertebrates often respond to sedimentation or metals contamination by exhibiting reduced densities, reduced taxa richness, and a shift from sensitive to tolerant taxa (Winner et al., 1980; Clements, 1994; Waters, 1995). The absence or low numbers of Ephemeroptera, Plecoptera, and Trichoptera may indicate metal contamination. Predictions of potential impacts can be made using the results of these relevant studies.

Additional analysis of macroinvertebrate data from a project study area can be used to monitor or confirm the projected impacts of mining projects. Numerous types of information or metrics have been used to evaluate the effects of various types of environmental stresses on macroinvertebrate communities. Examples of metrics that have been used to evaluate the effects of metals and sediment on macroinvertebrate communities include total abundance, total number of taxa, number of Ephemeroptera taxa, number of Plecoptera taxa, number of Trichoptera taxa, percent dominant taxon, percent Baetidae, and Metal Tolerance Index (Plafkin et al., 1989; Resh and Jackson, 1993; Wisseman, 1996; Fore et al., 1996; and Barbour et al., 1997). Refer to Section 3.2 for definitions of these metric terms. The final selection of the metric data should be made through discussions with appropriate Federal and state agency biologists. After completing the metric data analyses, comparisons should be made between the reference and downstream sites. Procedures for conducting macroinvertebrate metric data analyses are described by Plafkin et al. (1989), Wisseman (1996), and Barbour et al. (1997).

4.2 Sedimentation

Several types of analyses can be used to evaluate the potential effects of sedimentation on aquatic communities and their habitat. Indicators that can be used to discuss potential sediment-related impacts in streams include change in percent fines or cobble embeddedness. For all types of water bodies, aquatic life water quality standards also may exist for sediment-related parameters such as turbidity or total suspended solids (TSS). Baseline data should be used to characterize the range in values for one or more of these parameters. If possible, percent increases in these values that could occur as a result of project activities should be estimated (see Appendix H, *Erosion and Sedimentation* for a detailed discussion of methods to quantify sediment loadings). The predicted increase in the sediment-related indicators should then be related to levels that have been reported as limiting fish or macroinvertebrate development. For example, percent fines of 40 percent or greater have been reported to adversely affect salmonid fry development and emergence (Bjornn et al., 1977; McCuddin, 1977). Burton et al. (1991) proposed that no statistically significant increase in natural baseline percent embeddedness should occur in Idaho salmonid rearing habitats.

If quantitative predictions are not possible for the sediment indicators, then a qualitative analysis should be used to discuss potential adverse effects on aquatic communities using published literature. The duration of impacts that have resulted from similar mining projects should be included in the impact discussion. The impact analysis also should estimate the linear length of streams, surface area of lakes/reservoirs that could potentially exhibit increased sediment yield as a result of mining activities. The analysis should focus on the affected aquatic environments that support aquatic communities and habitat.

4.3 Habitat Alteration

The types of information that are needed to evaluate the potential effects of removing or altering habitat for important game and T&E fish species and other aquatic and semi-aquatic species include: (1) identify stream segments or water bodies affected by mining activities; (2) quantify the area of disturbance in square feet or acres; (3) determine list of fish species that utilize the affected areas; (4) characterize the general types of habitat affected; and (5) describe the fish life stages (i.e., spawning, young-of-the-year rearing, etc.) that potentially use the affected areas. The impact discussion should evaluate the significance of altering or removing the habitat for the important species by considering the magnitude (square feet or acres affected) and duration of impacts. The use of the impacted area should be related to the amount of similar types of habitat that are available within the project study area.

Mining activities also may involve the loss of aquatic habitat by physical placement of materials in a portion of a drainage, which may itself need a permit. In this situation, flows are usually diverted from the "affected stream segment" into a newly constructed channel. The impacts of removing and replacing stream segments should be quantified in square feet or acres in relation to the important fish and macroinvertebrate taxa that occur in the affected areas. The recovery of aquatic communities in the newly constructed channels needs to be discussed using published studies that have monitored aquatic biota after flow was returned to a stream.

4.4 Hazardous Material Spills

Transportation of fuel and other toxic chemicals to and from the mine site present potential risks to aquatic communities from spills that enter water bodies. At a minimum, the impact discussion should describe the effects of potential spills on aquatic communities using available literature on toxicity of fuel and the various chemicals being transported and/or stored on-site. The analysis should focus on stream segments or water bodies that are located adjacent to and downstream of the transportation route and project area---all areas where spills may occur. The discussion also should explain that the magnitude and duration of impacts would depend upon the chemical spilled, volume spilled, toxicity to aquatic species, time of year, weather conditions, and physical characteristics of the water body. Reference should be made to any relevant published studies that have conducted after similar types of spills.

A risk assessment may be used to analyze the impacts from potential spills, if this topic is identified as a significant issue. The following types of information are typically included in a risk assessment:

- Identify the types and volumes of toxic chemicals that are transported to and from, and/or are stored at the mine site;
- Determine the frequency and schedule of transporting toxic chemicals;
- Identify the transportation route;
- Define the spill scenarios to be analyzed;
- Determine the presence of important fish species in water bodies located adjacent to the transportation route;
- Characterize the condition of roads used in transporting toxic chemicals;
- Describe the effects of fuel or chemical spills on aquatic species using available published literature;
- Describe spill risks in terms of probabilities using vehicle accident data; and
- Describe methods (BMPs) for reducing the risk of spills from transport and/or storage of fuels and toxic chemicals.

The contents and methodology to be used in the risk assessment analysis should be discussed with the appropriate Federal and state agencies prior to commencing the work. Guidance documents that can be used in designing the risk assessment include EPA (1992; 1997; 1998).

4.5 Flow Alterations

Water use for mine operations could affect flows in streams that contain important game and T&E fish species. Stream flow and water volumes represent an important aspect of fish habitat. These parameters in combination with other factors such as substrate, depth, and overhanging cover define habitat conditions in a stream.

The type of analysis required to evaluate this issue depends upon the magnitude of flow change and the presence of important species in the affected water bodies. If flow data are lacking, studies may be required to obtain the necessary data. In general, key aspects of the data set (including sources of data, periods of time covered, definitions and descriptions of of data elements) that is used should be fully described. Mining companies (or their representative) should contact hydrologists with the lead Federal agency and appropriate state agency prior to designing flow studies. The simplest approach is to estimate the percent change in flow for the affected streams compared to pre-project or base flow conditions. If possible, the flow data should be summarized on a monthly basis to reflect any seasonal aspects of fish distribution, movements, or life history information. Using the percent flow changes, a qualitative discussion should be made to identify the types of impacts on fish species. For example, a 40 percent reduction in flows during the spring would reduce available wetted habitat for rainbow trout spawning. Relevant published literature should be used to identify the types of impacts that could result from flow changes. This qualitative approach is appropriate for projects that would result in relatively small flow changes or study areas that do not support important game or T&E species.

If flow alteration is a controversial issue for a project, a quantitative method such as the Instream Flow Incremental Methodology (IFIM) should be used to quantify the effects of flow regimes on fish habitat (Bovee, 1982). IFIM utilizes a hydraulic-simulation technique to predict depths, velocities, and substrates within a stream reach at different flows. Results from the simulation are then combined with microhabitat preferences for the fish species of interest to estimate the amount of suitable habitat. Microhabitat preferences are expressed in the form of habitat-suitability curves for the various life stages for each fish species of interest. Studies have been conducted to develop habitat-suitability curves for a variety of fish species (e.g., Bovee, 1978; Raleigh, 1982; McMahon, 1983; Raleigh et al., 1984; Raleigh and Nelson, 1985; Raleigh et al., 1986a; 1986b). These curves can be used in the habitat simulation analysis. If curves are lacking for the species of interest, curves should be developed for the project study area following techniques described by Bovee and Cochnauer (1977).

Implementation of the IFIM requires the use of a system of computer programs called PHABSIM (Physical Habitat Simulation) (Milhous et al., 1981). The PHABSIM programs simulate the physical habitat of fish as a function of stream flow and transform the hydraulic information (depth, velocity, substrate) into a measure of useable habitat. Field surveys are required to collect flow, depth, and substrate data along transects established in the streams affected by flow changes. After the hydraulic simulation is completed, suitability curves for the target species are used as input to a habitat program, which computes the amount of physical habitat that is available for each target species at a range of flows. This analysis should be completed for both pre- and post-project scenarios. The end product is a quantitative estimate of the change in available habitat in square feet for each target species. A significance level should be established through discussions with appropriate agency biologists or IFIM specialists to interpret the results. For example, a 25 percent reduction in spawning habitat for brown trout could represent a significant impact.

4.6 Obstruction to Fish Movement

If mining activities place materials or structures in a drainage on a temporary or permanent basis, the effects on fish movements need to be addressed. The initial step in the analysis is to identify whether important game or T&E fish species exhibit wide range movements in the affected stream segment. The period of movement then needs to be identified for each species. A particularly important period for trout and anadromous salmon species is spawning, when fish migrate to specific areas to lay eggs. Another critical period for salmon is out-migration of juveniles from their nursery streams to the ocean. Blockages or obstructions to these movements need to be identified in the impact assessment. In most instances, project mitigation is required to eliminate potential blockages to fish movement.

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6.0 CONTACTS AND OTHER INFORMATION SOURCES

6.1 Contacts for Fish Information

Alaska Department of Fish and Game, Juneau, AK and appropriate Regional Office

- Commercial Fisheries Management and Development Division
- Division of Subsistence
- Division of Sports Fish

Washington Department of Fish and Wildlife, Olympia, WA and Regional Office

- Fish Management Program

Oregon Department of Fish and Wildlife, Portland, OR and Regional Office

- Fisheries Division

Idaho Department of Fish and Game, Boise, ID and Regional Office

- Fisheries Division

6.2 Contacts for Habitat Information

Alaska Department of Fish and Game, Juneau, AK and appropriate Regional Office

- Habitat and Restoration Division

Washington Department of Fish and Wildlife, Olympia, WA and Regional Office

- Habitat Program

Oregon Department of Fish and Wildlife, Portland, OR and Regional Office

- Habitat Conservation Division

Idaho Department of Fish and Game, Boise, ID and Regional Office

- Fisheries Division

6.3 Contacts for Aquatic Life Water Quality Criteria

Alaska Department of Environmental Conservation, Juneau, AK and appropriate Regional Office

- Division of Environmental Quality

Washington Department of Ecology, Olympia, WA and Regional Office

- Water & Shorelands Division

Oregon Department of Environmental Quality, Portland, OR and Regional Office

- Water Quality Division

Idaho Division of Environmental Quality, Department of Health and Welfare, Boise, ID

- Division of Environmental Quality

APPENDIX H

EROSION AND SEDIMENTATION

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1.0 GOALS AND PURPOSE OF THE APPENDIX

Baseline knowledge of soil erosion and the subsequent transport and deposition of eroded sediment into streams and other water bodies is essential to mine planning and operation. Accurate measurement of natural erosion and erosion from disturbed areas is important to develop control practices. Significant environmental impacts, such as the irretrievable loss of soil, or the degradation of aquatic life from the sedimentation of streams, lakes, wetlands, or marine estuaries, can be minimized or prevented by employing control practices. The measurement and prediction of the amounts of erosion and sedimentation is inherently tied to the measurement and prediction of site hydrologic variables such as precipitation, runoff, and stream flow. An outline and comparison of methods, analytical procedures, and modeling for the characterization and measurement of site hydrology is presented in Appendix A*, Hydrology.*

The goal of this appendix is to outline the rationale and methods to characterize and monitor soil erosion and sedimentation. This appendix also outlines and discusses the design and effectiveness of control practices to minimize impacts to water quality and aquatic resources. This appendix includes reference sections of both cited literature and other relevant references. A reference by Barfield et al. (1981) provides an excellent compendium of both hydrologic methods, as well as methods to measure erosion and to design erosion control structures at mines. The reader is referred to this source for a detailed compendium of methods to measure erosion and design control measures to mitigate erosion and sedimentation at mines.

2.0 TYPES OF EROSION AND SEDIMENT TRANSPORT

Erosion is a natural geologic process that is easily induced and accelerated by man's activities. Mining activities can require the disturbance of large areas of ground and require large-scale earth moving activities which expose large amounts of soil to erosive forces. Operations can be planned, however, to minimize the amount of soil exposed and to reduce or prevent adverse effects on the streams or other water bodies from sedimentation.

Soil erosion can be defined as the detachment, transport, and deposition of soil particles. Detachment is the dislodging of soil particles from aggregates or soil peds from either rain drop impact or from the shearing forces of water or air flowing over the surface. Of these, rain drop impact is the primary force causing detachment, while the flow of water or air over the surface is the primary mechanism for transport. Rain drop splash can also be a cause of soil transport at a micro-scale (Maclean, 1997). Transport by runoff across the surface, therefore, does not generally occur until the rainfall rate exceeds the infiltration capacity of the soil. Once runoff occurs, the quantity and size of soil particles transported is a function of the velocity of the flow (Barfield et al., 1981). Transport capacity decreases with decreasing velocity causing deposition. As velocity decreases, the largst particles and aggregates are deposited first with smaller particles being carried down slope. Deposition, therefore, usually results in the size and density sorting of eroded soil particles, with increasingly smaller sized particles being deposited down slope or down stream. The deposition of detached soil in streams is often referred to as sedimentation.

2.1 Interrill and Rill Erosion

Erosion occurs on disturbed or exposed areas by either interill or rill erosion. Interill erosion is sometimes referred to as sheet erosion. The primary erosive force in interrill areas is rain drop impact, where increasing detachment and erosion rates occur with increasing drop size and drop velocity. Rills are small channels which form on the surface as a result of increasing amounts of runoff. By definition, rills can generally be removed by ordinary tillage equipment or from light grading. Larger channels are considered gullies (see Section 2.2). Detachment occurs in rills by the shear forces of flowing water in the rill. The number of rills and the amount of rill erosion increases as the slope or the amount of surface runoff increases. Interill erosion is the dominant process on shallower slopes. Surface roughness and soil cohesive properties are the primary factors in controlling the degree of interill and rill erosion that occurs from an exposed area. The amount of vegetation cover is the primary factor affecting surface roughness. Vegetation decreases the velocity of runoff across the surface and protects the soil from rain drop impact. Other measures can be employed to increase surface roughness and minimize erosion. These measures are discussed in Section 6.0, Best Management Practices.

2.2 Gully Erosion

Gullies can be either continuous or discontinuous channels that flow in response to runoff events. By definition, gullies differ from rills in that they cannot be removed by ordinary tillage or grading practices. Gullies may be a temporary feature by being erosively active, or in a state of "healing" where annual deposition within the gully is greater than the detachment and transport of eroded materials. Healing is usually caused by changes in land use that reduce the velocity of surface runoff, such as applying reclamation measures to increase surface roughness and promote infiltration. The physical process of erosion in gullies is essentially the same as that described for rills. Erosion in gullies occurs primarily from the shear forces of flowing water. Foster (1985), however, indicated that the amount of erosion from gullies is usually less than the amount that occurs from rills. This is because the amount of erodible particles are quickly removed from the gully channel, where rills are established on an actively eroding surface. Therefore, after initial formation, gullies usually serve as a principal transport mechanism for entrained soils. Gullies can form quickly during extreme events on denuded land and can rapidly expand both up and down slope (Maclean, 1997). In these cases, gullies temporarily serve as large sources of eroded soil and sedimentation to water bodies. Uncontrolled runoff and gully formation can be a large source of transported sediment at mine sites.

2.3 Stream Channel Erosion

Stream channels differ from gullies in that they are permanent channels that transport surface waters. Stream channels can be perennial, ephemeral or intermittent. In stable stream channels, erosion and deposition is controlled by the transport capacity of a given stream flow, which is, in turn, governed by the velocity of flow and by local variations in shear stress in the channel. Detachment and entrainment of soil particles will occur along the stream bed and sides of a channel when the transport capacity is greater than the sediment load being transported.

Deposition occurs when the transport capacity is less than the sediment load being transported. As described in Section 2.0 above, deposition occurs from the largest to the smallest particles as velocity and transport capacity decrease. Potential impacts from mine related activities on channel erosion processes are discussed in Section 3.0.

2.4 Mass Wasting, Landslides and Debris Flows

Landslides and slope failures that create large areas of mass wasting can occur naturally or can be induced as a result of man's activities. The potential for landslides to occur generally increases in steep areas containing unstable soils or where the bedrock has unfavorable dip directions. Landslides and slope failures occur naturally over time, usually during extreme precipitation events when saturation reduces the shear strength of the soils or rock. Slope failures and landslides can also be induced by construction activities that create cuts or slopes where soils or rock are left exposed at steep, unstable angles.

Landslides can expose large areas of soil and debris that are subject to the erosion and sedimentation processes discussed above. Landslides can block stream channels with soil and rock debris, causing ponding and eventual flooding. The eventual failure of an unstable blockage can result in flood flows that entrain large quantities of soil and rock debris. Scouring of the existing channel below the landslide also results from the high flood flows. Additional debris loading can occur from mass wasting along the side slopes, adding more sediment and debris loads to the flood flow.

Effects from avalanches can be similar to those of landslides. Avalanches can remove vegetation, increasing the erosion potential of exposed soils and rock. Debris and snow from an avalanche can temporarily block stream channels, creating floods, channel scour, and mass wasting along side slopes.

Landslides, slope failures, and avalanches can create large impacts to aquatic resources. Increased erosion and resulting sedimentation within a watershed can impact spawning gravels, egg survival and emergence of frye, as well as degrade benthic food sources. Flooding can create high velocity flows, scour stream banks and destroy gravel substrates either by scour or by burial beneath sediment. Cover created by large woody debris and stable banks also can be destroyed, which impacts rearing and resting habitat for fishes.

3.0 MINING-RELATED SOURCES OF EROSION AND SEDIMENTATION

Increased potentials for erosion and sedimentation at mines are related to mine construction and facility location. Tailings dams, waste rock and spent ore storage piles, leach facilities, or other earthen structures are all potential sources of sedimentation to streams. Road construction, logging, and clearing of areas for buildings, mills, and process facilities can expose soils and increase the amount of surface runoff that reaches streams and other surface water bodies. These activities increase the potential for rill and interill erosion and can increase peak stream flows, increasing the potential for channel erosion. 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 can increase flow velocities in a stream reach, potentially affecting fish passage to upstream reaches during moderate to high stream flows. Poorly designed stream diversions can also create channelization effects and alter flow velocities in a stream. Increased erosion upstream and the resulting sedimentation downstream can impact spawning gravels, egg survival and emergence of frye, as well as degrade benthic food sources. More detail on these potential impacts is given in *Appendix A, Hydrology*. Tailings dams and large embankments can also fail, creating impacts similar to those discussed in Section 2.4 above for landslides and debris flows.

4.0 METHODS TO MEASURE AND PREDICT EROSION AND SEDIMENTATION

Most methods to measure, predict and control erosion and sedimentation have been developed by the agriculture industry. These methods concentrate on predicting gross erosion and sediment yield from disturbed areas or areas under tillage. This is advantageous for evaluating and predicting impacts that result from mining because tillage agriculture and mining have several similarities (Barfield et al., 1981). Both industries can disturb and expose large areas of ground and both must apply practices to limit or eliminate soil-loss and sedimentation impact. It should be noted, however, that many mine sites are often located on steeper slopes and in more diverse topography than agricultural lands. Methods developed for the measurement of erosion and sedimentation from agricultural lands are generally not adapted or tested for use on steep slopes. For this reason, appropriate conservatism should be applied when choosing analytical methods and in evaluating predictive results.

Most methods to measure or predict erosion and sedimentation are designed to predict either: (1) "gross erosion", (2) "sediment yield", (3) a "sediment delivery ratio", or (4) sediment loading in streams. Gross erosion is defined as the total estimated amount of sediment that is produced from rill and interill erosion in an area (Barfield et al., 1981). The sediment yield from an area or watershed is the gross erosion, plus the additional erosion that is contributed from gullies and stream channels, minus the amount of deposition. The amount of deposition that occurs between the watershed and a down-gradient point of reference is quantified using a sediment delivery ratio. A sediment delivery ratio can be quantitatively defined as the ratio of sediment yield to gross erosion:

$$D = \frac{Y}{A}$$

where D is the sediment delivery ratio, Y is the sediment yield, and A is the gross erosion (Barfield et al., 1981).

Few methods have been developed to specifically predict gross erosion or sediment yield from undisturbed landscapes and watersheds. Methods for field measurement, as well as methods to analytically predict or model sediment yield are commonly employed on both disturbed and on undisturbed areas. For this reason, field and analytical methods that can be used to measure gross erosion or sediment yield on disturbed and undisturbed areas are outlined together in this appendix. This section summarizes methods to measure or predict gross erosion, methods to measure or predict sediment yield, including modeling, and methods to measure sediment loads and deposition in streams.

4.1 Gross Erosion

4.1.1 Field Measurements

Few field methods are usually employed to measure the amount of gross erosion which actually occurs from a small plot or watershed. A method commonly used, however, is to use erosion pins. Using this method, small pins or stakes are put into the ground to a depth that will prevent disturbance. The elevation of the top of the pin is surveyed and referenced to a permanent elevation. The difference between the top of the pin and the ground elevation below the pin is periodically surveyed to determine minute changes in elevation. The difference in measured elevation between sampling events reflects the amount of rill and interill erosion that has occurred at that point. Gross erosion that occurs from a sample plot can be estimated using measurements from several pins. Repeated measurements of water and sediment collected in permanently installed hill slope troughs can also be used to detect soil movement and storage over time.

Tracers have also been used to detect and measure actual soil movement on small plots. Kachanoski et al. (1992) describe the use of Cesium-137 (^{137}Cs) to detect soil movement and soil loss in a complex landscape and to monitor the down-slope movement of soils that occur from tillage. ^{137}Cs occurs in soils from atmospheric deposition (fall out) that occurred from above-ground nuclear testing conducted in the 1950s and 1960s. ^{137}Cs tightly binds to soils, is essentially insoluble and does not leach, and is not subject to significant uptake by plants. Monitoring gains or losses of ^{137}Cs at permanent points can be used to detect movement of soil. Other inert tracers can be used similarly.

The above field methods are commonly employed for research purposes where actual land treatment applications or practices are compared. They are often employed to aid model validation or to help calibrate modeled soil losses from a specific area. While these methods can be used to detect soil movement and estimate gross erosion on small plots, they may not be applicable at mine sites because they are not suitable for large areas, and they do not predict sediment yield or sedimentation of streams or other water bodies.

4.1.2 The Universal Soil Loss Equation.

The most commonly used procedure to predict gross erosion is the Universal Soil Loss Equation (USLE), in its original form. The USLE was proposed by Wischmeier and Smith (1965) based on a relationship known as the Musgrave equation (Musgrave, 1947). The USLE predicts gross erosion produced by rill and interrill erosion from a field sized area. Several authors have proposed modifications to the USLE to account for deposition so the model can also be used to predict sediment yield. These modifications will be discussed in Section 4.2 with methods to measure and predict sediment yield. The USLE predicts gross erosion by the following:

$$A = R * K * LS * C * P$$

where, A is computed soil loss per unit of area (tons/acre), R is a rainfall factor which incorporates rainfall energy and runoff; K is soil erodibility; LS is a dimensionless length slope factor to account for variations in length and degree of slope; C is a cover factor to account for the effects of vegetation in reducing erosion; and P is a conservation practice factor. A detailed discussion of how to calculate, incorporate, and use each of these factors is provided by Barfield et al. (1981) and Goldman et al. (1986). The USLE can be used to predict gross erosion from an area for average annual, average monthly, average storm, and annual return period, or for a single storm return period, depending on how R is calculated.

Use of the USLE, without modification, at mine sites has several disadvantages. The calculation does not account for erosion from gullies, or stream channels, or take into account deposition. It was primarily designed to predict soil-loss from small fields and should not be used to predict sediment levels in rivers at the drainage basin level. For most applications at mine sites, the unmodified USLE described above would not provide useful estimates because most impact analyses require knowledge of deposition and actual sediment yield from watersheds or disturbed areas, and calculations of sediment transport in gullies and channels. Consequently, this method is not recommended, except for calculations of potential soil-loss from a small disturbed area to aid in the application of best management practices (BMPs) and the design of other area-specific controls.

4.2 Sediment Yield

Most methods and mathematical models to measure or predict erosion are designed to predict sediment yield from an area or watershed. Many of the methods and models use the USLE, described in Section 4.1.2, however, they incorporate techniques to evaluate and route erosion from gullies and channels and estimate deposition, either on the land surface or in streams. The following discussion provides a brief review of commonly used methods to measure sediment yield and presents a review of mathematical models which have been used to predict sediment yield on an areal or watershed basis.

4.2.1 Modified and Revised Universal Soil Loss Equation

There have been several proposed modifications to the USLE that allow for more accurate predictions of parameters and erosion. For purposes of baseline characterization and prediction of sedimentation at mine sites, two modifications are applicable. The Modified Universal Soil Loss Equation (MUSLE) and the Revised Universal Soil Loss Equation (RUSLE). In the standard USLE model, the rainfall energy and runoff factor (R) and the length-slope factor (LS) do not account for deposition or assume that it does not occur until the end of the length of the ground segment being analyzed. Williams (1975) proposed that the R factor be replaced with several other terms to allow the equation to better account for deposition. This modification (MUSLE) can then be used to estimate the sediment yield from an area or from watersheds. The MUSLE equation is calculated by:

$$Y = 95(Q * q_{pi})^{0.56} * K * LS * P$$

where Y is the single storm sediment yield, Q is the runoff volume, q_{pi} is the peak discharge, and K, LS, and P are the same terms as for the USLE except that they represent weighted averages for these parameters, calculated from different areas of the watershed. The LS factor is also calculated differently than in the USLE, depending on the slope being analyzed (Williams, 1975). The RUSLE described by McCool et al. (1987) provides a further revision of the LS factor and modifies the model to be more applicable on steep slopes, greater than 10 percent.

The application of the MUSLE and the RUSLE to large, heterogeneous watersheds, such as those that occur at mine sites, requires that sediment yield calculations be analyzed for each subwatershed (see Williams (1975) and Barfield et al. (1981) for detailed discussions). The analysis requires that large, heterogeneous watersheds be divided into several subwatersheds with relatively homogeneous hydrologic characteristics and soil types. Consequently, particle size distribution (i.e., texture analysis) must be measured for the soils occurring in each subwatershed. The analysis also requires the calculation of a weighted runoff energy term ($Q* q_{pi}$) that is computed as a weighted average of the subwatersheds. From particle size distribution data, the median (D_{50}) particle diameter is used to calculate the sediment yield that would exit each subwatershed. The weighed runoff energy term is used to route sediments to the mouth of the large watershed or at some point of analysis.

4.3 Suspended Load and Sedimentation

The evaluation of water quality and impacts to aquatic resources is a primary concern at mine sites. Without mitigation and control measures, mining can disturb large areas of ground, causing accelerated erosion and sedimentation and potentially causing adverse impacts to aquatic resources. The measurement of sediment load in streams is a primary tool to evaluate the effectiveness of erosion control measures and potential impacts to water quality and aquatic life. Typically, it is a required component for monitoring compliance with NPDES permits. As discussed in Section 2.3, the amount of sediment load being carried at any given time in a stream depends on the transport capacity, which is primarily related to the stream flow velocity. As transport capacity increases, the amount and particle sizes of suspended sediment increases. Transport capacity decreases with decreasing flow velocity, causing deposition and sorting of materials. The transport and deposition of sediments within a stream, therefore, dependent on storm frequency and the velocity of peak flows. In many cases, high flow events are periodically required 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. Geomorphologically, a stable channel is one that over time, transport sediments with no net increase in deposition and without channel erosion.

The Equal Transient Rate (ETR) and Equal Width Increment (EWI) methods are commonly used field methods to sample suspended sediments during stream flow (USGS, 1960). Using these methods, several water samples are taken along cross-sectional transects (i.e., perpendicular to flow direction). Samples along the cross section are taken by lowering a sample bottle through the stream at a rate dependent on the flow velocity. The total mass of suspended sediment and its particle size distribution are measured for each sample. Automatic sediment samplers are also available that collect stream samples at scheduled times that are determined by the user. These data are used to develop a sediment rating curve or a sedigraph that defines the relationship between stream flow discharge (Q_w) and the mass of suspended sediment at a given sampling station. After a sediment rating curve has been developed, stream flow measurements can be used to estimate sediment discharge at a given station. Sediment rating curves and sedigraphs can be extremely useful for monitoring the effectiveness of control practices applied to minimize erosion and sediment yield from mine sites. The development of sediment rating curves, however, requires sampling across a large range of flows and at different seasons of the year. These relationships can be continuously recalibrated and refined as the size of the sampled data base increases.

Net increases in sediment deposition in streams and other water bodies are measured using substrate core samples at various times of the year. Core samples, taken using a variety of substrate and coring equipment, are analyzed for net changes in particle size distribution over time. It is important for water quality analyses at mines, that sampling programs to monitor sedimentation in stream beds incorporate comparisons with stream flow events. Regular sampling throughout the year is required to determine if net deposition of sediments is occurring in a stream over time. Sediments are naturally deposited during seasonal low flow periods and are naturally entrained and transported during high flow periods. These processes make impact analysis by sedimentation extremely difficult to monitor.

In addition to the above analyses, characterization of pre-mining stream morphology from drainages potentially affected by a mining operation are often necessary to determine potential impacts caused by changes in flow regime and from sedimentation. These analyses may include photo documentation of streams and riparian vegetation, determining geomorphological classifications of streams using the Rosgen (1994) method, and measurements to define channel cross sections, width to depth ratios, longitudinal profiles, sinuosity, and pool/riffle ratios. These data would support studies conducted to characterize site hydrology and aquatic resources.

4.4 Software and Watershed Models for Prediction of Sediment Yield

Characterization of mine sites requires the accurate calculation of sediment yield on a large watershed basis. To characterize baseline conditions at mine sites and to predict potential adverse impacts from sedimentation requires adequate spatial and areal characterization of gross erosion and sediment yield. Several analytical software programs are available to predict sediment yield and sediment transport in large watersheds. Some of these can be incorporated into GIS applications to provide spatial evaluation of erosion potential and sediment yield for one or more watersheds.

The MUSLE and RUSLE, applications described in Section 4.2.1 could be used to characterize baseline conditions of sediment yield and to evaluate potential changes in expected sediment yield that would result from development of mine facilities. Most software, watershed models, and GIS applications that are commonly used to predict erosion and sediment yield apply either the USLE, MUSLE, or RUSLE algorithms. A brief description of analytical software used for watershed analysis and for the evaluation of sediment yield is provided in Section 4.4.2. Particular emphasis is given to those methods that are commonly used in mine settings.

The following questions, modified from Maclean (1997), can be used to determine the type and level of modeling effort needed and software required to evaluate erosion and sedimentation at mine sites:

- What are the basic assumptions and method(s) applied in the model?
- Is the output suitable to make the evaluations and analyses required and is the accuracy sufficient for characterization, impact analysis, and detection monitoring?
- What are the temporal and spatial scales of the required analysis?
- What are the input data requirements of the software or model?
- What data are needed for model calibration and verification?
- Are the required data available and are they at the correct scale?
- What input data are the most important (i.e., have the most sensitivity)?
- Can surrogates be used for missing data without compromising an accurate analysis?
- If the model uses empirical (i.e., statistical) relationships, under what conditions were those formed?

Answering these questions will help the mining hydrologist to select appropriate techniques and models and to design adequate sampling programs to obtain the required input data. As previously discussed, to adequately evaluate and monitor impacts at mine sites typically require temporal and spatial analysis of a large watershed. This necessitates the design of a sampling programs that will provide adequate data on a watershed basis. Monitoring programs to evaluate erosion and sedimentation should be coordinated with baseline hydrological and water quality characterization studies. The reader is referred to Appendix A, *Hydrology* and Appendix B, *Receiving Waters* for related discussions.

4.4.1 Development of a Conceptual Site Model.

A conceptual site model can be used to expedite an evaluation of the questions and parameters discussed in Section 4.3. A conceptual site model is a depiction, descriptive, or pictorial, of subwatersheds, soil-types, slopes, stream channels and any erosional features. Such a model should be developed in conjunction with studies to characterize baseline soil and vegetation types and surface water bodies. The purpose of building or developing a conceptual model of a site is to show important interrelationships that need to be evaluated, studied, or modeled. Programs to analyze impacts and monitor site conditions can then be developed. The conceptual model should be complex enough to adequately depict system behavior and meet study objectives, but sufficiently simple to allow timely and meaningful development of field sampling programs and predictive models.

4.4.2 Analytical Software and Models.

AGNPS - Agricultural Non-Point Source Pollution Model

AGNPS is a distributed river basin model which combines elements of several other models to predict erosion, runoff, and sediment and chemical transport. The model incorporates the USLE to predict gross erosion from defined grids within a the river basin. Runoff and overland flow is calculated using Natural Resource Conservation Service (NRCS [Soil Conservation Service]) procedures (see Appendix A, *Hydrology).* Transport and deposition relationships are used to determine sediment yields and route sediment through the modeled basin. The program is designed for large basins and requires very detailed site characterization data for input. The level of accuracy necessary for the prediction of sediment yield and transport at mine sites would require detailed field sampling to provide input data. The model has the inherent problems associated with the USLE, described in Section 4.1.2, and problems associated with the SCS hydrologic methods to predict runoff (See Appendix A , *Hydrology*). The assumptions of the USLE and the SCS methods should be completely understood when using this model for predictive purposes. A review of this model is provided by Jakubauskas (1992).

ANSWRS - Areal Non-Point Source Watershed Response Simulation Model

ANSWRS is a distributed river basin model that is similar to the AGNPS model. The model uses the USLE to predict the upland component for gross erosion and a set of steady state equations to simulate sediment transport through the basin. A review of this model is provided by Jakubauskas (1992). Both the ANSWRS and AGNPS models are designed to evaluate erosion and plan control strategies on areas with intense cultivation.

WEPP - Water Erosion Prediction Project Hydrology Model

WEPP is designed to use soil physical properties and meteorological and vegetation data to simulate surface runoff, soil evaporation, plant transpiration, unsaturated flow, and surface and subsurface drainage. The model uses the Green and Ampt infiltration equation to estimate the rate and volume of storm excess precipitation. Excess precipitation is routed downslope to estimate the overland flow hydrograph using the kinematic wave method. In WEPP, surface runoff is used to calculate rill erosion and runoff sediment transport capacity. The infiltration equation is linked with the evapotranspiration, drainage, and percolation components to maintain a continuous daily water balance for a watershed.

GSTARS - Generalized Stream Tube Model for Alluvial River Simulation

GSTARS is a generalized semi-two dimensional water and sediment routing model. The model is capable of computing alluvial scour/deposition through subcritical, supercritical, and a combination of both flow conditions involving hydraulic jumps. The program can be used as a fixed-bed or a moveable bed model to route water and sediment through alluvial channels. A one-dimensional model can be created with the selection of a single stream tube. By selection of multiple stream tubes, changes in cross section geometries in the lateral direction can be simulated.

HEC-6 - Scour and Deposition Model

HEC-6 is designed to evaluate long-term river and reservoir sedimentation behavior. The program simulates the transportation of sediment in a stream and can determine both the volume and location of sediment deposits. It can analyze in-stream dredging operations, shallow reservoirs, and scour and deposition effects in streams and rivers, in addition to the fall and rise of movable bed material during several flow cycles. The program is primarily designed to analyze sediment transport and geomorphologic effects in rivers and streams. It is not intended for use in analyzing gross erosion or sediment yield from watersheds.

Sedimot-II - Hydrology and Sedimentology Model [1]

Sedimot-II is designed to generate and route hydrographs and sediment loads through multiple subareas, reaches and reservoirs. It can also be used to evaluate the effectiveness of sediment detention ponds and grass filters. The program can predict peak sediment concentration from a flow event, trap efficiency of a sediment retention basin, sediment load discharge, peak effluent sediment concentration, and peak effluent settleable concentration.

SEDCAD+ [2]

SEDCAD+ provides computer-aided design (CAD) capabilities for the design and evaluation of storm water, erosion, and sediment control management practices. The software combines hydrological and sediment yield modeling with CAD capabilities to design and evaluate the performance of sediment detention basins, channels, grass filters, porous rock check dams, culverts and plunge pools. In addition, the program provides determinations of land volumes, areas, and cut/fill volumes. The program uses the MUSLE and RUSLE algorithms to calculate sediment yield from watersheds. The software has used as a part of the Office of Surface Mining's Technical Information Processing System (TIPS). TIPS is a series of integrated programs to provide automated software to support a full range of engineering, hydrological, and scientific applications required for permitting.

[1] Haestead Methods, Waterbury, Connecticut.

[2] Civil Software Design, Ames, Iowa

PONDPACK [1]

PONDPACK is designed to provide CAD capabilities for the design and evaluation of storm water detention ponds. The program provides analysis of detention storage requirements, computes a volume rating table for pond configuration, routes hydrographs for different return frequencies, and provides routing data for inflow and outflow hydrographs for comparing alternative pond designs.

4.4.3 Application of Remote Sensing and Geographical Information Systems).

Recent research has evaluated the use of Geographical Information Systems (GIS) and data obtained from satellites in predictions of large-scale erosion potential. Example studies are provided by MacLean (1997) and DeRoo et al. (1989); other references are provided at the end of this appendix. In general, GIS systems can be used to provide spatial data for soil-types, vegetation cover types, aspect, slope, slope-lengths, and other variables that are required inputs for large-scale watershed models. These data may bes incorporated or estimated using remotely sensed data obtained from SPOT or LANDSAT imagery. Modeled data can also be presented and analyzed using a GIS system as demonstrated by the studies referenced above, which incorporated spatial data into large-scale, river basin models that evaluated erosion potential and prediction using the USLE. In general, these studies showed that a GIS system could be used to manage, provide and evaluate large amounts of spatial data in conjunction with erosion modeling. These studies, however, indicated that model accuracy and validation were deficient because specific site data were not available or had to be assumed. DeRoo et al. (1989) suggested that model accuracy is extremely sensitive to the "lack of detailed" input data such as infiltration capacities, antecedent soil moisture, and rainfall intensity information for specific sites. MacLean (1997) indicated that confidence in the results generated using GIS was low.

These studies indicate that large, spatially integrated systems could be used at mine sites for baseline characterization and analysis of impacts. However, mining hydrologists and other scientists must be aware that specific information regarding soil-types, soil particle size analysis, vegetation types, slopes, slope-lengths, and sub-basin hydrology are required to produce accurate erosion and sedimentation analyses. Caution should be used when integrating spatial data bases with predictive modeling in cases where site-specific data are inadequate.

5.0 REPRESENTATIVENESS OF DATA

The representativeness of data and statistical concepts related to sampling and the development of data quality objectives are discussed in detail in *Appendix A, Hydrology.* In general, the principles associated with sample adequacy, statistical techniques and the development of Quality Assurance programs for erosion and sedimentation are similar to those associated with hydrological measurements. A detailed discussion of these concepts is not repeated herein; the reader is referred to Appendix A for a discussion of statistical techniques and important parameters to consider in developing adequate sampling designs. Several concepts related to the measurement of erosion and sedimentation should be considered when developing Data Quality Objectives and sampling programs. The following points provide specific concepts which should be applied or noted in developing programs for monitoring erosion and sedimentation at mine sites:

- The processes of gross erosion, sediment yield, and sediment deposition in streams depends on the frequency and probability of hydrologic events, both seasonally and on an event basis. The amounts of sediment erosion, transport, and deposition vary seasonally and in response to individual precipitation-runoff events of different frequencies. For this reason characterization and monitoring programs at mine sites must be designed to evaluate erosion and sediment yields with respect to the frequency of storm events, as well as account for both seasonal and annual climatic variations. Similarly, characterization and monitoring programs to evaluate suspended loads in streams must take into account stream discharge measurements. Impact analysis can only be conducted if adequate relationships are developed between precipitation and runoff, stream flow, and sediment load.

- The effectiveness and accuracy with which mathematical models and empirical equations predict gross erosion, sediment yield, and sediment deposition depends on the quality of site-specific data collected to characterize soils, vegetation types, slopes, slope-lengths, and other watershed or subwatershed parameters. Of specific importance is that the samples collected to determine the particle size distributions (i.e., texture) of each soil type provide a statistically adequate population. Adequate sampling to characterize vegetative cover and other surface roughness factors controlling soil detachment and water flow velocities is also essential.

- The use of spatial data and GIS analyses should be encouraged to evaluate and predict potential impacts on a watershed basis. These analyses can be used to develop maps and provide spatial analyses of areas susceptible to erosion. As discussed in Section 4.4.3, however, the accurate prediction of erosion and sedimentation on a large-scale depends on having adequately characterized site-specific data.

6.0 METHODS TO MITIGATE EROSION AND SEDIMENTATION

Best Management Practices (BMPs) are schedules of activities, prohibitions of practices, maintenance procedures, and other management practices that effectively and economically control problems without disturbing the quality of the environment. Erosion and sedimentation may be effectively controlled by employing a system of BMPs that target each stage of the erosion process. Fundamentally, the approach involves minimizing the potential sources of sediment from the outset. In order to accomplish this, BMPs are designed to minimize the extent and duration of land disturbance and to protect soil surfaces once they are exposed. BMPs are also designed to control the amount and velocity of runoff and its ability to carry sediment by diverting incoming flows and impeding internally generated flows. BMPs also include the use of sediment-capturing devices to retain sediment on the project site. The types of BMPs discussed in this appendix include surface stabilization procedures, runoff control procedures and conveyance measures, outlet protection procedures, sediment traps and barriers, and stream protection procedures. Table H-1 provides an outline, by categorical type, that are used at mine sites. Sections 6.1.1 through 6.1.5 provide brief descriptions of these BMPs. Many of the BMPs are complementary and are used together as part of an erosion control program.

An important BMP used at mine sites to capture, manage and control sedimentation is the use of *Sediment Detention Basins.* Section 6.1.6 describes detention basins and discusses important design parameters for these basins at mine sites.

Table H-1. Mining BMPs for Control of Erosion and Sedimentation

Category	***Best Management Practice***
Surface Stabilization	Dust control Mulching Riprap Sodding Surface roughening Temporary gravel construction access Temporary and permanent seeding Topsoiling
Runoff Control and Conveyance Measures	Grass-lined channel Hardened channel Paved flume (chute) Runoff diversion Temporary slope drain
Outlet Protection	Level spreader Outlet stabilization structure
Sediment Traps and Barriers	Brush barrier Check dam Grade stabilization structure Sediment basin/rock dam Sediment trap Temporary block and gravel drop inlet protection Temporary fabric drop inlet protection Temporary sod drop inlet protection Vegetated filter strip
Stream Protection	Check dam Grade stabilization structure Streambank stabilization Temporary stream crossing
Source: NCSU Water Quality Group (1998).	

6.1 Best Management Practices (BMPs) Categories

The following discussion of Best Management Practices is adapted from NCSU Water Quality Group (1998).

6.1.1 Surface Stabilization Measures

Dust Control is the manipulation of construction areas through specific measures to prevent soil loss as dust. Effective control measures include watering, mulching, spriging, or applying geotextile materials. These measures are designed to minimize the contamination of runoff water from air born dust. These practices are especially effective in regions with a dry climate or in drier seasons.

Mulching is the protection of vegetative surfaces with a blanket of plant residue or synthetic material applied to the soil surface to minimize raindrop impact energy, increase surface roughness and reduce the velocity of runoff. These practices are designed to foster vegetative establishment, reduce evaporation, insulate the soil, and suppress weed growth. As well as providing immediate protection from environmental hazards, mulch is used as a matrix for spreading plant seeds.

Riprap is a retention wall of graded stone underlain with a filter blanket of gravel, sand and gravel, or synthetic material designed to protect and stabilize areas which are prone to erosion, seepage, or poor soil structure. Riprap is used in areas where vegetation cannot be established to sufficiently reduce or prevent erosion. This includes channel slopes and bottoms, storm water structure inlets and outlets, slope drains, streambanks and shorelines.

Sodding is the continuous covering of exposed areas with rolls of grass to provide permanent stabilization. This procedure is especially useful in areas with a steep grade, where seeding is not conducive. As with mulching, sodding fosters vegetation growth, minimizes raindrop impact energy, increases surface roughness and reduces the velocity of runoff.

Temporary Gravel Construction Access is a graveled area or pad on which vehicles can drop their mud and sediment. By providing such an area, erosion from surface runoff, transport onto public roads, and dust accumulation may be avoided. This BMP is designed to capture potentially exposed sediment sources so they may be further managed and controlled.

Temporary and Permanent Seeding involves planting areas with rapid-growing annual grasses, small grains, or legumes to provide stability to disturbed areas. Areas are temporarily seeded if the soils are not to be brought to final grade for more than approximately one month. Permanent seeding is established on areas which will be covered with vegetative growth for more than two years. This BMP establishes a relatively quick growing vegetative cover.

Topsoiling is the application of loose, rich, biologically active soil to areas with mildly graded slopes. Often, facilities will stockpile topsoil for future site use. To ensure that runoff contamination does not occur, sediment barriers and temporary seeding should be used.

6.1.2 Runoff Control and Conveyance Measures.

A *Grass-Lined Channel* is a dry conduit vegetated with grass. Grass channels are used to conduct storm water runoff. In order for this system to function properly, the grass must be w-established and rooted before flows are introduced. Lining of the channels is required if design flows are to exceed 2 cubic feet per second (cfs). A grass channel increases shear stress within the channel, reduces flow velocities and promotes the deposition of sediments in storm water. The channel itself is also protected from erosion of the bed and sides.

Hardened Channels are conduits or ditches lined with structural materials such as riprap or paving. These channels are designed for the conveyance, transfer, and safe disposal of excess storm water. These channels are often used in places with steeply graded slopes, prolonged flow, potential for traffic damage, erodible soils, or design velocity exceeding 5 cfs.

Paved Flumes are concrete-lined conduits that are set into the ground. Flumes are used to convey water down a relatively steep slope without causing erosion. This system should have an additional energy dissipation feature to reduce erosion or scouring at the outlet. Flumes also should be designed with an inlet bypass that routes extreme flows away from the flume.

Runoff Diversions are temporary or permanent structures which channel, divert or capture runoff and transport it to areas where it can be used or released without erosion or flood damage. The types of structures used for this purpose include graded surfaces to redirect sheet flow, dikes or berms that force surface runoff around a protected area, and storm water conveyances which intercept, collect, and redirect runoff. Temporary diversion may be constructed by placing dikes of spoil materials or gravel on the down-gradient end of an excavated channel or swale. Permanent diversions, which are built to divide specific drainage areas when a larger runoff flows are expected, are sized to capture and carry a specific magnitude of design storm.

Temporary Slope Drains are temporary structures constructed of flexible tubing or conduit which convey runoff from the top to the bottom of a cut or fill slope. In conjunction with diversions, these drains are used to convey concentrated runoff away from a cut or fill slope until more permanent measures, such as stabilization with vegetation, can be established.

6.1.3 Outlet Protection.

Level Spreaders are a type of outlet designed to convert concentrated runoff to sheet flow and disperse it uniformly across a slope. The landscape of the receiving area must be uniformly sloped, the outlet lip leveled, and the land unsusceptible to erosion. To avoid the formation of a gully, hardened structures, stiff grass hedges, or erosion-resistant matting should be incorporated into the design. This type of outlet is often used for runoff diversions.

Outlet Stabilization Structures are outlets that reduce outlet flow velocity and dissipate flow energy. These types of structures are used at the outlet of a channel or conduit where the discharge velocity exceeds that of the receiving area. The most common designs are riprap-lined aprons, riprap stilling basins, or plunge pools.

6.1.4 Sediment Traps and Barriers

Brush Barriers are temporary sediment barriers that are constructed to form a berm across or at the toe of a slope susceptible to interill and rill erosion. They may consist of limbs, weeds, vines, root mats, rock, or other cleared materials.

Check Dams are temporary, emergency, or permanent structures constructed across drainageways other than live streams where they are used to restrict flow velocity and reduce channel erosion. In their permanent application, these dams gradually accumulate sediment until they are completely filled. At that point, a level surface or delta is formed into a non-eroding gradient over which the water cascades to a dam through a spillway into a hardened apron. Other alternatives for protecting channel bottoms should be evaluated before selecting the check dam on a temporary basis. Dams may either be porous or nonporous. Porous dams will decrease the head of flow over spillways by releasing part of the flow through the actual structure.

Grade Stabilization Structures are designed to reduce channel grade in natural or constructed channels to prevent erosion of a channel caused by increased slope or high flow velocities. This type of structure includes vertical-drop structures, concrete or riprap chutes, gabions, or pipe-drop structures. In areas where there are large water flows, concrete chutes or vertical-drop weirs constructed of reinforced concrete or sheet piling with concrete aprons are recommended. For areas with small flows, prefabricated metal-drop spillways or pipe overfall structures should be used.

*Sediment Detention Basin*s can be either permanent pool or self dewatering (i.e., complete flow through) types. They are primarily designed to allow ponding of runoff or flows so eroded soils and sediments can settle out and be captured before they can enter streams or other water bodies. The design and use of these basins is perhaps the most important BMP applied to control erosion at mine sites. Section 6.2 provides a detailed discussion of important design and management considerations for Sediment Detention Basins.

Sediment Fence (Silt Fence)/Straw Bale Barriers are temporary measures used to control sediment loss by reducing the velocity of sheet flows. They consist of filter fabric buried at the bottom, stretched, and supported by posts, or straw bales staked into the ground. Overflow outlets and sufficient storage area need to be provided to control temporary ponding.

Sediment Traps are small, temporary ponding basins formed by an embankment or excavation. These are less permanent structures than sediment detention basins. Outlets of diversion channels, slope drains, or other runoff conveyances that discharge sediment-laden water often use this system. Sediment traps should be designed to minimize the potential for short citcuiting, include features such as embankment protection and non-erosive emergency bypass areas, and provide for periodic maintenance.

Temporary Block and Gravel Inlet Protections are control barriers made of concrete block and gravel around a storm drain inlet. These structures filter sediment from storm water entering the inlet before soils have stabilized, while allowing the use of the inlet for storm water conveyance.

Temporary Excavated Drop Inlet Protections are temporary excavated areas around a storm drain inlet or curb designed to trap sediment. By trapping sediment before its entry into the inlet, the permanent inlet may be used before soils in the area are stabilized. This system requires frequent maintenance and can be used in combination with other temporary measures.

Temporary Fabric Drop Inlet Protections are fabric drapes placed around a drop inlet, on a temporary basis, during construction activities to protect storm drains. This practice can be used in combination with other temporary inlet protection devices.

Temporary Sod Drop Inlet Protection is a grass sod sediment filter area around a storm drain drop inlet. This is used when soils in the area are stabilized, and is suitable for the lawns of large buildings.

Vegetated Filter Strips (VFS) are natural or planted low-gradient vegetated areas consisting of relatively flat slopes which filter solids from overland sheet flow. Dense-culmed, herbaceous, erosion-resistant plant species are appropriate for vegetating these strips. The effectiveness VFSs is increased, if channelized flows are absent; however, the main factors influencing removal efficiency are vegetation type and condition, soil infiltration rate, and flow depth and travel time. Level spreaders are often used to promote even distribution of runoff across the VFS.

6.1.5 Stream Protection

Check dams, grade stabilization structures, and streambank stabilization techniques are also BMPs used for stream protection. An additional stream protection BMP is a *Temporary Stream Crossing.* These crossings may be in the form of a bridge, ford, or temporary structure installed across a stream or watercourse for short-term use by construction vehicles or heavy equipment. Wherever possible, bridges should be constructed in lieu of other types of stream crossings, because they cause the least damage to streambeds, banks, and surrounding floodplains, provide the least obstruction to flow, and have the lowest potential to increase erosion . Culvert crossings are the most common and are the most destructive form of crossings. Culverts generally cause significant impacts to a stream bed and increase the potential for channel scour. Low-span bottomless arched conduits offer the simplicity of a culvert crossing and minimize impacts to the stream bed. These crossings can be placed over the top of stream channels without disturbing the streambed at the crossing. Fords are cuts in the banks with filter cloth held in place by stones. They are used in steep areas prone to flash flooding, but should be used only where crossings are infrequent and banks are low. Another technique which can be applied is to size a main culvert to handle normal bankfull flows. Additional culverts are then placed along side of the main culvert at a higher elevational base. The additional culverts route flood flows that exceed the capacity of the main culvert and would normally move out across a floodplain. The advantage to this design is that overly sized culverts can often cause channelization, increases in flow velocity and scouring of the channel down stream. A multi-culvert design reduces these effects by sizing the main culvert to handle normal stream flows. All stream crossings should be located on a permanent basis to prevent overtopping and minimize erosion potential.

6.1.6 Sediment Detention Basins

Sediment detention basins are commonly used to prevent or control sediment deposition in streams and water bodies (Barfield et al., 1981). Detention basins are designed to capture runoff or conveyed storm water and reduce water velocity to allow sediments to settle out. Storm flows eventually pass through an outflow structure leaving the sediment (i.e., settleable solids) in the basin.

Detention basins must be designed to account for several storage volumes including: (1) a sediment storage volume (V_s); (2) a storage volume for detention storage (V_d); (3) and a final flood storage volume (V_f). The design storage for V_s depends on the loading and volume of sediment that would be expected for a specific design period. The design period can be the life of the mine, or a shorter period in which accumulated sediments are periodically dredged or removed from the detention basin. Estimates for V_s are made using the methods or models to predict expected sediment yields entering the basin (see Section 4.2). In general, the USLE or the MUSLE are used to calculate sediment loading to a detention basin, either on an annual or a design storm basis. V_d is the storage volume that is required to detain and hold the volume of runoff from a specified design storm long enough to allow the sediment to settle out. A variety of methods are used to calculate storm runoff volume (V_f) (see Appendix A, *Hydrology)*. V_f is the final flood storage volume or free board which is added as contingency to prevent overtopping and dam failure during extreme events that exceed the design capacity.

Sediment detention basins are designed to maximize trap efficiency in order to minimize the release of suspended loads downstream at mine sites. Trap efficiency is defined as the ratio between the mass of sediment flowing into a basin and the mass of sediment flowing out of a basin. Barfield et al. (1981) outline several parameters that affect the performance and trap efficiency of a basin:

- Particle size distribution of sediments
- Detention storage time
- Reservoir shape, amount of dead storage, and turbulence
- Water chemistry
- The use of flocculants

Because sediment detention basins are usually flow-through structures, trap efficiencies are optimized by setting design criteria or goals that maximize the capture of all settleable solids for a given design storm (i.e., storm frequency). At mine sites, it is common practice to design sediment detention basins based on the 10-year, 24-hour precipitation event. This design standard is based on the criteria for exemption for discharge of excess storm water at mine sites.

The particle size distribution sediments flowing into a detention basin is the single most important factor affecting trap efficiency (Barfield et al., 1981), because particle size is directly related to settling velocity. Assuming steady-state flow through a reservoir, a decrease in particle or aggregate size requires an increased flow length to allow a particle to settle out. For this reason, accurate characterization of particle size distributions of potentially incoming sediments is critical to pond design and management.

The detention storage time is the volume-weighted average time that a volume of flow will be detained in a reservoir. The detention time of a settling basin is a function of basin shape, basin length and the design of the outlet structure. The design of the outflow structure determines the characteristics of the outflow hydrograph and its relationships to the inflow hydrograph.

Basin shape strongly influences how effectively the storage volume of the basin is used for sedimentation. The basin shape determines flow path length, flow velocity, areas of turbulence within the basin, and if dead storage areas occur. Small localized zones of turbulence within the basin can inhibit particle settling because of locally increased flow velocities. Dead storage areas are zones within the basin that are bypassed and, therefore, ineffective in the settling process. EPA (1976) suggests that dead storage volume can be minimized by maintaining a 2:1 ratio between reservoir length (i.e., the length of the flow path) and reservoir width.

Water chemistry also affects particle settling and trap efficiency. In general, the ionic strength of the water is a primary factor affecting particle flocculation or dispersion. Flocculation of particles to larger, heavier aggregates generally increases with increased ionic strength. The types of cations present, however, also affect this process. Because they are divalent, calcium and magnesium cations tend to be very effective in increasing flocculation. Effects of ionic strength on flocculation and dispersion can be specifically related, therefore, to the relative concentrations of these cations in solution. The Exchangeable Sodium Percentage (ESP) and the Sodium Absorption Ration (SAR) are useful parameters that should be examined when evaluating the effects of water chemistry (Barfield et al., 1981).

Flocculant, which are compounds that enhance the aggregation of particles, often are used to aid the performance of a detention basin and, in some cases, to ensure that water quality standards are met at the basin outlet. Flocculants create larger particles that have greater settling velocities. They can be particularly useful when a large proportion of entrained sediment are clay, fine silt, or colloidal materials. Colloidal particles remain in suspension and will not settle out even under quiescent conditions. Barfield et al. (1981) provides a detailed discussion on water chemistry, flocculation and the design of programs in enhance settling using flocculants in sediment detention basins.

CAD and modeling software usually is employed to design sediment detention basins. In particular, SEDCAD+, PONDPACK, and SEDIMOT II, described in Section 4.3.2, are specifically used to apply both hydrologic and erosion measurements to the design of sediment detention basins. Using these types of software, a hydrologist can iteratively design detention basins to optimize basin size and shape, detention storage time, and the type of outflow structure required to meet design criteria. These models provide analyses of both inflow and outflow hydrographs and inflow and outflow sedigraphs. Analyses are performed to provide estimates of trap efficiency, mass of settleable solids captured, and mass of suspended solids not retained by the basin. Basins designed using software packages depend on accurate input data for hydrologic and soil variables. In particular, accurate information regarding soil types and particle size distributions (texture) are necessary for accurate design.

6.2 Innovative Control Practices

Most erosion and sediment control BMPs have been standard practice for many years. As discussed in Section 6.1, standard BMPs include surface stabilization measures, diversions and channels, and sediment traps and barriers. Some innovative BMPs, however, include variations of these practices that offer particularly effective controls. These practices include:

- The design and construction of artificial wetlands to provide natural filtration and enable sediment deposition. Artificial or constructed wetlands can effectively remove suspended solids, particulates and metals attached to sediments through the physical processes of velocity reduction, filtration by vegetation, and chemical precipitation as water flows through the wetlands.

- The use of geotextiles for soil stabilization and erosion control blankets and mattings. Geotextiles can be made of natural or synthetic materials and are used to temporarily or permanently stabilize soil. Synthetic geotextiles are fabricated from non-biodegradable materials and are generally classified as either Turf Reinforcement Mats (TRMs) or Erosion Control and Revegetation Mats (ECRMs). TRMs are three-dimensional polymer nettings or monofilaments formed into a mat to protect seeds and increase germination. ECRMs are composed of continuous monofilaments bound by heat fusion or stitched between nettings. They serve as a permanent mulch.

- Biotechnical stabilization techniques that use layers of live brush to help stabilize slopes. Biotechnical stabilization can control or prevent surface erosion and mass slope failures. This technique involves the use of cut branches and stems of species such as willow, alder and poplar. The live brush is embedded into the ground in a criss-cross pattern so that roots and shoots will eventually develop. Biotechnical stabilization is most effective when shrubs are cut and utilized during dormant periods.

7.0 SUMMARY

Mining activities have the potential to expose large areas of soil and rock to the processes of erosion. Mine pits, roads, tailings dams, waste rock and ore piles, and other facilities are potential sources of sediment that can be transported and deposited in streams and other water bodies. If properly planned and managed, however, adverse impacts to water quality and aquatic resources can be minimized or prevented. To prevent potential impacts, water and sediment management needs to be considered from the beginning of any mining plan.

The development of an effective erosion control plan must start with accurate baseline characterization of erosion and sediment potentials on a watershed basis. Accurate knowledge of existing conditions is necessary to design and implement effective erosion control programs and to allow accurate monitoring for impacts. Baseline characterization depends on sampling programs that adequately determine existing soil types and their particle size distributions, existing vegetation types and cover values, slopes and slope lengths, as well as the relationships between existing drainages and stream channels. Programs to characterize baseline water quality must take into account variations in stream flow. This includes variations that occur on a storm basis, as well as on a seasonal or annual basis. Developing monitoring programs that accurately detect or evaluate impacts and control effectiveness depends on having accurate knowledge of natural erosion and degradation rates and patterns.

The choice of methods to predict gross erosion and sediment yield from natural or disturbed areas may be dependent on the type of input data required. It is very important that the mining hydrologist understands all assumptions inherent in a model or method when conducting analyses to predict sediment yields or design erosion controls. Accurate analyses by available software programs and models requires accurate site-specific sampling for input data. Vegetation parameters, soil types, and soil particle size distributions are, perhaps, the most important parameters that are input to predictive models and CAD programs.

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APPENDIX I

WETLANDS

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1.0 PURPOSE AND GOALS OF THE APPENDIX

Wetlands constitute an important resource, in terms of impact assessment. Any project or activity with the potential to impact wetlands should fully characterize this resource as part of establishing baseline conditions and consider potential permit requirements in project planning. Accurately describing existing wetland conditions at a site and identifying sources of potential impacts should facilitate the development of alternatives and mitigation, including avoidance, minimization, and as necessary, compensation.

The purpose of this appendix is to provide guidance on determining data needs, identifying data gaps, collecting necessary baseline information and conducting an impact analysis for wetland resources. The subsequent sections discuss wetland terminology and issues; characterization of the affected environment; and impact analysis. A list of reference materials and contacts are provided in the final section. This appendix does not address in detail, the Clean Water Act Section 404 permitting process, a topic discussed in the main body of the source document.

2.0 TERMINOLOGY AND ISSUES

2.1 Terminology

Terminology surrounding wetland science is often confusing. Ambiguity results from the wide variety of disciplines (e.g., plant ecology, wildlife biology, soil science, and hydrology) involved as well as the fact that the terminology often has both regulatory and ecological connotations. The list of definitions that follows is based on terminology that is generally accepted in the wetland science community. The key point is that *wetland*, is a general term that applies to a type of feature or habitat occurring within the landscape; while *jurisdictional wetland* applies to specific wetlands under jurisdiction of the U.S. Army Corps of Engineers (COE), U.S. Environmental Protection Agency (EPA), and some state and local governments. To the untrained observer, the mere presence of certain features, such as standing water or aquatic vegetation, might warrant classification of an area as a wetland; however, these areas may or may not meet the regulatory definition of jurisdictional wetlands as defined below. All jurisdictional wetlands are wetlands while all wetlands are not jurisdictional. All discussions of wetlands in this Appendix refer to jurisdictional wetlands or other Waters of the United States.

Jurisdictional wetlands are wetlands that occur within jurisdiction of the COE and EPA authority under Section 404 of the Clean Water Act. Under normal circumstances, wetlands exhibit three criteria: hydrophytic vegetation; hydric soils; and wetland hydrology that must be identified in accordance with the COE 1987 Wetlands Delineation Manual (1987 Manual). Plants that grow in undrained hydric soils are referred to as *hydrophytes or hydrophytic vegetation*. These plants tolerate varying degrees of soil saturation or inundation and some species even continue to grow partially submerged. Undrained *hydric soils* are oxygen depleted soils, a condition attributable to the prolonged presence of water in the soil. *Wetland hydrology* is found where water saturates or inundates soils for an extended period during the plant growing season. "Atypical" or "problem" areas may still be classified as jurisdictional wetlands despite the absence of one or more of the aforementioned criteria.

A professional wetland scientist can be retained to make wetland determinations and to conduct wetland delineations as per the 1987 Manual. Wetland determinations only denote whether or not the land being assessed is a wetland. A wetland delineation defines the physical boundary of a wetland once it has been determined that one exists on the property. It should be noted that only the COE and EPA have regulatory authority to make jurisdictional determinations.

Waters of the United States is a regulatory phase that defines the limits of jurisdiction for the COE under the Clean Water Act. The term generally applies to 'navigable waters' and watercourses that possess a 'bed and bank,' including those that may be intermittent or ephemeral. Jurisdictional wetlands are considered a type of Waters of the United States and the Clean Water Act defines wetlands as "…those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions" (33 CFR Section 328.3). Where a question exists as to the designation of a Water of the United States, the local COE district office should be contacted for their interpretation.

Wetland functions. Wetlands may provide habitat for threatened or endangered species as well as numerous other plant, wildlife, and fish species. Wetlands may perform other functions, in addition to providing habitat, including: shoreline stabilization; storage of flood waters; and filtration of sediments, nutrients, and toxic chemicals from water; and serving as recharge and discharge areas for ground water. Destruction of wetlands specifically can result in higher downstream water treatment costs and the potential for property damage from increased flooding.

Wetland Values. Although often used in conjunction with "function," wetland "value" refers to wetland attributes determined to be valuable to society. Examples of wetland values include education, recreation, esthetics, tribal harvest areas, scientific study, contribution to the economy and other social/cultural attributes.

Navigable waters of the United States are those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce (33 CFR § 328.3). A determination of navigability, once made, applies laterally over the entire surface of the waterbody, and is not extinguished by later actions or events which impede or destroy navigable capacity (33 CFR § 328.3).

The USFWS's *National Wetland Inventory* (NWI) is a federal classification system for the nation's wetlands and deepwater habitats (USFWS, 1998). USFWS publishes NWI maps for many areas of the country. NWI maps identify wetland and deepwater habitat and are often superimposed on U.S. Geological Survey (USGS) maps of various scales. USFWS produces these maps through interpretation of remote sensing data (i.e., aerial photography) and limited field investigations. NWI maps occasionally miss certain types of wetlands (e.g., forested wetlands) and in other cases these maps include water bodies (e.g., wastewater treatment lagoons) not under COE jurisdiction (Rolband, 1995; Stolt and Baker, 1995). Therefore, NWI maps should not be used as the only source of information to determine if an area contains wetlands.

Riparian is a term that refers to "plant communities contiguous to and affected by surface and subsurface hydrologic features of perennial or intermittent lotic and lentic water bodies (rivers, streams, lakes, or drainage ways). Riparian areas have one or both of the following characteristics: 1) distinctly different vegetative species than adjacent areas, and 2) species similar to adjacent areas but exhibiting more vigorous or robust growth forms. Riparian areas are usually transitional between wetland and upland" (USFWS, 1997). Riparian areas also often include wetlands.

2.2 Issues

There are a number of issues that should be kept in mind when undertaking an assessment of wetlands. Four issues presented in this appendix are particularly relevant to mine projects: (1) wetland boundaries may vary over time; (2) local, state, and federal regulatory considerations; (3) 404(b)(1) Guidelines; and (4) compensatory mitigation.

2.2.1 Wetland Boundaries

Wetlands often occur as transitional zones between upland and aquatic habitats. Hydric soils persist over a relatively long period and, therefore may indicate that an area may still be a wetland even after it has been successfully drained. Hydrology, on the other hand, may vary significantly over both the short- (seasonally) and long-term (annually or longer), which is why one must rely on a "normal year" (i.e., 30 year period) cycle. Vegetation, depending on form (i.e., tree, shrub, or forb), may or may not reflect long-term conditions at the site because plants respond relatively quickly to changes in hydrology. Any mapping effort should, ideally, consider the conditions of a site over multiple seasons and preferably multiple years rather than relying solely on site conditions at a particular instant in time. Also, the easiest and most reliable time to delineate a wetland boundary is during the wettest period of the growing season.

2.2.2 Local, State, and Federal Regulatory Considerations

The need to conserve wetlands, and the benefits they provide, is reflected in the potential protections afforded jurisdictional wetlands established under the Clean Water Act and cross-cutting federal environmental statutes. Beyond federal requirements, some state and local governments may require permits for projects that may impact aquatic habitat and/or wetlands; or sometimes place additional restrictions on projects that could impact wetland habitat (e.g., setbacks or buffer zones around wetlands and other Waters of the United States). Therefore, once wetlands have been identified in a project area, early consultation with state, federal, local planning offices, and resource agencies can help to clarify all issues and concerns. Communications with interested agencies will help to focus data collection efforts and may improve the options for avoiding impacts through project design and mitigation.

2.2.3 404(b)(1) Guidelines

The regulatory requirements of permitting under Section 404 of the Clean Water Act are presented in the body of the source document. However, a brief acknowledgment of the 404(b)(1) Guidelines (Guidelines) may shed additional light on the subject of permitting and environmental impact analysis. Prior to issuance of a permit by the COE for unavoidable impacts to wetlands and other Waters of the United States, the Guidelines require the proponent to demonstrate that the selected project alternative is the least environmentally damaging practicable alternative. Often, the preferred alternative selected from the environmental impact analysis of the National Environmental Policy Act (NEPA) process, is not the least environmentally damaging practicable alternative because NEPA does not have the same requirement as the Guidelines. It is therefore important to avoid and/or minimize all impacts to wetlands to the fullest extent possible.

2.2.4 Mitigation

A Memorandum of Agreement (MOA), dated February 6, 1990, between the COE and the Environmental Protection Agency establishes the policy and procedure in determining the type and level of mitigation necessary to comply with Section 404(b)(1) Guidelines. The MOA sets ‘no net loss’ of wetland functions and values as a national goal and defines the types of mitigation, for practical purposes as minimization and compensatory. Although compensatory mitigation is often the focus of project proponents, from a regulatory perspective, avoidance and minimization should be the focus of any project with the potential to impact wetlands and other Waters of the United States. Due to their importance, avoidance and minimization are discussed here as they apply to the early stages of project planning and design. Compensatory mitigation will be discussed in Section 4.1 along with other aspects of impact assessment.

Avoidance addresses the portion of the Guidelines which states that no permit shall be issued if there is a practicable alternative to the proposed discharge which would have less adverse impact to the aquatic ecosystem including wetlands. The minimization aspect of the MOA addresses the requirement that all appropriate and practicable steps taken which minimize the potential adverse impacts of the discharge. Avoidance and minimization would typically be implemented during early phases of project design through such things as alternative siting of roads and infrastructure; minimizing the footprint of facilities that encroach on wetlands; and reducing or eliminating the amount of fill for stream and wetland crossings (e.g. using bridges instead of culverts where feasible).

A project description submitted as part of an environmental impact assessment or permit application should clearly demonstrate how avoidance and minimization have been addressed. Realize that avoidance and minimization are part of an iterative process that will begin at the earliest conceptual stages and continue through final designs. A pre-application meeting with the COE may facilitate the permit process by identifying less damaging alternatives. Optimizing avoidance and minimization may also be achieved by working with the COE, EPA and any other interested agencies once the basic design criteria have been developed. Failure to consider compliance with the Guidelines may result in project delays later in the permitting process or outright permit denial.

3.0 AFFECTED ENVIRONMENT

3.1 Introduction

Descriptions of the affected environment, as required in National Environmental Policy Act (NEPA) documentation, may require: (1) an initial inventory and classification; (2) a jurisdictional delineation; and (3) a functional assessment of wetland resources within the project area. Prior to any assessment of the wetland resource, however, the affected environment to be described must be established. Defining the affected environment and assessing wetland resources within this environment are discussed below.

The first step in describing the affected environment is to establish the study area or region of influence (ROI) in terms of the proposed action and potential direct and indirect effects to wetland resources. For wetlands, the ROI typically extends beyond the footprint of the proposed ground disturbance. A larger ROI ensures that potential indirect effects to wetland hydrology, water quality, and other functions are considered, including potential affects to down-gradient areas that may occur as a result of the wetland impacts.

Once the ROI is established, an initial inventory and classification of wetlands and other Waters of the United States is typically performed to determine the general nature and extent of these resources within the ROI and to facilitate impact avoidance and minimization through project design. Following refinement of alternatives, a delineation of wetlands within the ROI is conducted to provide a comparison of the effects of each alternative. A functional assessment of wetlands is also conducted to facilitate the comparison of effects between alternatives and between pre- and post-project conditions.

The remainder of this section presents additional information on inventory, classification, delineation, and functional assessment of wetlands and how they relate to describing the affected environment.

3.2 Wetland Inventory and Mapping

Due to the typical large size of ROIs and the numerous and conceptual nature of project alternatives early stage in the review process, the initial inventory and classification of wetlands is generally performed by use of existing information (e.g., NWI maps, aerial photography, local and/or regional soil surveys). NWI maps are an effective starting point for inventorying and classifying potential wetlands. Aerial photography and satellite imagery (collectively referred to as remote sensing products) are interpretive tools, often used in conjunction with NWI maps, for identifying the location of wetlands in the field. Remote sensing products can be obtained from a variety of different sources including US Forest Service, USGS, COE, USDA Farm Services

Agency, USDA Natural Resource Conservation Service, state departments of transportation or natural resources, and private contractors.

Depending on the season and type of remote sensing products available, wetlands are often best identified using color infrared (CIR) aerial photography. However, wetlands can also be identified using panchromatic photography. When using remote sensing images it is helpful to obtain coverage for the same area over a period of years and seasons as the vegetation boundaries of wetlands may vary due to seasonal hydrologic changes. Where the use of a stereoscope is possible, photography should be ordered as stereo pairs in the largest scale available to enhance the ability to locate wetlands on the photographs. Wetlands observed on aerial photographs should be checked against the NWI maps recognizing that some wetlands appearing on NWI maps may not be evident in available aerial photography and vice versa.

Soil surveys and hydric soil lists obtained from the USDA Natural Resources Conservation Service can also be used to identify potential wetland areas. A soil survey map in conjunction with aerial photographs can be used to identify areas exhibiting hydric soil and hydrophytic vegetation respectively.

Once potential wetlands are identified using NWI maps and/or interpretation of remote sensing images and other resources, a field survey should be conducted to ground truth the information and other potential locations (e.g. topographic depressions and seeps) should be investigated during the field survey. Specific boundaries and NWI classification categories (e.g. PSSb) should be verified (or determined) in the field and a list of dominant plant species generated. A brief assessment of wetland functions (see below) may also be completed at this time. The data collected may then be used to draft descriptions of the resource.

A geographic information system (GIS) or other means may be used to add wetland locations to other mapped features of the project area. Attributes (descriptors) may be assigned to the different wetland 'polygons' occurring on the map. The locations and characteristics of these mapped wetlands may then be used as part of the description of the affected environment, for impact assessment, and for planning purposes. The usefulness of GIS, however, is limited by two factors. First, since wetland boundaries and conditions can change over the years, the GIS data represent only a snapshot in time. Second, the GIS is only as accurate as the input data (i.e., field surveys, NWI maps, or photo interpretation). Acknowledging its limitations, GIS is useful for generating *approximate* acreages by type of wetland, potential impact, or other descriptor.

3.3 Wetland Determination and Delineation

3.3.1 Delineation Criteria.

The COE of Engineers Wetlands Delineation Manual (1987 Manual) (Environmental Laboratory, 1987) defines how the three criteria – hydrophytic vegetation, hydric soils, and wetland hydrology – are used to delineate wetlands. Under normal circumstances, wetlands possess at least one positive wetland indicator for each of these parameters, for purposes of the CWA. The 1987 Manual identifies a number of indicators available for each parameter. This section presents an overall summary of the three criteria and some of their indicators; however, the reader is referred to the 1987 Manual for complete details. Wetland delineations may not necessarily be conducted for all wetlands within a study area. Due to practical matters and costs associated with intensive sampling, delineations may be focused only on wetlands that could be impacted by a proposed disturbance. Regardless of the jurisdictional status and whether or not a wetland boundary is established, there are other characteristics used to describe wetlands within a discussion of the affected environment. Other methods for describing wetland resources are discussed in Section 3.4.

Both EPA and COE accept the 1987 Manual as the standard document for wetland delineation, as of this writing. The reader should be aware that several manuals spelling out specific methodologies for wetland identification and delineation have been written or proposed which might someday replace the 1987 Manual if the federal government determine they are an acceptable substitute. Consultation with the COE or other relevant federal agency will help ensure that delineations are completed using the appropriate manual and techniques.

3.3.1.1 Hydrophytic Vegetation

The delineation process considers all of the dominant plant species occurring at a site when determining the presence or absence of hydrophytic vegetation. Hydrophytic vegetation refers to plants that are adapted to growing in anaerobic soil conditions, or those conditions that typically exist under prolonged soil inundation or saturation. The delineation process requires identifying the dominant plants occurring at a site and determining their 'indicator status.' The indicator status is established in USFWS's *National List of Plant Species that Occur in Wetlands* (USFWS, 1988) and reflects the likelihood of a plant species occurring in wetlands. A site supports hydrophytic vegetation if more than 50 percent of the dominant plant species present at the site are more likely to occur in wetlands than in uplands. Other indicators include visual observations of plants growing in inundated/saturated conditions, morphological adaptations, physiological adaptations, and technical literature (Environmental Laboratory, 1987).

3.3.1.2 Hydric Soils

Soils exposed to prolonged periods of anaerobic conditions, such as those created by saturation or inundation, develop distinct characteristics. These characteristics result in particular soils being classified as hydric under US Department of Agriculture Soil Conservation Service (now Natural Resources Conservation Service [NRCS]) nomenclature. Hydric soil lists for particular areas are available through the NRCS. These lists identify hydric soils (or those with hydric inclusions) within a particular soil survey. Since all hydric soils within an area may not be mapped, or mapped at too small a scale to be useful, field studies are recommended to determine the presence of hydric soils. Common field indicators of hydric soil include a dark color or chroma, gleying (gray colors), and the presence of colored mottling or iron and manganese concretions (Environmental Laboratory, 1987).

3.3.1.3 Wetland Hydrology

The term 'wetland hydrology' applies to characteristics that demonstrate or imply a site is periodically inundated or the soils are saturated to the surface for an extended period during the growing season. Indicators of wetland hydrology often appear through the characteristics of the site's vegetation and soils – vegetation adapted to saturated conditions and soils exhibiting hydric indicators. However, direct indicators of wetland hydrology include recorded data (e.g. gauging stations, floodplain maps) and field data (e.g. visual observations, watermarks, drift lines) (Environmental Laboratory, 1987). The reader is referred to Appendix A, *Hydrology,* for a discussion of hydrological analyses and methodology.

3.3.2 Delineation Methods

The 1987 Manual establishes three approaches to completing a wetland delineation. The first, *onsite inspection unnecessary*, may be used when sufficient information is available about the site to make a wetland determination. This approach is usually not used, as all the necessary information is seldom available. The other two methods, which are typically employed, are the *routine onsite* and *comprehensive* determinations (Environmental Laboratory, 1987).

3.3.2.1 Routine

The routine onsite approach to delineating wetlands begins with a review of existing data including US Geological Survey (USGS) quadrangle maps, NWI maps, soil surveys, gauge data, and aerial photography. Resource management agencies (local, state, or federal) may also be sources for additional information on a particular area. The site must also be evaluated to determine whether an 'atypical situation' exists, that is, have vegetation, soils, and/or hydrology been altered by recent human-activity (e.g., land clearing, farming, water diversions, filling, diking/ditching, etc.) or natural conditions changing the area from having wetland characteristics to non-wetland characteristics. An atypical situation requires the completion of additional analytical procedures, which will not be summarized here (see Section F of the 1987 Manual).

There are two procedures for field delineation depending on the size and complexity of the assessment area. The delineation process for areas five acres or less and thought to be relatively homogeneous with respect to vegetation, soils, and hydrologic regime, involves sketching locations of individual plant communities on a map and characterizing each community type by establishing sample points in representative locations (see Figure I-1). Sampling involves collecting data for vegetation, soils, and hydrology and completing a data form for each sample point. Dominant plant species are identified and their indicator status determined to establish whether the site is dominated by (more than 50 percent) hydrophytic vegetation. Soil pits are excavated to determine if soils exhibit hydric characteristics. Soil pits are also used to demonstrate the presence of and if present, depth to saturated soil. This observation can also be used in support of a wetland hydrology determination. Sample locations demonstrating positive results for all three criteria are considered wetlands. After sample points have been established in each plant community, boundaries must be established between upland and wetland communities. Where boundaries between the vegetation types are unclear, additional sample points are completed to ascertain the absolute boundary. A map is then completed depicting the locations of wetlands within the study area. From a practical standpoint, the boundaries should be staked or flagged and surveyed in order to have adequate location data for use in permitting and when detailed project designs are being drafted (Environmental Laboratory, 1987).

Areas greater than five acres require the establishment of a baseline and transects to frame the sampling regime (see Figure I-2). The length of the baseline, number of transects, and spacing of transects depend upon the size of the study area. Each community type must be sampled within at least one transect. Under this approach, sampling occurs within each plant community along each transect, and a data form is completed for each sample location. Boundaries between uplands and wetlands are established as described in the preceding paragraph (Environmental Laboratory, 1987).

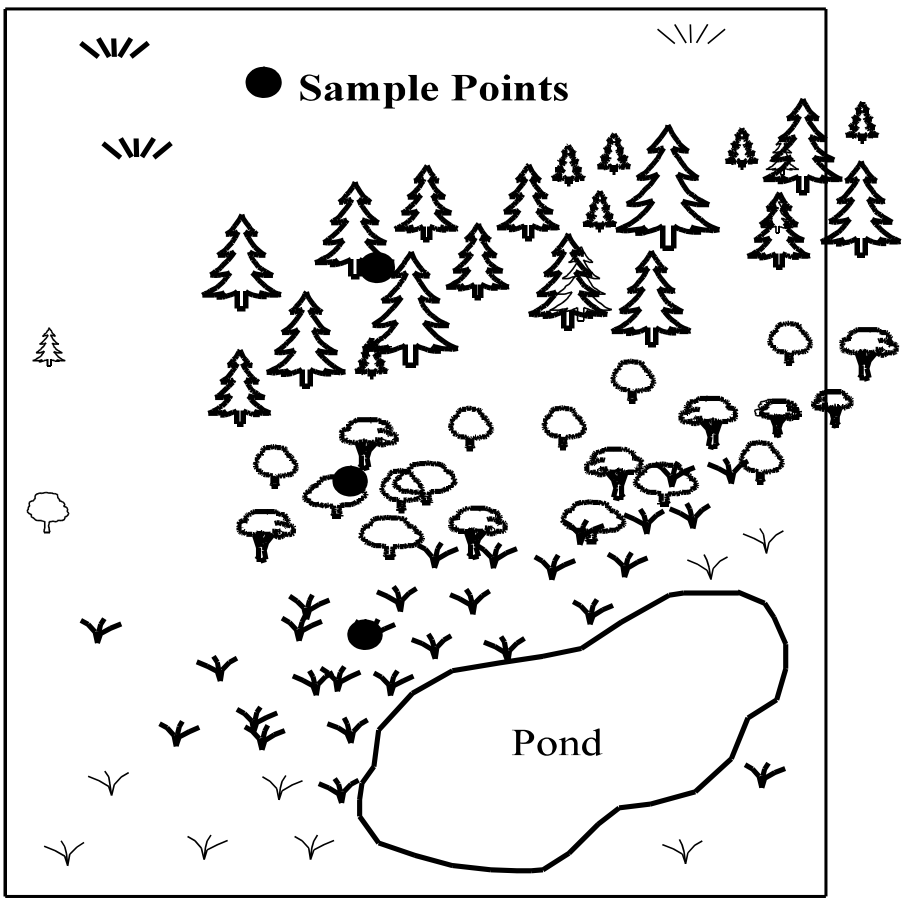

Figure I-1. Routine wetland determination for areas 5 acres or less and with relatively homogeneous vegetation, soils and hydrology

3.3.2.2 Comprehensive

The comprehensive approach is used for complex projects or when a project requires more documentation than would typically be necessary. A comprehensive study may be undertaken for example, where there is a likelihood of litigation at some point in the future or where a wetland may be suspected of providing habitat for threatened or endangered species. Under the comprehensive method, the preliminary work is completed as in a routine survey. The vegetation must be characterized to determine the number and location of plant communities that need to be sampled. A baseline and transects are then established, based on the size of the area. Sample data are collected on a different form than that used in routine delineations. In this case, the information is recorded in greater detail and includes species composition and density data for the different vegetation layers (trees, saplings/shrubs, grasses/forbs, and woody vines). Vegetation data are then summarized on a second data form in making a determination on the presence/absence of hydrophytic vegetation. Soils and hydrology data are recorded similarly to the process used in the routine approach. Boundaries between wetland communities and non-wetland communities are determined by observing distinct changes in vegetation or topography, or completing additional sampling points. Boundaries between transects may be developed based on surveying a contour between sample points across transects or again conducting additional sampling (Environmental Laboratory, 1987).

The results of wetland delineations should be summarized in a report that includes a map and copies of the data forms. The report may then be used to support a Section 404 permit application and/or environmental impact analysis.

3.4 Describing Wetlands

Wetlands represent a transitional zone between uplands and aquatic habitats and tend to occupy a relatively small percentage of the landscape (Mitsch and Gosselink, 1993). However, in some areas, such as portions of Alaska and within floodplains, wetlands may encompass large areas. Different classification schemes may be used to describe wetland resources in each of these cases. The so-called Cowardin system is one method of classifying wetlands and deepwater habitats; this method is used to describe wetlands on NWI maps (see Section 2.0). In some cases, vegetation classification schemes, such as *The Alaska Vegetation Classification* (Viereck et al., 1992), may be more appropriate than the Cowardin system. For example, in Alaska, the *Alaska Vegetation Classification* is tailored to local conditions and plant species and therefore allows the user to be more specific in the description of wetland resources. Other descriptors, in addition to a classification scheme, include wetland functions (see below). The descriptions that result from gathering this information provide a basis for comparing the types of

wetlands present and will aid in assessing the potential impacts (Section 4.0). The approaches to classifying and describing a project's wetlands will be discussed in more detail below. Note that all wetlands, regardless of jurisdictional status should be described.

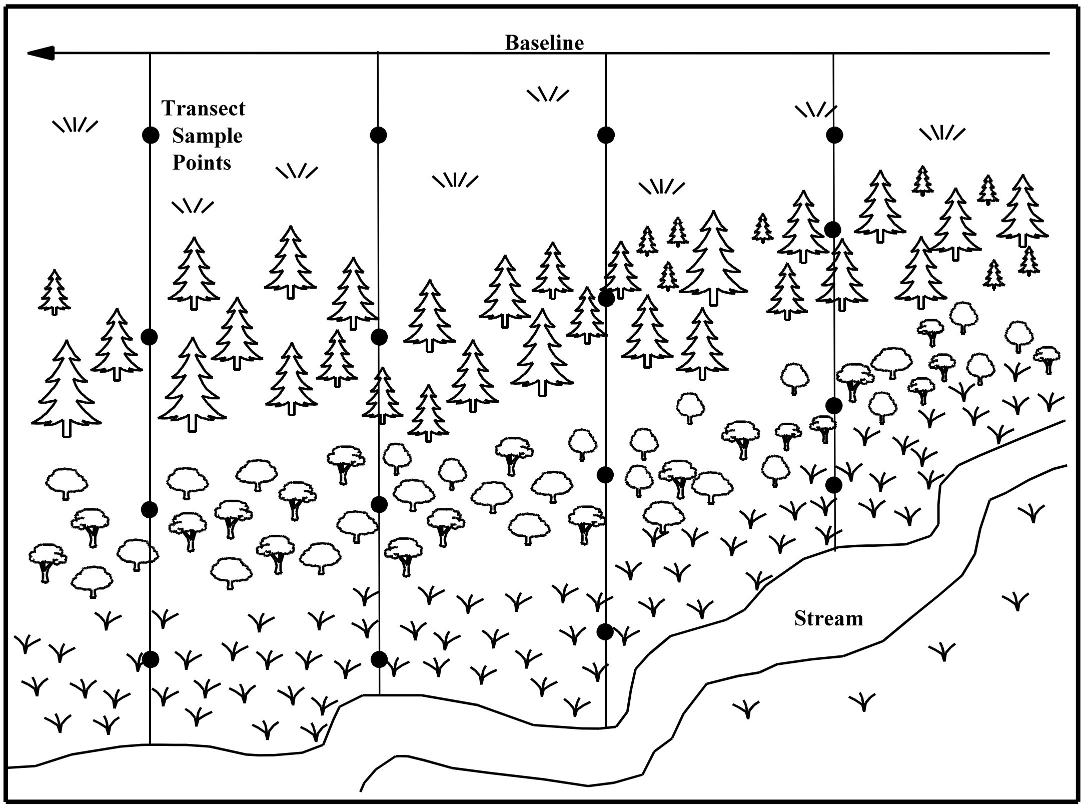

Figure I-2. Routine wetland determination for assessment areas greater than 5 acres and/or with complex vegetation, soils and hydrology

3.4.1 Cowardin System

The Cowardin classification scheme characterizes both wetlands and deepwater habitats using a hierarchical approach (Cowardin et al., 1979). The Cowardin scheme does not include nor should it be used to determine jurisdictional status of wetlands and other waters of the United States. Indeed, the Cowardin classification scheme does not use the same definition for wetlands as used by the COE and EPA in accordance with the CWA. Under this classification scheme, *systems* represent the first tier followed by *subsystems, classes,* and *subclasses*. *Dominance type* and *modifier* constitute the lowest tiers of the scheme. Each successive tier provides a greater level of detail for individual wetlands. Classifying wetlands using the Cowardin system facilitates comparisons with wetlands exhibiting similar characteristics both within and outside the project area.

Cowardin's scheme includes three freshwater 'systems' – palustrine, lacustrine, and riverine. Palustrine systems are commonly referred to as marshes, swamps or bogs. They encompass all non-tidal wetlands and tidal area wetlands where ocean-derived salinity is below 0.5% that are dominated by trees, shrubs, and persistent emergents. Lacustrine systems include lakes and reservoirs. Lacustrine systems are generally larger than 20 acres in size; situated in a topographic depression or dammed river channel; and lack trees, shrubs, and persistent emergents. If smaller than 20 acres, lacustrine systems are generally defined by depth. Riverine systems include wetlands and deepwater habitats that are contained within a channel. Riverine systems exclude wetlands dominated by trees, shrubs, or persistent emergent, which would be considered palustrine. Classes within each system describe the substrate or dominant life form of the plant species within an individual wetland. Examples of classes include forested, scrub-shrub, aquatic bed, and unconsolidated bottom. Dominance type refers to the plant species that dominate an individual wetland. A modifier may provide insight to the individual wetland's hydrology (e.g. excavated, diked, and beaver). An example of a willow thicket classified under the Cowardin system would be a willow-dominated palustrine scrub-shrub (PSS). A beaver pond could be described as a palustrine aquatic bed (PAB) with a beaver modifier (PABb).

3.4.2 Alaska Vegetation System

The Alaska Vegetation System also uses a hierarchical approach to classification but applies to vegetation communities rather than wetlands in particular (Viereck et al., 1992). This system identifies plant communities with wetland characteristics to a limited extent in its second and third tiers and more so in its fourth tier. The first two tiers (Levels I and II) describe the life form of the dominant community. Level I consists of Forest, Shrub, and Herbaceous; Level 2 includes descriptors of these life forms – such as broadleaf or needleleaf; tall or low scrub; and graminoid or forb communities. Level III describes the degree of canopy closure and, in some cases whether it occurs in wet areas. Levels IV and V describe the dominant species and the associated vegetation, respectively. Examples of descriptions based on the Alaska Vegetation System include Closed (canopy) Sitka Spruce Forest and Open Tall Alder-Willow Shrub. Using this classification as a basis for the description of the environment can include vegetation in general and also wetlands, particularly where wetlands encompass a large portion of the project area. The Cowardin system may be applied on top of the plant associations described using the Alaska classification system. For example, an Open (canopy) Tall Alder-Willow Shrub vegetation community that occurs in wet conditions would be consistent with Cowardin's Palustrine Scrub-Shrub class.

Where wetlands cover a large portion of the landscape, a routine delineation may be undertaken using these vegetation units as the basis for the delineation. Since this method could potentially over- or under-represent the extent of wetlands at a site, an agreement should be reached with the COE and lead agency if this approach is proposed. The COE will require that a field delineation be performed for all wetlands potentially impacted by the project.

3.4.3 Function Assessment

Wetland functions are physical, biological or chemical processes that occur in wetlands. Examples of wetland functions include but are not limited to, fish and wildlife habitat, groundwater recharge/discharge, or flood storage. Wetland functions, as physical, biological, and/or chemical processes or conditions, are not always easily quantifiable and are often described qualitatively. Wetland functional assessment provides a basis for comparing wetlands, a necessary component of wetland analysis. A common, early approach to assessing wetland functions is the Federal Highway Administration's (FHWA) Wetland Evaluation Technique (WET) or some modification thereof. The Hydrogeomorphic (HGM) method is a quantitative approach to wetland functional assessment currently under development. HGM assesses the functional level for individual wetlands within different wetland 'classes' wetlands. Analyses completed using HGM are not directly comparable with WET analyses. These two methods or modifications thereof, are the typical methods used to assess and describe wetland function; however, there is no required method for describing wetland function.

3.4.3.1 Wetland Evaluation Technique (WET)

The FHWA method for wetland functional assessment, WET, provides a procedure for converting typical wetland field observations (e.g., wildlife, plant species, recreation) into preliminary statements regarding the wetlands probable functional value (FHWA, 1983a). WET rates a broad range of functional attributes and values on a scale of high, moderate, and low (Mitsch and Gosselink, 1993).[1] Each wetland function is rated on three attributes: social significance; effectiveness; and opportunity (Mitsch and Gosselink, 1993; FHWA, 1983b). Social significance assesses the societal value of a wetland in terms of economic value, strategic location, or special designation (Mitsch and Gosselink, 1993). Effectiveness relates to the wetland's capacity to carry out a function because of its physical, chemical, or biological characteristics (Mitsch and Gosselink, 1993). The degree to which a wetland functions at its level of capability is assessed for the opportunity rating (Mitsch and Gosselink, 1993). WET has some limitations including its limited transferability from site-specific to landscape level analysis (Mitsch and Gosselink, 1993) and comparability with analyses completed using other techniques. The WET manual often uses the terms function and value inter-changeably. See Section 2.1 for a discussion of these terms.

3.4.3.2 Hydrogeomorphic Method (HGM)

HGM represents a new approach for evaluating wetland function. The HGM approach focuses on comparisons among wetlands with similar characteristics (i.e., within the same wetland class) and includes methods for assessing human induced changes to wetland functions (Brinson, 1996; Brinson, 1993). HGM uses indicators from the literature and field measurements in describing measurable properties of a particular function within a particular wetland class. These measurements and models are calibrated on regional reference wetlands and then used to develop an index of functionality for each wetland function. This information

[1] Functional attributes include: groundwater recharge and discharge; flood storage and desynchronization; shoreline anchoring and dissipation of erosive forces; sediment trapping; nutrient trapping and removal; food chain support; habitat for fisheries and wildlife; active and passive recreation; and heritage value (FHWA, 1983).

can be used not only to describe the extent to which a particular wetland is performing specific functions but also to establish mitigation goals, evaluate the mitigation potential for different sites, and monitor progress of mitigation activities (Rheinhardt et al., 1997).

HGM focuses on comparing wetlands within particular classes (e.g. depressional or riverine) rather than trying to compare characteristics across classes. For example, a fish habitat may be rated for riverine wetlands but might not be considered at all for certain types of seasonal wetlands within the depressional class. The HGM approach is still in development but may be available for broader use within the foreseeable future.

4.0 IMPACT ASSESSMENT AND COMPENSATORY MITIGATION

4.1 Impact Assessment

Impact assessment is the description of impacts to wetland resources from all aspects of mine construction, operation, and closure. While there are many sources of impacts that may occur to wetlands, the two general categories of impacts are direct and indirect. Direct impacts result from a discrete action and occur at a particular point in time and at a particular location. Filling a wetland to construct a road would be considered a direct impact. Indirect impacts on the other hand, result at a time or location removed from the point of disturbance. The change in species composition of downstream wetlands over a period of years in response to changes in hydrology upstream would be considered an indirect impact.

4.1.1 Direct and Indirect Impacts

A number of mining-related activities may result in direct or indirect impacts to wetlands. These activities include exploration, geotechnical drilling, construction and operation of facilities; excavation, heap leaching, surface water diversions; withdrawal of groundwater; and accidental and permitted discharges. The results of these types of activities include direct wetland loss through filling or draining; changes to the hydrologic regime with subsequent changes in flora and fauna; habitat fragmentation due to human encroachment; and changes in sedimentation patterns. Identifying, attributing, and describing the short- and long-term range of environmental impacts to individual resources is the key to impact assessment.

Impact assessment relates to a wide range of questions and while many would be applicable to most projects others will depend on the specific conditions related to each individual project. Some of the relevant questions include:

- How many acres of wetlands will be directly and/or indirectly impacted by fill activities?
- To what extent will changes in surface water flows affect wetlands within (and outside) the project area?
- Will groundwater withdrawals influence wetlands and if so, to what extent?
- Will sediment loading to particular wetlands be increased?

- To what degree would mining-related activities affect habitat values?
- To what degree would mining-related activities affect water quality (i.e., temperature, toxins, etc.) within wetlands?

Descriptions of potential impacts to wetlands are usually presented in terms of absolute loss (acres filled or drained) and in loss of function. The former analysis is quantitative and relatively straight forward and tends to only address direct impacts while the latter is significantly more complicated but necessary to adequately address indirect impacts. For example, wetlands tend to be greater than the sum of their parts and, thus, a 1:1 relationship does not necessarily exist between wetland acreage and functions. Therefore, filling 50 percent of a wetland may have either a greater or lesser effect on the functions demonstrated by the wetland than simply halving them. This situation needs to be considered in describing potential impacts to wetland functions. Likewise, the loss of all or part of a wetland can impact the functions of other wetlands and other aquatic areas, and even nonwetland areas, beyond its boundary.

The most practical approach to determining the extent of impacts to wetlands is to assess each type of activity that could cause impacts. This 'checklist' should go from the obvious to the subtle. Obvious items include calculating the number of wetland acres that will be filled to construct and operate the various facilities and determining of the extent to which surface water diversions and groundwater withdrawals will affect wetlands. Less obvious items might include determining the affect of human encroachment on habitat values, assessing the potential for long-term changes to the local hydrology; and projecting the results of permitted discharges over the long-term. The duration of wetland impacts should also be considered and discussed. Some impacts may only occur during construction (e.g., noise from construction equipment), while others could continue throughout the life of the project or longer. For example, fill used to construct a wetland crossing may only be needed during mining operations and could be removed upon closure. Such an impact would be considered temporary compared to a wetland permanently buried under a waste rock dump. For example, impacts to a forested wetland would likely require more time to recover than impacts to an emergent marsh. This aspect also requires consideration during the mitigation process.

Ultimately, the analysis should summarize the impacts that are anticipated by class or category of wetland. The direct impacts may be presented in tabular form, similar to that presented in Table I-1. Indirect impacts should be clearly described and include the type of wetland impacted, size of impact area, description of functions to be impacted, and the source of the potential impact. All of the discussions should indicate whether the impacts would be temporary (e.g., noise during summer construction), short-term (e.g., mowing of herbaceous vegetation), long-term (e.g., sedimentation from erosion of exposed soil), or permanent (e.g., wetlands buried by construction of buildings).

4.1.2 Cumulative Impacts

Aspects of the direct and indirect impact analyses should also be considered and described in terms of a cumulative impact analysis. Cumulative impacts are defined as the sum of all individual impacts occurring over time and space, including those of the foreseeable future

(EPA, 1992). Proposed changes to the nationwide permitting process by the COE resulted in part, because of cumulative impacts to small isolated wetlands, through permitted and unpermitted activities. In their rationale for proposing these changes, the COE stresses that the "only

Table I-1. Example of Direct Impacts Table for Wetlands

Wetland Class[1]	***Acres***						
	Within Study Area		*Short-Term Impacts*		*Long-Term Impacts*		
	Jurisdictional	*Non-Jurisdictional*	*Jurisdictional*	*Non-Jurisdictional*	*Jurisdictional*	*Non-Jurisdictional*	*Total Impacts*
Palustrine Aquatic Bed	12.3	0.6	1.4	0	1.4	0	12.9
Palustrine Emergent	28.8	0	2.3	N/A	1.5	N/A	28.8
Palustrine Forested	4.2	3.5	0	1.5	0	1.5	7.7
Palustrine Scrub-Shrub	12.8	0	3.2	N/A	2.4	N/A	12.8
Total	58.1	4.1	6.9	1.5	5.3	1.5	62.2

[1]Cowardin et al. 1979.

technically sound approach" to cumulative impact assessment is on a watershed basis (Federal Register, 1998).

A cumulative impact analysis should consider impacts to the resource in the context of what other projects have occurred or could foreseeably occur in the area. For example, a proposed action could result in the loss of half of the forested wetlands in a study area. The cumulative impact analysis may indicate that a different project, also in the planning stages or already occurring/completed, would also cause the loss of a large portion of the same forested wetland. In this case, the cumulative impact may be much more significant that the impact caused by either project individually. Cumulative impacts to wetlands may be addressed by considering the extent of impacts on wetland classes and function within a particular area – the boundaries may include a drainage basin, watershed, or some other land management unit. The boundaries of the cumulative impact area and the sources of potential cumulative impacts are typically identified in conjunction with the lead agency at the beginning of the actual environmental impact assessment process.

4.2 Compensatory Mitigation

Section 2.2 introduced the concept of mitigation in terms of the Guidelines and the COE/EPA MOA. Within this framework, mitigation usually refers to avoidance, minimization, and compensatory mitigation. The two former terms were discussed previously while this section focuses on the latter. Compensatory mitigation refers to the restoration, enhancement, or creation of wetlands to restore or replace functions of unavoidable and/or accidental wetland impacts by a particular project. No net loss of resource value requires that an ecological assessment of wetland functions and wetland delineation be performed as mentioned previously. A description of wetland functions and delineation of boundaries identifies resources that could be impacted and catalogues what will need to be replaced if compensatory mitigation is required.

Compensatory mitigation is an important component of impact assessment. After an applicant demonstrates avoidance and minimization of impacts to the extent practicable, some type of compensatory mitigation will generally be required in order to obtain CWA 404 authorization from the COE.

Compensatory mitigation requirements vary by location and are determined by the COE on an individual project basis, usually in conjunction with public comment. The extent of mitigation often relates to the size of the project, nature of impacted wetlands, and the degree and amount of wetland impacts expected. The relative level of success or failure (i.e., level of risk and temporal rate of replacement) of mitigation efforts to replace impacted functions are also considerations in determining required mitigation. Some districts require compensatory mitigation in excess of a one for one ratio (loss to replacement) other areas (such as Alaska), may not necessarily require any compensatory mitigation.

Frequently, the preferred approach to mitigation is termed *on site, in kind* mitigation, which equates to replacing the specific characteristics of an impacted wetland within the project area. *Off site, in kind* mitigation may be an alternative when no on site options are available or practicable. Likewise, *on site, out of kind* may also be possible, particularly when the functions and values of such an undertaking would surpass those of the impacted wetland and where in-kind is not practicable and/or desirable based on identified regional or watershed wetland functional priorities. *Off site, out of kind* mitigation is generally the last choice when other options are unavailable or regionally less desirable. The success of mitigation projects often relates directly to the type of mitigation undertaken. Restoration tends to be more predictable than wetland creation as some wetland characteristics already exist (or existed) at the site. Establishing an adequate hydrologic regime is one of the keys to successful wetland mitigation; this can be a difficult task for wetland creation projects, but relatively much easier for wetland restoration. Enhancement of degraded wetlands is often a more practical approach than creation because again, the site presumable already possesses some wetland characteristics. A qualified professional, with experience in designing and implementing wetland mitigation projects, should be consulted prior to the development of any mitigation plan. Likewise it is often important to confer with the regulatory and resource agencies through a pre-application consultation process before finalizing mitigation plans/design.

5.0 REFERENCES

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6.0 CONTACTS AND OTHER INFORMATION SOURCES

Code of Federal Regulations - http://law.house.gov/4.htm

Natural Resources Conservation Service (http://www.nrcs.usda.gov/) – information available through Web page or state and district offices.

Society of Wetland Scientists - http://www.sws.org/

U.S. Army COE of Engineers (http://www.usace.army.mil/) Note that Sacramento District (http://www.spk.usace.army.mil/cespk-co/regulatory/) has information specifically related to jurisdictional wetland delineations and 404 permitting:

U.S. Environmental Protection Agency, Office of Water (http://www.epa.gov/owow/wetlands/) provides information on wetlands as well as a wetland Hotline Number: 1-800-832-7828, email to wetlands-hotline@epamail.epa.gov

U.S. Fish and Wildlife Service (http://www.fws.gov/) – provide National Wetland Inventory maps; may be a source for information regarding potential mitigation opportunities.

USFWS NWI maps are available as paper copies, mylar overlays, and occasionally as digital layers. The USFWS NWI homepage (http://www.nwi.fws.gov) contains information on NWI products, available maps, and ordering information.

USFWS endangered species home page-http://www.fws.gov/~r9endspp

U.S. Geological Survey's EROS data center (http://edcwww.cr.usgs.gov/eros-home.html) serves as a clearinghouse for aerial photography compiled by federal agencies and allows on-line searches by location.

APPENDIX J

EPA RESPONSES TO COMMENTS ON THE DRAFT SOURCE BOOK

Commentors on the Draft Source Book		
Number	***Name***	***Affiliation***
1	Kenwyn George	Alaska Department of Environment and Conservation
2	Steven Borrell	Alaska Miners Association
3	Luke Russell	Coeur d'Alene Mines Corporation
4	Clyde Gillespie	Fairbanks Gold Mining (Kinross Gold Corp.)
5	Rens Verburg	Golder Associates
6	Keith Brady	Pennsylvania Bureau of Mining and Reclamation
7	Pierre Mousset-Jones	University of Nevada - Reno, Mackay School of Mines
8	Lisa Kirk	Northwest Mining Association
9	David Chambers	Center for Science in Public Policy

Comments on 1999 Draft Source Book and EPA Responses

No.	Commenter	Section	Comment	Response
1	ADEC, Juneau	General	When opening the documents using Adobe Acrobat Reader 3.0 you get the message "Could not find the ColorSpace named Cs9", followed by the message "This file contains information not understood by the viewer. Suppress further errors?"	No response necessary.
2	ADEC, Juneau	General	I do not see anything on bonding for reclamation costs. Maybe add an Appendix just for Reclamation and Bonding? Bonding is required by state & federal permits (e.g. the USFS). The issues are many, from immediate maintenance and continuing operation of units to executing the exclamation plan (with the hope that the plan is sufficiently detailed that one could bid work from it). We are currently looking at bonding/reclamation of the Greens Creek mine in conjunction with the USFS and other agencies and the City & Borough of Juneau. Pete McGee of the Fairbanks office has recent experience with bonding problems at the Illinois Creek mine (and we will be using his knowledge and experience from this mine for the Greens Creek requirements). [Would you like this information/contacts?]	EPA has added a brief discussion of bonding in the main text, but has not added an entire appendix or section.
3	ADEC, Juneau	2.0	Page 7- How about having a second page similar to page 7, Figure 1, that incorporates State Certification? Also, perhaps on Figure 1, in the lower right box, Consider other applicable regulations, include State Regulations and Water Quality Standards?	EPA made no changes. This document focuses on EPA actions and permits, not state ones.
4	ADEC, Juneau	5.1.2	There are two page 32's (Table 6), and no page 33. In adobe this equates to two Table 6's on electronic pages 35 and 36.	Change made as suggested.
5	ADEC, Juneau	B-2.2	Page B-6 Item 2.2- how about listing the state web pages where state WQS are listed.	EPA added a reference to state web pages that include state water quality standards. Since URLs can change relatively frequently, EPA did not include the URLs.
6	ADEC, Juneau	B-3.2.2	Page B-18; Table B-2 is split onto two pages - it would be good to keep it all on one page.	EPA has modified the formatting to ensure that, at a minimum, the table's second half will include a title/header.
7	ADEC, Juneau	B-4.3	Pg B-21; 4.3 Is equal the sum [either equals, or is equal to]	Correction made as suggested.
8	ADEC, Juneau	C-4.4.1.3	Item 4.4.1.3 wastes using a a batch leach [duplicate a's]	Correction made as suggested.
9	ADEC, Juneau	C-4.4.5	4.4.5 batch test tended...(but not always)	How about "batch tests frequently, but not always, tended..."Correction made as suggested.
10	ADEC, Juneau	E.4.1	4.1 Surface water Hydrology provides [there is a hard return after water]	Correction made as suggested.

Comments on 1999 Draft Source Book and EPA Responses

No.	Commenter	Section	Comment	Response
11	ADEC, Juneau	D-2.2.3	Pg D-9 - put Figure D-1 on the same page & just under the reference to the table.	Correction made as suggested.
12	ADEC, Juneau	D-2.2.3	Pg D-10 Figure D-1 - include intermittent and permanent surface discharges from the lake?	Correction made as suggested.
13	ADEC, Juneau	D-3.0	Pg D-11 3.0 (e.g. heap leach piles, [tailings piles?]	This change was not made, since tailings are addressed in section 4 of Appendix D.
14	ADEC, Juneau	D-3.0	Second paragraph - add to second sentence "and the design of the engineered, or reclamation cap"?	This concept has been included in a separate sentence.
15	ADEC, Juneau	D-3.1	Pg D-12 3.1 Similarly, actions taken at closure...[include "design of the final cover".]	Correction made as suggested.
16	ADEC, Juneau	D-3.1	Pg D-14 Figure D-2 needs to be larger - you cannot read the text at its current size.	Correction made as suggested.
17	ADEC, Juneau	D-3.1.1	Pg D-16 - last sentence of 3.1.1 - readers should refer to this document [which? this source book?, Appendix A?, a specific EPA publication?]	Two documents are cited at the beginning of the sentence. The sentence has been changed to read "...these documents," which should remove any ambiguity.
18	ADEC, Juneau	D-3.2.1	Pg D-16 3.2. and run-off (for run-off). ?? [Was this meant to be for run-on]?	The parenthetical "(for run-off)" will be deleted to for clarification
19	ADEC, Juneau	D-4.1	Pg D-20 4.1 run-on/runoff [Use run-off for consistency?]	The hyphenated version has now been used throughout the Source Book.
20	ADEC, Juneau	D-4.2.2	Pg D-25 Put Figure D-3 just after the reference to it?	Correction made as suggested.
21	ADEC, Juneau	D-6.0	Pg D-24 6.0 (e.g. the Multi-Sector General Storm Water Permit, [Sector G - add this?]	Correction made as suggested.
22	ADEC, Juneau	E-2.0	Pg E-2 In Table E-1, Storm Water Description, "contracts" should be "contacts"	Correction made as suggested.
23	ADEC, Juneau	E-3.0	Pg E-3 Item 3.0, last para - a range of different of options [remove second "of"]	Correction made as suggested.
25	ADEC, Juneau	E-5.1.1.2	Pg E-6 Item 5.1.1.2 Some sulfide precipitation occur [should be "occurs"]	Correction made as suggested.
26	ADEC, Juneau	E-5.1.1.2	Pg E-7 Put Figure E-1 with the text reference, i.e. on the previous page, with the last part of 5.1.1.2 on pg E-7 instead of E-6.	Correction made as suggested.

Comments on 1999 Draft Source Book and EPA Responses

No.	Commenter	Section	Comment	Response
27	ADEC, Juneau	E-5.1.1.3	Pg E-8 Item 5.1.l.3 ...precipitation efficiency beyond the use... [How about "greater" rather than "beyond"?]	EPA modified the wording to clarify the sentence.
28	ADEC, Juneau	E-5.1.1.3	.......to describe a different type water treatment [type of...]	Correction made as suggested.
29	ADEC, Juneau	E-5.2	5.2 reactivesurface [should no doubt be reactive surface]	Correction made as suggested.
30	ADEC, Juneau	E-5.2	ions from the waste water.. [Extra period]	Correction made as suggested.
31	ADEC, Juneau	E-5.2	treated or disposed. [disposed of?]	EPA believes the meaning is clear, and so did not make any changes.
32	ADEC, Juneau	E-5.2	is used by , electroplatersdischarging [remove space, split the two words]	Correction made as suggested.
33	ADEC, Juneau	E-5.1.3	Pg E-9 5.1.3 semipermeable [hyphenate]	Correction made as suggested.
34	ADEC, Juneau	E-5.1.3	........the volume of brine stream [either "of the" or delete "stream"]	Correction made as suggested.
35	ADEC, Juneau	E-5.2	Pg E-11 5.2 uses a number of treatment processes destroy” ... [to destroy]	Correction made as suggested.
36	ADEC, Juneau	E-5.2.1	5.2.1 Change "...remove all forms of cyanide excluding" to "...cyanide, excluding"	Correction made as suggested.
37	ADEC, Juneau	E-5.2.1	Under ideal conditions, [delete comma]	The existing punctuation is consistent with the remainder of the document, so no change was made.
38	ADEC, Juneau	E-5.2.1	WAD cyanide, using a chemical, chlorine, that is.......[How about WAD cyanide, using chlorine, which is.…	The sentence was revised to make it simpler.
39	ADEC, Juneau	E-5.2.1	and cyanide complexes [How about "and the problem that iron cyanide complexes....."]	Correction made as suggested.
40	ADEC, Juneau	E-5.2.4	5.2.4 Disadvantages include limited application and [application, and.....]	Correction made as suggested.
41	ADEC, Juneau	E-5.2.4	may need to be reduced , due [delete extra space]	Correction made as suggested.
42	ADEC, Juneau	E-5.2.4	to toxic effect [effects]	Correction made as suggested.
43	ADEC, Juneau	E-5.2.5	5.2.5 bacteria present [why not just "bacteria"?]	Correction made as suggested.
44	ADEC, Juneau	E-5.3	Pg E-14 5.3 electrical repulsive [electrically repulsive]	Correction made as suggested.

Comments on 1999 Draft Source Book and EPA Responses				
No.	**Commenter**	**Section**	**Comment**	**Response**
45	ADEC, Juneau	E-5.3	(e.g. anthracite coal or garnet sand) [Wouldn't this be and, rather than or?]	Correction made as suggested.
46	ADEC, Juneau	E-6.0	Pg E-16 6.0 sulfide precipitation), , [extra comma]	Correction made as suggested.
47	ADEC, Juneau	E-6.2	Pg E-17 6.2 At present, it unclear [it is....]	Correction made as suggested.
48	ADEC, Juneau	E-7.1	Pg E-20 7.1 extraction processes. . [extra period]	Correction made as suggested.
49	ADEC, Juneau	E-8.0	Pg E-21 8.0 disposal of wastewaters [Needs a period]	Correction made as suggested.
50	ADEC, Juneau	E-8.2	"surface water). Wastewater and ground water monitoring plan..." [How about] surface water), and "A wastewater and ground water monitoring plan...."	The bullets were corrected to be consistent with other bullet formats.
51	ADEC, Juneau	E-8.3	Pg E-23 8.3 demonstrate the ability maintain [to maintain]	Correction made as suggested.
52	ADEC, Juneau	E-9.0	9.0 STORM WATER MANAGEMETN [MANAGEMENT]	Correction made as suggested.
53	ADEC, Juneau	E-9.0	Pg E-24 Section 2 of Source Book [the Source Book]	Correction made as suggested.
54	ADEC, Juneau	E-9.0	...process water NPDES permits, may [delete comma]	Correction made as suggested.
55	ADEC, Juneau	E-9.0	...require preparation of BMP [require the....?]	The sentence actually reads "...require preparation of BMP plans", so no change will be made.
56	AK Miners, NWMA	Main text	Clarification of Intent - The Source Book is not meant to be a prescriptive regulation or policy document but rather general information listing of the types of data that will or may be necessary to meet the permitting requirements of the Clean Water Act (CWA) and the National Environmental Policy Act (NEPA). Several persons have raised the concern that although a document like this is not meant to be prescriptive, over time it may be used that way. The intent of the Source Book, that it is not prescriptive, regulatory or a policy document should be stated at specific locations within the individual sections which we will mention later. This intent also needs to be stated prominently and highlighted in the front of the document, possibly on the inside front cover and the introduction.	The purpose of the Source Book has been clarified on the title/disclaimer page and in section 1.1.

Comments on 1999 Draft Source Book and EPA Responses

No.	Commenter	Section	Comment	Response
57	AK Miners, NWMA	General	Existing Studies Completed - There is need for the mining industry to know what work has already been done for other projects, how it was done, the parameters, the methodology, the QA/QC of both sampling and lab work, etc. In other words, what have other projects done and how have they approached the issues. The very best, most comprehensive source of this information is the EPA's own library of files from past projects. These are examples of what has worked, what has been determined to be acceptable, etc. A listing of these studies would be a valuable tool in assisting other companies in knowing how to approach their specific project. The industry has spent multiplied millions of dollars developing these reports and they would be of tremendous benefit to future permitting by other companies. That an appendix be created listing the major mines and mining projects, by state, and for each provide a bibliography of the studies that were completed for that mine/project. The bibliography should list all baseline and other studies of all types developed for NEPA compliance and for final permitting for - air, surface water, groundwater, climatological, wetlands, fish, wildlife, endangered species, etc. The bibliography should list the study name, author(s), date completed, etc. For Alaska this appendix would include, at a minimum: Greens Creek, Red Dog, Red Dog Expansion, Fort Knox, Illinois Creek, Nixon Fork, Alaska-Juneau, and Kensington.	Although such a compilation of cases studies and project bibliographies could be valuable, this is beyond the scope of this Source Book. EPA would encourage the independent compilation of such case studies and bibliographies.
58	Alaska Miners Association	General	The Source Book should also contain descriptions of the various research programs, where the information has been obtained, who has generated that information, etc. It would also be beneficial to know how to contact the authors and what past work they have performed. These research programs should be developed into a cross-referenced stand-alone section organized by topic.	This would be useful, but is beyond the scope of the Source Book. EPA encourages independent preparation of such an "encyclopedia" of mining research.
59	Alaska Miners Association	General	Mining Specific References - Most of the texts, reference documents, etc. utilized by the mining industry are not mentioned. For example, the Mining Environmental Handbook is mentioned in the first chapter but it is not cited again after that. Many of the references cited are from meetings and workshops of limited exposure to the general public, and most particularly the mining industry. That a bibliography of mining specific texts, technical articles, references, etc. be added and that these items be referenced in the Source Book along with the existing references.	A comprehensive bibliography of references used by the industry is beyond the scope of the Source Book.
60	Alaska Miners Association	General	State by State Summary. A discussion and/or table should be included showing which regulatory programs have been delegated to each of the states in Region 10 and any differences, peculiarities, or special situations that exist for each of the states.	EPA has added a section to the main text.

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61	Alaska Miners Association	Title Page	Title Page - should include a list of the States to which the source book applies. It should also clarify that "hardrock" mines do not include placer/alluvial mines or sand and gravel operations.	The introduction has been revised to move this information closer to the beginning of the document.
62	Alaska Miners Association	1.1	Section 1.1, page 1, second paragraph notes that each mining operation is unique, that it is impracticable to develop guidance applicable to all sites, and that the guidance in the source book is not mandatory guidance. We support that concept, but are concerned that the source book will become mandatory either through adoption as EPA Region 10 policy or Regulation. Accordingly, we recommend the stated purpose of the source book be placed on the flyleaf as a Note to readers to clearly emphasize the information is only suggested guidance since each mine is unique. The Note should also indicate that new technologies and/or permit requirements could cause a significant revision to the data and methodologies described	EPA has no intention of adopting the Source Book as a formal policy or regulation. The purpose of the Source Book has been clarified in the introductory section.
63	Alaska Miners Association	1.2	Section 1.2, page 2, first paragraph notes that EPA Region 10 has difficulty in providing timely and consistent permitting advice to the mining industry and interested publics. A short discussion of why this difficulty exists and the extent that other EPA Regions also have this issue would be helpful in understanding the Problem Statement and the extent the source book resolves the issue of timely and consistent advice from EPA Region 10.	EPA has clarified the meaning of its statement. The basic premise is that EPA's role in the environmental review and permitting of new mines is not well understood by industry and the public in general. The Source Book is intended to clarify EPA's role and EPA's general information needs for timely processing of environmental reviews and permits.
64	Alaska Miners Association	1.2	Section 1.2, page 2, second paragraph generally describes the ecosystems in Region 10. We suggest that it would be more descriptive to add "Arctic Ocean" after "high plateau".	The sentence has been modified to show a greater range of ecosystems.

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65	Alaska Miners Association	1.3	Section 1.3, page 3 provides a list of things that Applicants can do to minimize delays in the NEPA and CWA decision process by EPA. This is good, but we recommend that a second list of things EPA Region 10 can do to provide timely and consistent advice be added. For example, the National Research Council in its 1999 report "Hardrock Mining on Federal Lands" notes in RECOMMENDATION 10 that from the earliest stages of the NEPA process all agencies must cooperate effectively in the scoping, preparation and review of environmental impact assessments for new mines. The NRC further noted that it is imperative that key staff for the relevant agencies actively participate. On page 112 the NRC expressly notes "The EPA was frequently singled out a an agency that often creates such problems because of its unwillingness to participate early in the NEPA process." Accordingly, EPA Region 10 should indicate in the source book their commitment to be more effective and proactive in providing timely and consistent guidance. Another area that EPA should comment on is a prompt review and timely report to the mining company that required monitoring data has been received, reviewed and the mining operation is consistent with EPA permit requirements, or if not, corrective action that is required to bring the project into compliance.	EPA is continually trying to improve the way in which it fulfills its responsibilities under the Clean Water Act, NEPA, and other statutes under which it has responsibilities. The development of the Source Book is in part a response to criticism that EPA does not engage in the NEPA process early on. The Source Book could in fact be viewed as a detailed yet generic scoping document intended to provide pre-proposal guidance to any mining company considering the development of a new mining operation in the Northwest or Alaska. Comments regarding early feedback on compliance monitoring have been referred to our enforcement and compliance assistance staffs.
66	Alaska Miners Association	2, 3, 4, 5	Sections 2, 3, 4 and 5 provide a general overview of the EPA role in mine permitting. We recommend these discussions be more focused on mining operations in the EPA Region 10. In general, EPA's role in mine permitting and approval is not different in Region 10 than elsewhere in the nation.	Region 10 is necessarily more involved in mine permitting than are other Regions by virtue of the fact that two Region 10 states (AK and ID) are not yet authorized to implement the NPDES program and so the program is implemented by EPA.
67	Alaska Miners Association	General	The source book gives short attention to mines in the coastal zone. We recommend that the EPA role for mine permitting in the coastal zone be expanded so the Applicant knows the extent of EPA involvement and any additional data requirements.	Text has been added to clarify additional procedures and information that may be required to comply with the Coastal Zone Management Act, which is implemented primarily by states.
68	Alaska Miners Association	General	The source book should have a thorough discussion about EPA permitting requirements for mining projects involving marine, estuary and intertidal waters. This should include discussions about marine discharges considered for the A-J Mine and Kensington Mine and Quartz Hill, all in Alaska.	As a general rule, tailings may not be discharged into waters of the U.S., including marine waters. The exceptional circumstances that led to consideration of submarine tailings disposal in marine waters for the A-J and Quartz Hill projects are so limited that a detailed discussion is not warranted.
69	Alaska Miners Association	2.0	Section 2.0, Figure 1 would be improved by adding the time it takes to get through each step for a simple and a complex mining operation.	The time required to go through each step is so variable that it would be misleading to add time to the figure, even ranges. A note has been added to the text indicating that the time required to complete each step is greatly influence by the timeliness and completeness of information provided by the applicant.

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70	Alaska Miners Association	2.0	Section 2.0, page 8 notes that EPA is not obligated to permit an application to mine. This is an issue that should be firmly resolved during the first meeting between EPA and the potential Applicant discuss a proposed project. If EPA believes the proposed project is not permittable by Region 10, the Applicant should be immediately notified in writing that no permit will be issued and why. This avoids unnecessary expense and frustration by the Applicant and should be listed as things EPA Region 10 will do. (see comment 65).	In general, EPA cannot state with authority that a permit cannot be issued so early in the process. EPA often tells applicants when a particular approach might be extremely difficult, and advises of the steps that would be required. This in turn often leads applicants to make their projects more "permittable." However, it is entirely up to the applicant to decide how to design its project and then up to EPA to determine whether the project can be issued a permit.
71	Alaska Miners Association	2.2	Section 2.2, page 10 notes that the EGL guidelines do not apply to placer gold mines. This needs to be discussed in Sections 1.1 and 1.2. (also see comment 61)	The introduction has been clarified to state that the Source Book does not address placer mines.
72	AK Miners, FGMI	2.2	On page 13 the discussion regarding the use of Best Professional Judgement (BPJ) to develop technology-based limits is of concern. When technology-based limits cannot be defined, discharges should only be required to meet the applicable water quality standards for the receiving stream.	A sentence has been added to make the commenter's point. The existing discussion is not otherwise changed.
73	AK Miners, FGMI	2.3	On page 16 the explanation of Anti-degradation is not appropriate and we recommend that the text be replaced with the following: Anti-degradation: Each State must adopt an anti-degradation policy. In states that have approved NPDES permit programs the states will incorporate compliance with their anti-degradation policy as a part of the permitting process. For states without an approved NPDES program where EPA will be issuing the permit, EPA will require that the affected state to determine compliance with the state's anti-degradation policy and provide EPA with certification of compliance. Applicants should consult with the affected state agency and be prepared to demonstrate that the proposed project will comply with the state's anti-degradation policy as a part of the permitting process.	EPA does not agree that the discussion of anti-degradation is “not appropriate” and has left it unchanged. However, we have added the commenter’s language concerning the process that applicants should follow to ensure compliance with anti-degradation requirements.
74	AK Miners, FGMI	3.0	Pages 22 and 23 contain discussions regarding EPA's authority to veto permits issued by the Corps of Engineers. Since EPA's veto authority is based on a resource value determination, it appears this determination must be made early in the permitting process - this would be very beneficial to the mine seeking the permit and could save delays along with significant financial commitments (see comment 65).	EPA agrees that an early determination is desirable but notes that sufficient information to make a determination may not be available until later than desirable. That makes it incumbent on applicants to provide the right information as early in the process as possible.

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75	AK Miners, FGMI	4.3	On page 29 a bullet should be added to the second list of bullets to read: Impacts may be both beneficial and adverse. A significant effect may exist even if the Federal agency believes that on the balance the effect will be beneficial. This point, found in 40 CFR 1508.27(b), appears to have been overlooked.	The commenter's point has been noted in the text.
76	Alaska Miners Association	6.1.1	Section 6.1.1 page 43 indicated an Applicant should have a baseline hydrological study extending beyond the boundary of the proposed operation. We do not disagree with the concept, but recommend that EPA Region 10 give some examples of how to determine how far the boundary should be extended.	The precise boundaries cannot be defined except on a site-specific basis. The text has been modified to indicate that the boundary may need to encompass the entire watershed.
77	Alaska Miners Association	6.2	Section 6.2, page 45 discusses water quality on a watershed basis. As noted in comment 77, Region 10 should include several examples of what has been required of mining operations in Alaska and the other Region 10 States so the Applicant and the public have a common starting point.	Section 6.2 is a summary of information needs regarding potential impacts to water quality. Appendices A and B provide detailed guidance for characterizing hydrology and receiving water quality at the appropriate watershed scale.
78	Alaska Miners Association	6.3	Section 6.3, page 51, last paragraph discusses aquatic resources studies. This, like most of the topics are issues that are finalized in the NEPA scoping process. Accordingly, we recommend the first sentence be modified by changing "predict changes that might occur..." to "predict relevant changes that might occur..."	Correction made as suggested.
79	Alaska Miners Association	B-2.4.1.1	Appendix B, pages B-13 and B-14 discuss the Red Dog Mine. This is the sort of description of permitting actions that are suggested for greater use in the final document (see comment 67). The discussion of the Red Dog Mine should also be expanded to include a summary of the EPA decisions in the NEPA process for base line information and how that baseline information has been used in the ongoing water quality classifications for waters downstream from the mine, including the fact that fish have migrated into the project area where naturally there were none, or limited fish due to natural high metals loading of the streams.	The specific decisions are not as important as the point made in the existing discussion: applicants should document even subtle effects of mineralization so they can be considered in decision making.
80	Alaska Miners Association	B-4.4.2	Appendix B, page B-22 discusses QAPP being a potentially fatal flaw in using existing and historical data sets. In Alaska there are relatively few existing or historical data sets that meet QAPP standards. Accordingly, we recommend EPA construct a conceptual Figure, similar to Figure 1 on page 7, showing the steps and timing for an Applicant to obtain a data set that EPA Region 10 would reasonably accept for a mining operation in Alaska and for the other States in the Region.	EPA agrees with the commenter about existing and historical data sets. EPA QA/G-5 Guidance on Quality Assurance Project Plans (EPA/600/R-98/018, February 1998) provides guidance on developing Quality Assurance Project Plans (QAPPs) that will meet EPA expectations and requirements, and this guidance is now cited. This document provides a linkage between the Data Quality Objective (DQO) process and the QAPP. It contains tips, advice, and case studies to help users develop improved QAPPs.

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81	Alaska Miners Association	I-2.1	Appendix I, page I-3 discusses "riparian" plant communities within the context of being jurisdictional wetlands. We agree that most riparian plant communities are likely to be considered jurisdictional wetlands in Alaska because of permafrost induced soil saturated conditions or heavy precipitation along coastal rainforest. But since the source book also is intended to also cover semiarid high plateau, either include all NWI plant communities or delete the inference that "riparian plant communities are automatically jurisdictional	The discussion cited by the commenter does not state and is not intended to imply that "riparian plant communities are automatically jurisdictional wetlands."
82	AK Miners, FGMI	5.1.2	On page 31, Table 6 includes several facilities that are not considered point sources and included in Title V permits. Typically only emission units are included in Title V permits. Fugitive emissions from overburden piles, waste rock piles, tailing, and spent ore need only be evaluated to determine the HAP portion of the emissions when making a major source determination. Land applications, ore handling piles, heap and dump leaches, process ponds, mine pit, underground workings, blasting, construction, reclamation/post reclamation, and abandoned mines need only be included in the evaluation to determine if a source is a major source by Title V definition.	EPA has added a note in Table 6 to make the commenter's point that some of these fugitive sources are generally only evaluated when making a major source determination.
83	AK Miners, FGMI	5.1.2	Table 6 includes vehicle emissions that should not be included in a Title V permit. Table 6 should be revised to include emission units typically included in an air quality operating permit or the table should be removed from the source book..	The table does not purport to show emissions regulated in a Title V permit. Rather, it shows various potential emission sources and their regulatory status.
84	AK Miners, FGMI	6.0	Section 6.0 discusses EPA's requirements for the NEPA process. This section fails to discuss the scoping process that is required as part of NEPA. The scoping process is crucial to the process and defines the significant issues to be addressed in the NEPA document and should also determine the area to be studied. This needs to be spelled out along with the importance that all agencies (including EPA) and groups define their issues and concerns during scoping.	Scoping is generally an agency responsibility, often assisted by the applicant. The discussion of public participation in section 4.3 ("EPA Requirements for Environmental Review Under NEPA and the CWA") has been revised slightly to clarify the purpose of scoping.
85	AK Miners, FGMI	6.1	The first paragraph of section 6.1 includes a discussion of the need for long term meteorological and hydrological data collection to be used for facility design, water balances, and impacts analysis. Since most designs of storm water diversion channels, development of water balances, and impacts analysis require use of the 25 year or 100 year storm events, sentences four, five, and six of this paragraph should be deleted.	EPA believes that the fact cited by the commenter ("most designs ... require use of the 25 year or 50 year storm events,..." makes it even more important to establish a long-term meteorological and hydrological record. Thus, EPA did not delete the sentences.
86	AK Miners, FGMI	6.1.1	The third paragraph in section 6.1.1 discusses the extent of the hydrologic study. The extent of the hydrologic study should be defined during the scoping process.	EPA agrees in part, but notes that applicants would be prudent to consider conducting comprehensive hydrologic studies to avoid the need for additional information.

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87	AK Miners, FGMI	6.1.1	The list of data needs included in Table 7 should be refined during the scoping process. Not all of the data listed will be necessary to determine the impacts from every proposed mining project.	EPA agrees in part, and notes that this table is a generally comprehensive list of data needs. When scoping or other factors identify concerns about impacts to any specific resource area, then most or all of the data listed for that resource area should be provided.
88	AK Miners, FGMI	6.1.1	On page 40 Table 8 proctor moisture/density testing is listed for rock, soils, and sediment. However, this testing is for design and construction of facilities and it has little applicability to an impact analysis and should be removed from Table 8.	EPA agrees with the purpose of the testing, but disagrees as to the need for this information in an EID. It is common for on-site materials (rocks, soils, and sediment) to be used in construction, and EPA needs proctor moisture/density testing results to evaluate their suitability.
89	AK Miners, FGMI	6.1.1	On page 42 Table 10 references the need to predict the stability of piles, impoundments, and backfill. Backfill stability should not be an issue and should be removed from Table 10.	EPA disagrees that backfill stability should not be an issue.
90	AK Miners, FGMI	6.2.3	Section 6.2.3 on page 46 should be changed to clarify that the design described would apply only if the facility is expected to generate acid or mobilize metals. The discussion seems generic as if it should apply to all facilities.	EPA agrees, and has clarified the discussion.
91	AK Miners, FGMI	6.2.4	Section 6.2.4 on page 48 needs to include the option of blending in neutralizing material with acid generating material to neutralize the acid as it is formed. This is common practice throughout the world.	This option has been added.
92	AK Miners, FGMI	6.2.7	Section 6.2.7 regarding heap leach pads and capping is not science based but rather is quite subjective. The discussion should be changed to specify that leach pad effluent water quality at closure must be addressed and included in the NEPA analysis.	EPA notes that the discussion is very general, but disagrees that the discussion is subjective. EPA agrees with the commenter's last point (leach pad effluent water quality) and has added this concept to the paragraph.
93	AK Miners, FGMI	6.4	Section 6.4 discusses the impact analysis for wetlands but does not address the potential for mitigation. The discussion should include the potential to offset lost acres of wetlands with developed wetlands and to offset lost wetlands by upgrading/improving other wetlands.	EPA has added a discussion that makes the commenter's points.
94	Coeur d'Alene Mines Corporation	General	We believe that EPA can play an important role in improving the permitting process, and see the Source Book as an initial step in that direction.	EPA appreciates the recognition of its intent.

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95	Coeur d'Alene Mines Corporation	Introduction	Coeur supports EPA's efforts to develop "guidance" on how the mine permitting process can be expedited and coordinated between EPA and other agencies. We agree that EPA requirements and expectations are all too frequently not presented early enough in the permitting process, and that this lack of communication has led to increased costs and delays. This has created confusion and controversy and we appreciate EPA's efforts in the development of this draft guidance document. However, it is not clear what this guidance means or how it will be used to streamline the permitting and NEPA review process. The footnote on page 1 states that the document does not provide Agency policy or guidance for meeting any regulatory requirements. How then does EPA see this document being utilized?	EPA has revised the Introduction to clarify the purpose and intent of the Source Book
96	Coeur d'Alene Mines Corporation	General	The draft report provides good general background on recommended permitting data needs, but it fails to provide specifics on how EPA will promote predictability and consistency within Region X. It also fails to clarify how EPA Region X intends for operators to proceed with permit development using the various methods of technical evaluation presented, which at times is inconsistent and subjective.	EPA acknowledges that the Source Book is relatively general at times and may even seem inconsistent due to the need to cover very diverse contingencies, but believes that the site-specific nature of mining impacts makes detailed guidance inappropriate. In general, applicants have the responsibility of satisfying EPA's (and the state's) information requirements, and this Source Book is intended to provide a rough road map to EPA's requirements.
97	Coeur d'Alene Mines Corporation	General	The document attempts to define where problems have been encountered in previous permitting efforts. The document would be more useful if the agency identified common problems and pitfalls more clearly, perhaps as short case studies, and made recommendations on how operators should proceed in these areas.	The text has been modified in section 1.2 Common pitfalls and problems include water balances that do not properly bracket high and low flow scenarios, underestimating water treatment needs, using detection limits that are too high, using inappropriate modeling approaches and assumptions, overall data quality problems (e.g., non-representative samples) and failure to consider temporary shut-downs and post-closure scenarios.
98	Coeur d'Alene Mines Corporation	General	An element lacking in this draft report is how EPA in the implementation of its authorities, will recognize and defer to other agencies, especially state authorities. For example, Coeur and EPA have successfully developed Memorandums of Understanding between EPA and other regulatory authorities to improve communication, coordination, and streamlining of the permitting process (e.g. Kensington). This process could be used to clarify EPA and state requirements and expectations early in the process. While this draft is silent on this type of approach we encourage EPA to use this type of a collaborative permitting process more often.	To the extent possible, EPA works collaboratively with applicable federal, state, and local agencies. That point has been added to the discussion of NEPA in section 4.0.
99	Coeur d'Alene, NWMA	2.1	The document refers to the broad definition of point source, but fails to include that a point source must be a "discharge of pollutants" as found in the Clean Water Act. This section also suggests that non-point sources could require an NPDES permit which is not the case.	EPA has clarified what a point source is. The section is not intended to imply that nonpoint sources may require an NPDES permit.

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100	Coeur d'Alene, NWMA	2.2	The document points out that the Effluent Limitation Guidelines (ELG) established technology based limits and that neither the ELGs nor other regulations require the use of any particular treatment technology. We agree, yet we question why then is EPA apparently pressuring mines within the region to install specific treatment technologies (e.g. sulfide precipitation).	EPA does not intend to "pressure" mines to select any particular technology, and does not believe that the Source Book does so. However, sulfide precipitation is a type of conventional treatment that has the capability of achieving a very high degree of metals removal from mine waste waters.
101	Coeur d'Alene, NWMA	2.3	Mixing zones are of critical importance to any discharge under the NPDES point source program. The document in this section states that discharge must show "where appropriate", dilution of the effluent in the receiving water (mixing zones) would meet the limitation. Given that the use of mixing zones are a state lead effort (CWA Section 101(b) the document fails to clarify how EPA will work with the states early in the permitting process to clearly establish how and where mixing zones can be utilized to meet water quality standards.	EPA consults with states early on in the NEPA process. Generally NEPA documents will display effluent criteria based on various dilution scenarios.
102	Coeur d'Alene, NWMA	2.3	The trend in effluent limitation establishment seems to be designed to set limits that cannot be routinely measured, are beyond reasonable treatment capabilities, or use overly conservative factors of safety. This results in deadlocked permitting. It would be very helpful if the document could provide clarification on how site-specific standards can be efficiently reviewed and processed.	EPA disagrees that there is any such "trend." It is beyond the scope of the Source Book to define the review and processing of site-specific standards.
103	Coeur d'Alene, NWMA	2.3	There are many ways in which a discharge may be regulated under the NPDES program. There are now over 8 different methods and measures of compliance including: effluent water quality tests, whole effluent toxicity tests (WET), receiving water quality tests, background comparisons, anti-degradation mon-degradation, bioassay tests, sediments and narrative tests. The present "policy" between states, permit writers or enforcement officers is not consistent. It would be helpful if EPA could clarify how discharge permits will be enforced and how applicants can better ensure compliance.	This type of discussion is beyond the scope of this Source Book.
104	Coeur d'Alene, NWMA	2.3	The document suggests that the TMDL program is for point sources, nonpoint sources, and natural background sources. The TMDL program is to regulate points sources that exceed 25% of the load into a particular stream. The document should clarify how the CWA categorizes streams under Section 303 (d)(l) and (d)(3);(d)(1) TMDL's are for waters impaired by point sources operating under effluent limitation guidelines developed under Section 301(b)(1)(A) & (B) of the CWA,(d)(3) TMDL's are for informational purposes only and do not require EPA oversight or approval. Waters impaired by nonpoint sources are required to be listed and addressed under CWA Section 19.	EPA has revised the paragraph on TMDLs to describe the intent and implementation of 303(d) more clearly. EPA does note that one goal of the TMDL process is to identify all sources of pollutant loadings, including nonpoint and background sources. However, this comment refers to a provision in Idaho state law (i.e., a TMDL is only required when the point source exceeds 25% of the load into a particular water body). It should be noted that this provision of Idaho law conflicts with CWA requirements under section 303 which does not limit TMDL's to only point sources.

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105	Coeur d'Alene, NWMA	4.1	Section 4.1 overviews various NEPA steps but fails to clarify how EPA can and is willing to expedite the process and how it will interact with other regulatory agencies.	EPA has added a brief discussion of the interactions with other agencies. The Source Book is part of EPA's attempts to expedite the process by clearly explaining process and information requirements to prospective permit applicants as well as other regulatory agencies.
106	Coeur d'Alene, NWMA	5.2	The document should clarify how and when EPA will coordinate with the National Marine Fishery Service and how their role in the permitting process can be streamlined.	Figures 3A and 3B illustrate how and when EPA coordinates with NMFS. To the extent possible, EPA streamlines other agencies' participation in the permitting process, but cannot control those agencies' processes and procedures.
107	Coeur d'Alene Mines Corporation	E-5.2	EPA discusses several potential cyanide destruction techniques. However, cyanide recovery has also been successfully used in Region X (DeLamar) and we strongly encourage EPA to add this approach to the document.	EPA has added a paragraph on cyanide recovery.
108	Coeur d'Alene Mines Corporation	E-5.2	There is a patented process called Cyanisorb that employs high efficiency packed towers to strip cyanide from either slurries or clear solutions at a near-neutral pH. Cyanisorb recovers both free cyanide and weak-acid complexes and returns the recovered cyanide back into the leaching cycle. This reduces consumption, transportation requirements, and cyanide concentrations remaining in the tailings impoundment. EPA should consider including a discussion of this technology.	A discussion of cyanide recovery technologies has been added to section E.5.
109	Fairbanks Gold Mining	2.2	The flow sheet on page 14 appears to have the "Yes" and "No" arrows switched for the step entitled; are pollutants discharged at levels well below benchmark threshold values? If the pollutants in runoff are below benchmark levels the water should be considered storm water and be covered by the multi-sector, general storm water permit.	The commenter is correct, and EPA has corrected this figure.
110	Fairbanks Gold Mining	3.0	Near the bottom of Page 22, EPA suggests evaluating alternatives and proposing mitigation on lands not owned or controlled by the proponent. This suggestion has many underlying considerations that may or may not be resolved to allow the acquisition of additional property. For most mine permitting processes the land acquisition involves mining claims that complicate the acquisition process, especially acquiring additional claims near a site that is active or actively acquiring permits. In most instances land acquisition is not an easy process and can be very time consuming. [The commenter] suggests the two sentences discussing alternatives and mitigation on land owned by others be removed from the document.	The sentences were not removed as suggested, but additional clarifying language has been added. The CWA 404(B)(1) guidelines (see 40 CFR 230) limit issuance of CWA 404 permits for non-water dependent projects (e.g., a mine) to the "least environmentally damaging practicable alternative". The term "practicable" is defined [40CFR230.3(q)] as "available and capable of being done after taking into consideration cost, existing technology and logistics in light of overall project purposes." It is therefore appropriate to include in the discussion property that is not owned by the applicant.

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111	Fairbanks Gold Mining	4.3	The last sentence in the second bullet (first set of bullets) on Page 28 would more accurately reflect the language of 40 CFR 6.605(a) if written as follows: In this case, the broad cumulative impacts of the proposals would be addressed in an initial comprehensive document, while other EISs or EAs may have to be prepared to address issues associated with site-specific proposed actions or can be addressed in the cumulative document.	The meaning of the recommended revision is unclear, so no change has been made.
112	Fairbanks Gold Mining	4.3	The last bullet on Page 28 would better reflect the language in 40 CFR part 6.605(b) if it was written as follows: The environmental impacts of the issuance of a new source NPDES permit would have a significant direct adverse impact on a property listed or eligible for listing in the National Register of Historic Places.	The correction was made as suggested, except that the wording was changed to read: "The issuance of the new source permit would result in a significant direct adverse impact..."
113	Fairbanks Gold Mining	4.3	The first bullet on Page 29 would better reflect the language in 40 CFR part 6.605(b) if it was written as follows: Any major part of the new source will have significant adverse effects on parklands, wetlands, wild and scenic rivers, reservoirs or other important water bodies, navigation projects, or agricultural lands.	The correction was made as suggested, except that the wording was changed to read: "The issuance of the new source permit would result in significant adverse effects..."
114	Fairbanks Gold Mining	5.1	The last sentence in the second paragraph on Page 30 would be more concise if written as follows: Mines with complex oxidation processes or smelters generally trigger at least one of the threshold values for the six parameters and are typically sources subject to the PSD program.	The change was made as suggested.
115	Fairbanks Gold Mining	5.1	Section 5.1 Clean Air Act, intermingles the Title V and PSD permitting processes. A major source by definition in 40 CFR 70.2 is a source that emits more than 100 tons of a criteria pollutant or 10 tons of a specific HAP or 25 tons of total HAPs. Designating these facilities as minor is confusing to the reader.	While the processes are discussed together, EPA believes the discussion is clear as it is.
116	Fairbanks Gold Mining	5.1.1	The last sentence in the first paragraph under section 5.1.1 on Page 31 discusses the opacity standard for particular matter. [The commenter] believes EPA is discussing particulate matter.	The correction has been made.
117	Fairbanks Gold Mining	6.1.1	The second bullet on page 38 states that the hydrologic analysis should include any impacts due to current or historic mining activities. The hydrologic analysis should include any impacts from any activity relative to the proposed project.	The change was made as suggested.

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No.	**Commenter**	**Section**	**Comment**	**Response**
118	Fairbanks Gold Mining	6.1.2	At the top of Page 43 the source book discusses the extent of the groundwater study area. This should be defined during the scoping process. The last bullet on this page discusses the effects from current or historic mining activities. FGM believes all activities (current or historic) that may effect groundwater within the study area should be included.	EPA agrees that the scope of the groundwater study should be defined early in the process, ideally during scoping. EPA agrees with the second point and has revised the text accordingly.
119	Fairbanks Gold Mining	6.1	A general comment on section 6.1 - groundwater models used to assess impacts from mining operations should be updated annually throughout the operation of the mine and the impacts determination modified if the model changes significantly.	EPA agrees and has modified table 10 accordingly.
120	Fairbanks Gold Mining	6.2.4	At the top of page 48 the source book implies the use of a 40-week humidity cell test. Testing to date indicates most material will generate acid within eight to 14 weeks. Testing is only extended beyond the 20-week time frame on a case by case basis. The implication of a 40-week test should be removed unless EPA has data supporting the benefit of a 40-week test.	EPA does not necessarily recommend the use of 40-week tests, merely indicates that it would "be viewed favorably." EPA cited the source (Price et al. 1997) that does advocate a 40-week period. The commenter notes that "most" material will generate acid within 8 to 14 weeks; EPA is concerned with the difference between "most" and the actual number, and thus encourages longer studies and consequently reduced uncertainty. In general, the text is meant to convey EPA's belief that longer test times should be considered as necessary and to note that there is a growing body of evidence that longer test times are needed for samples that are on the borderline.
121	Fairbanks Gold Mining	6.3	Beginning with the fourth sentence in the first paragraph of section 6.3 on Page 50, the remainder of the paragraph reads like a predetermined impact analysis. These sentences should be re-written to state the issues that must be addressed and leave the impact analysis to the EIS preparers.	EPA disagrees. These sentences merely point out some of the impacts that can occur from mining and mining-related activities to help applicants identify the potential impacts for which information should be provided.
122	Fairbanks Gold Mining	6.3	The third full paragraph on page 51 discusses the study area for the aquatic resources. The study areas should be determined during the scoping process.	EPA generally agrees, but notes that scoping more often simply identifies potential impacts to aquatic resources as an area that must be assessed. The nature of the operation and of the aquatic resources in the area generally define the potential area where impacts might occur, and this area may or may not be defined during scoping.

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No.	Commenter	Section	Comment	Response
123	Golder Associates	6.2.4	It is somewhat misleading to suggest that only "recently" we have come to the realization that the number of tested samples should reflect the material's variability. This concept has been around for a long time, as representative testing of material for environmental purposes is not fundamentally different from determining ore grade. Clearly, if an ore deposit is heterogeneous, more samples are required for resource characterization. In addition, it would be useful to point out that the volumetric distribution of the various materials should be taken into account. A material that is only present in minor quantities, will likely require less testing, unless it can be demonstrated that it may have a disproportionally large environmental impact despite its small volume. Conversely, materials that are present in large quantities generally require more testing, unless it can be demonstrated that they are very homogeneous. Ideally, therefore, the number of samples is a function of both compositional variability and volume. This issue is addressed in Appendix C, but the casual reader may not get that far.	EPA generally agrees with the commenter. However, EPA notes that many applicants, who clearly recognize the need for additional assays of ore with variable grades, still resist the idea that the same concept applies to environmental samples. The text in this section has been modified to make these points more clearly.
124	Golder Associates	6.2.4	Petrographic analysis is generally not considered cheap (in the order of $500/sample). As a first step, mineralogical analysis by x-ray diffraction is commonly conducted, which is a truly inexpensive ($50-100) and rapid method. Petrographic analysis is generally part of a second-stage mineralogical evaluation, when more detail is required (for instance w.r.t. weathering behavior or in the case of a large proportion of non-crystalline material).	EPA does not disagree, and has revised the text accordingly.
125	Golder Associates	6.2.4	Use of composite samples results in a "smoothing" of the characteristics of interest. In my opinion, compositing must be founded on a good understanding of the entire range of properties of the materials of interest. If compositing is performed without an understanding of the potential "extreme" behaviors, certain environmental impacts (e.g., those resulting from the presence of "hot spots") may not be adequately predicted.	EPA agrees with this comment.
126	Golder Associates	6.2.4	A commonly-used way to describe static vs. kinetic testing is that static testing provides information on the potential for acid generation, but not on the likelihood or rate at which this will take place. Although I realize this section represents a summary of Appendix C, it may be useful to point out in this paragraph that long-term information can also be obtained from on-site activities, such as monitoring of waste rock/tailings test pads specifically designed for this purpose.	A note has been added to this section to make this point.
127	Golder Associates	6.2.4	I would strengthen the wording w.r.t. the need for material characterization before and after kinetic testing. In my opinion, this is essential for understanding and predicting the long-term behavior.	While EPA agrees with the concept, we believe the wording is sufficiently strong.

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No.	Commenter	Section	Comment	Response
128	Golder Associates	6.2.4	I agree with the observation that interpretation of test results is not straightforward. This requires, therefore, considerable professional judgment, which can only be obtained through the necessary formal training and experience. Too often, ABA and other results are evaluated by novices, whose only frame of reference is the guidance provided by authors such as Mills and Price. Perhaps it would be wise to point out that specialized knowledge is required - and expected by EPA - for proper evaluation of the characterization results.	This point has been added to the text.
129	Golder Associates	6.2.4	It may be useful to point out that metals leaching can occur in the absence of acidic conditions. Too often it is thought that acid generation and metals leaching necessarily go hand in hand, but there are numerous instances in which metal leaching can occur in a neutral to alkaline environment. For instance, I am currently involved at a site where leaching of zinc from smithsonite (ZnCO3) in a limestone is a major problem, despite the fact that no acid is being generated and conditions are alkaline.	This point has been added to the text.
130	Golder Associates	B-4.5	PHREEQC Version 2 is now available at: http://wwwbrr.cr.usgs.gov/projects/GWC_couple/phreeqc. The new capabilities of Version 2 include (1) a general formulation for kinetically-controlled reactions, and (2) a complete formulation for ID diffusive or advective/dispersive transport with double porosity.	EPA has now cited the updated PHREEQC Version 2.
131	Golder Associates	C-4.3.1.3	Why are the Price (1997) guidelines for static test interpretation not used, as these guidelines have become widely used (to Bill's chagrin, I should add; I don't think he anticipated such proliferation of his guidelines). On a more general note, why the numerous references to a rather old guidance document (BC AMD Task Force, 1989) when Price's document represents a more updated version?	Price (1997) guidelines are now discussed in the text.
132	Golder Associates	C-4.4.1.2	I think it would be appropriate to point out that the TCLP test has little or no relevance w.r.t. characterization of mining wastes. Its goal is to provide a regulatory classification rather than be used for characterization. The TCLP test simulates conditions that are almost certain to be absent on mining sites. In addition, the Bevill amendment excludes most mining wastes from RCRA Subtitle C regulation, so the regulatory applicability of TCLP is limited.	EPA does not necessarily agree that the TCLP has little or no relevance on mining sites. We have clarified in the text that the Bevill exemption generally removes the regulatory applicability of the TCLP to extraction and beneficiation wastes.
133	Golder Associates	C-4.4.1.2	On a related note, I could not find any reference in the document to the role of the Bevill amendment (I fully admit that I only glanced at some pages, so I may have missed it. It might be appropriate to add a paragraph on Bevill if it's not already present).	There is now a section that briefly summarizes the Bevill Amendment and how mining wastes are addressed under RCRA.

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No.	Commenter	Section	Comment	Response
134	Golder Associates	H-4.4.2	The correct name for the model is "Sedimot-II" model, not "Sedimont-II".	The correction has been made as suggested.
135	Golder Associates	H-4.4.2	Why is the GSTARS2 model not included in the listing of models, in particular since EPA helped develop it?	EPA has added this model to the list.
136	PA Bureau of Mining & Reclamation	6.2.4	In coal mining we use other prediction tools in addition to "static" and "kinetic" tests. These tools include: results of previous mining, premining water quality, & geologic factors (such as rock type, effects of surface weathering, glaciation, etc.). These, along with laboratory tests, are described in our recent book "Coal Mine Drainage Prediction & Pollution Prevention in Pennsylvania." Although some of these methods may not be applicable to hard rock mining, others must certainly have parallels. As for geologic factors there has been some excellent work by Kathy Smith, Geoff Plumlee & Walter Ficklin at the USGS-Denver. Plumlee, GS, KS Smith, WH Ficklin, et al., 1993. Empirical studies of diverse mine drainages in Colorado--implications for the prediction of mine-drainage chemistry: Proceedings, 1993 Mined Land Reclamation Symposium, Billings MT, v.1, p.176-186. Smith, KS, GS Plumlee, & WH Ficklin, 1994. Predicting water contamination from metal mines and mining waste: Notes, Workshop No.2, International Land Reclamation & Mine Drainage Conference and 3rd International Conference on the Abatement of Acidic Drainage: US Geol. Survey Open-File Report 94-264, 112 p.	EPA agrees that these are important factors, and has modified section 6.2.4 and Appendix C accordingly.
137	PA Bureau of Mining & Reclamation	6.2.4	Over a decade ago, we circulated a paper that examined mine drainage prediction in Pennsylvania, and one of the primary criticisms was that it emphasised laboratory methods too heavily. I think the same criticism could be leaveled at your Hard Rock Mining source book. Non-laboratory methods (i.e., field methods) should be examined and discussed. The USGS work should certainly be included, near-surface weathering (oxidation of pyrite & dissolution of carbonates) has to be a factor in many places, and results from previous mining must also occur. As with coal mining, I'm sure that there are plenty of caveats that must be considered for each of these, but there also have to be some useful rules of thumb. We have found that the best predictions are those that are made using a variety of tools. It's especially reassuring when the different methods of prediction all point in the same direction.	EPA agrees that non-laboratory methods are useful as complements to laboratory data, and has added discussions to 6.2.4 and Appendix C.

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No.	Commenter	Section	Comment	Response
138	Mackay School of Mines	C	Appendix C is severely lacking in detailed guidance on sampling protocol to achieve adequate characterization of the waste rock. Typically mining companies are very interested in the mineralised rock which may be a resource or a reserve and under appropriate conditions it can be classified as ore (an often misused and misunderstood word). Usually proper attention is paid to the sampling process to minimise error and bias using Gy's sampling formula to determine size of sample, sample preparation protocol (crushing and splitting), assay protocol, and finally Geostatistics is used to characterize the regionalised variable i.e. the mineral grade/rock property, taking into account the geology of the area, rock type, structure, faulting, etc., using variograms and various kriging methods to interpolate/extrapolate between sample locations to arrive at a resource/reserve estimate.	Section 6.0 of Appendix C describes sampling programs. EPA has expanded the section somewhat.
139	Mackay School of Mines	C	This same approach (refer to comment 155) needs to be taken with the waste rock but the process/practice has not been so rigorous as with mineralised rock/ore and few guidelines are available on such matters as number of samples, size of samples, location of samples, sample preparation, etc. Appendix C is inadequate in this regard, Section 6.0 and Figure C-3 need to be considerably enhanced to include many of the procedures used by industry to appropriately characterize the mineralised rock. Unfortunately, there is little published on proper characterizing of waste and few studies have been undertaken on this topic. I think it is an area that EPA needs to consider, since nowadays waste characterization is as important as mineralised rock characterization and should be given equal attention starting at the exploration phase.	EPA agrees that this is an important area, and has expanded the section somewhat. EPA also agrees that a full examination of the issue is needed, but it is beyond the scope of this Source Book.
140	Northwest Mining Association	General	The [commenter] supports EPA efforts to develop "guidance" on how the mine permitting process can be expedited and coordinated between EPA and other agencies. We appreciate the effort to provide a reference document of use to both industry and agency personnel. We agree that EPA requirements and expectations are all too frequently not presented early enough in the permitting process, and that this lack of communication has led to increased costs and delays. This has created confusion and controversy and we appreciate EPA's efforts in the development of this draft guidance document. We also applaud EPA's efforts to respond to industry concerns raised in review of the Hardrock Mining Framework. The Mining Source Book is certainly comprehensive, and like other overview documents, could prove useful to those applying for environmental permits. It is especially useful as a literature review, providing citations to a cross section of the best available literature on the topic of mining environmental management.	EPA appreciates the recognition of the Source Book's intent.

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No.	*Commenter*	*Section*	*Comment*	*Response*
141	Northwest Mining Association	General	EPA has statutory authority over mining impacts to surface water, under the Clean Water Act; air, under the Clean Air Act; and wetlands, under the 404 provisions. EPA also has authority for CERCLA sites. The guidelines set forth in the Mining Source Book are much broader in scope, however, and offer guidance for aspects of non-CERCLA sites in areas where EPA does not have statutory authority. Operators and proponents should more properly be focused on meeting the requirements of the agencies that do have authority over the various resources.	EPA disagrees. The Source Book does not present "guidelines" *per se.* Rather, the Soruce Book describes the types of information and analyses that should be submitted to allow (a) permitting and approvals to proceed most efficiently and (b) impacts to be assessed under NEPA.
142	Northwest Mining Association	General	The draft document provides good general background on recommended permitting information, but it fails to provide specifics on how EPA will promote predictability and consistency within Region 10. It also fails to clarify how EPA Region 10 intends operators to proceed with permit development (e.g. how to choose from among the various methods of technical evaluation), given the site specific, subjective, and at times, vague or inconsistent guidance provided in the document. Further, such guidance is only meaningful if it enables an operator to meet a regulatory requirement.	As noted in section 1.1, mines are too site-specific to allow EPA to identify the precise technical evaluations that should be done. The Source Book is intended to provide applicants and others with an idea of the types of information and analysis that are needed.
143	Northwest Mining	General	The Mining Source Book guidance may be useful for larger mining companies, who have the resources to attempt the level of comprehensive characterization defined in the Mining Source Book. Ironically, these larger companies also possess much of the information presented in the document, which could literally serve as an introductory text to mine permitting. Paradoxically, it is these same companies who, after preparing permit applications that follow these guidelines closely at the cost of millions of dollars, have also been unable to permit significant mining operations in the Northwest in the past 5 years. Members of NWMA who have shared in this experience include Crown Butte Mines at New World, SPJV at McDonald Gold, and most recently, Battle Mountain at Crown Jewel.	EPA notes the comment (and also that the examples sited are outside of Region 10 except for the Crown Jewel project which was ultimately rejected by the State of Washington Pollution Control Hearings Board).
144	Northwest Mining	General	It seems likely that the guidance presented in the Mining Source Book would be particularly helpful for small business mine operators, who may lack the comprehensive expertise needed to address the range of issues presented in the source book. These smaller operations are likely, however, to struggle in attempting to meet the lofty and comprehensive goals of the programs defined in the guidance document. For this reason, it might be useful to present a focused "must do" section for small mine operators.	EPA believes that a small operator can use the Source Book to identify the approximate level of detail that is required, and with a knowledge of the operation and property at issue, should be able to identify the areas to focus on during data gathering.

Comments on 1999 Draft Source Book and EPA Responses

No.	Commenter	Section	Comment	Response
145	Northwest Mining	General	An element lacking in this draft report is how EPA, in the implementation of its authorities, will recognize and defer to other agencies, especially state authorities. We are aware of cases within the region where Memorandums of Understanding have been developed between EPA and other regulatory authorities to improve communication, coordination and streamlining of the permitting process (e.g. Kensington). This process could be used to clarify EPA requirements and expectations early in the process. While this draft is silent on this type of approach we encourage EPA in doing more of this type of collaborative permitting.	EPA does indeed collaborate as much as feasible. The Source Book acknowledges the role of other agencies, but the intent of the Source Book is to assist applicants in dealing with EPA, not necessarily other agencies.
146	Northwest Mining	1.3	EPA refers to a problem of "metal constituents in surface water samples may be measured using methods with detection limits that are higher than water quality standard values." However, this statement is disingenous because it completely disregards the fact that EPA has been setting the water quality values for many metals below the reliable limits of detection of any currently available testing method. We believe that this constitutes an arbitrary and capricious approach to setting compliance standards. Thus, the real problem often lies not with the applicants, but with EPA.	EPA notes that water quality standards are not based on compliance, but rather on science (specifically, toxicology, aquatic and benthic biology, and other disciplines relevant to identifying and evaluating effects of pollutants on organisms and other receptors). State water quality standards are reviewed every three years with the understanding that the science upon which they are based, and corresponding detection methods and limits, is continually improving.
147	Northwest Mining	1.3	...we do agree that many in the mining community need to be more cognizant of the limitations to water sampling protocols, parameters, and precision that are completely suitable for mineral exploration. As discussed in the draft document, this information has often fallen short of what is needed to properly analyze and evaluate water quality from an environmental viewpoint. Our experience has shown that the difference in time and cost between having information useful for both environmental and geologic purposes and single purpose data sets is relatively small, if the need is fully considered early in the project.	EPA generally agrees with the comment, and encourages applicants to bring the same rigor to evaluating water quality as it does to evaluating ore bodies.
148	Northwest Mining	1.3	[The commenter] notes that EPA raised the "chain of custody" issue in its discussion of gathering water quality samples. To the degree that accurate tracking of samples is intended to maintain good quality control, we would agree that maintaining records documenting the who, when, where, and how's of sampling, storage, transport, and analysis is both useful and necessary. However, based on direct experience, we are convinced that EPA desires what could be turned into a very cumbersome mechanism, if the purpose evolved into a making sure the resulting data was absolutely "bulletproof' in court.	EPA made the point because it is common for EPA to have serious questions about various aspects of data collection, and in some cases such straightforward procedures such as maintaining chain-of-custody could resolve any questions and disputes. Thus, a seemingly "cumbersome" procedure can save applicants time and money.

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No.	**Commenter**	**Section**	**Comment**	**Response**
149	Northwest Mining	A-3.1	Page A-3 - Paragraph 3 "Increases in constituent concentrations will be highest for those areas with the largest amount of surface runoff'. This would not be expected in there is a negative correlation between stream flow and constituent concentration. It should be noted that the relationship between streamflow and constituent concentration is not limited to positive and negative as the text implies.	EPA has rewritten this paragraph to be more clear.
150	Northwest Mining	A-4.1	Section 4.1 - The authors correctly indicate the problems associated with the measurement of precipitation at remote sites. The discussion of point estimation techniques is inappropriate. The precise technique for estimation should begin first with an understanding of the purpose for the prediction. If the data is to be used to simply characterize mean annual conditions at the site, the exact method is probably not critical. If the precipitation estimate is to be used to size a storage pond in an area where human life or property would be threatened if the structure fails, the selection of the appropriate prediction method may be more critical.	In general, EPA agrees with the concepts raised by the commenter and has clarified the discussion.
151	Northwest Mining	A-4.1	Section 4.1 - It should also be noted that techniques like Theissen do not necessarily produce less accurate results than contouring or kriging (see, for example, Applied Geostatistics). Rather, the Theissen method makes some assumptions about conditions within a polygon and that the edges of polygons that may be unrealistic. There are other methods that may be appropriate as well. It is probably most important that no single method be relied upon blindly. It is critical that the values obtained using one method be compared to values obtained using other methods. If the predicted values agree relatively well, then a greater degree of confidence can be assigned to this prediction. If; on the other hand, the values obtained using different methods vary significantly, it is important to understand why the predictions are different and to then use professional judgement to select the most appropriate value for the task at hand. It is incorrect to assume that this is "prescribed" process.	EPA will clarify the discussion to indicate that the method used should be dependent on specific objectives and that no method is specifically prescribed.

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No.	Commenter	Section	Comment	Response
152	Northwest Mining	A-4.3	Page A- 15 - the authors feel that prediction methods that use the SCS number approach are inherently inferior. Given the level of detail available for most design projects in general, this is not necessarily true. The estimation of an SCS curve number for a project certainly involves professional judgement but it is at least as reasonable as the rational method. Again, several prediction methods should be used and compared rather than relying on the conventional EPA prescriptive approach. It should also be remembered that approaches like water balance models and some unsaturated flow numeric models use the SCS approach as well. Depending on the situation and the nature of the prediction, the multiple uses for the curve number approach may have a great deal of merit.	EPA agrees that the SCS approach may be appropriate given specific project objectives. EPA will revise the discussion to emphasize that no method, including the SCS number approach, is prescribed, but instead should depend on project objectives.
153	Northwest Mining	A-4.3	Page A- 18, paragraph 2- This paragraph is really the key to this section and the other information is less relevant. However, it should be noted that it is not simply the time-consuming nature of some of the predictive methods that makes them unattractive. Often, the lack of realistic input data and the uses of the predictive results makes more sophisticated methods unattractive. In many cases, sufficient information is missing not because the applicants neglected to collect it but simply because it is impossible to accurately measure the parameters over a reasonable period of time. This problem is not unique to mining projects but is equally true of all development projects. In addition to attempting to bound critical estimates with stochastic approaches, it is also wise to make sure that the final designs include relatively conservative factors of safety.	EPA agrees.
154	Northwest Mining	A-4.5	Page A- 19 - Paragraph 1..." Aquifer pump tests and drawdown tests of wells need to be conducted under steady-state or transient conditions..." Are there any other conditions???	This should have read "...steady-state and transient conditions..." and has been corrected.
155	Northwest Mining	A-4.5	Page A- 19 paragraph 1 ".. It is important that these tests be performed at the pumping rates that would be used by a mining operation...". This is often difficult to estimate and is even more difficult to replicate. In general, it is not necessary if sufficient baseline information is available and predictive strategies can be used.	EPA does not entirely agree, but does acknowledge there is some uncertainty in future pumping rates. However, EPA emphasizes the need for the tests in most if not all cases.
156	Northwest Mining	A-5.0	Page A-20 - Paragraph 3 - We know of no operation that is in a constant need of adding make-up water.	EPA's point was that make-up water flows are often relatively constant over time, but neglected to include "over time." The sentence has been clarified.
157	Northwest Mining	A-6.2	Page A-26 drop all reference to specific models since the list is by nature incomplete and again, the specific software should be selected based on the available input data and the model purposes.	EPA believes it is appropriate to mention a few of the models. EPA has clarified that the models mentioned do not constitute a comprehensive list.

Comments on 1999 Draft Source Book and EPA Responses				
No.	**Commenter**	**Section**	**Comment**	**Response**
158	Northwest Mining	B-2.4	Appendix B - pages 11-16. EPA correctly points out that applicants need to evaluate an area of appropriate size when assessing surface hydrology. However, while noting that the term "watershed" goes undefined in the draft document, the statement that using a "watershed perspective" is a common approach is not supported by information provided by our members. We are especially concerned since it is apparent that the "watershed" being referred to by EPA is not just the local drainage or drainages that could be potentially affected by the proposed mining operation. EPA is clearly referring to a much larger geographic area, such as those increasingly described in federal documents pertaining to "ecosystem management" or more recently in the so-called "clean water initiative."	In general, the "watershed" of concern is the upstream portion of a drainage basin that contributes surface and shallow ground water flows to the project area and the downstream portion(s) whose water quality or quantity may be affected by mining-related activities. EPA did not mean to refer to an enormous expanse beyond the reach of the operation. This is clarified in the text.
159	Northwest Mining	B-2.4	Appendix B - pages 11-16. Thus, NWMA objects to the assertion by EPA that mining companies applying for an NPDES permit always should start at the "watershed" level. While a very few projects may need to evaluate a larger than normal area, such should hardly be the norm. Our member support the use of good science, but the community of natural resource industries should not be subsidizing other activities or public entities by paying for expensive research projects that have nothing to do with project impacts.	EPA does not intend, and has not suggested, that the mining industry should "subsidize" any other entity. EPA's intent also is to emphasize good science. See the changes made in response to comment 158.
160	Northwest Mining	B-2.4	Appendix B - pages 11-16. Based on past experience with EPA in general, and NMFS and USFWS in particular, the Association is deeply concerned the Agency may soon force NPDES applicants into evaluating much larger areas than is justified by the science to fulfill other agendas. This view is substantiated by statements made on the record of high level Forest Service and BLM officials to NWMA staff during hearings in Spokane on the Columbia Basin Ecosystem Management Project. Needless to say, we are definitely seeking "clarification" of EPA's intent and specifics on the definition of what a "watershed" is in the context of NPDES permitting.	As noted in other responses, the "watershed" of general concern to EPA is the upstream portion(s) of a drainage basin that contributes surface and shallow ground water flows to the project area and the downstream portion(s) whose water quality or quantity may be affected by mining-related activities. EPA did not mean to refer to an enormous expanse beyond the reach of the operation. This has been stated explicitly in section B.2.4.
161	Northwest Mining	B-2.4	Appendix B - pages 11-16. At the minimum, [the commenter] urges EPA to be very specific in defining what constitutes a "watershed." We strongly recommend that the agency use the existing accepted clarification system established by the U.S. Geological Survey (USGS). The USGS has already divided the United States into hydrologic units which are the standard reference for reporting and tracking water related data.	Under this system, cataloging units appear to be the most appropriate size of "watershed" that may need to be evaluated for the majority of mining projects (see the USGS Information Sheet Hydrologic Units, February 1999). As noted in other responses, the "watershed" of general concern to EPA is the upstream portion(s) of a drainage basin that contributes surface and shallow ground water flows to the project area and the downstream portion(s) whose water quality or quantity may be affected by mining-related activities. EPA did not mean to refer to an enormous expanse beyond the reach of the operation.

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No.	Commenter	Section	Comment	Response
162	Northwest Mining	B-2.4	Appendix B - pages 11-16. If filling data gaps is a motivating factor for EPA and the other agencies, [the commenter] urges a collaborative basin wide approach, a position we have advocated for a decade. Under such circumstances, [we] would consider supporting cooperative studies conducted jointly between mining project proponents and agencies to expand the water quality database, as long as an equitable cost-sharing approach was utilized. Involving other interested parties would be highly desirable.	EPA generally agrees with this comment.
163	Northwest Mining	B-2.4	Appendix B - pages 11-16. Another approach to this conundrum is to make sure all users of data gathered by industry pay for the privilege of using that data, and any related analysis. We will suggest to our member companies that they copyright all reports in the future, as they qualify as intellectual property with a market value. Of course, a license will be granted to the lead permitting agency to use the data and related analysis as needed for that specific permit. Any other use by the lead agency or anyone else would require the payment of an additional fee. The principal is exactly the same as with geophysical companies that gather extensive data over wide areas and then sell it. Naturally, anyone is free to duplicate the work if they do not wish to buy the information from the vendor.	EPA notes the concept.
164	Northwest Mining	B-2.4	Appendix B - pages 11-16. The licensing fee (for protected data] also would be waived for any entity that acted as a partner in the original data gathering and analysis phase. This would be a fair and equitable approach. For example, if the science required a company to assess a number of drainages in one or more watersheds, it could be to the advantage of federal, state, local, or tribal entities to contribute resources to complete the picture. Such cooperative cost sharing is an approach long espoused by the Association, an publicly endorsed by several state and federal agencies in the past.	EPA notes the commenter's intent.

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No.	Commenter	Section	Comment	Response
165	Northwest Mining	B-2.4	Appendix B - pages 11-16. Our final point on EPA imposing "watershed" analysis as the standard for gathering data for future NPDES permits is procedural. While basing government planning efforts on a "watershed" approach may have some merit, at least conceptually, we would question the legality of imposing a host of expensive new requirements on industry without prior notice or rulemaking. This general concern is heightened by recent EPA efforts to expand the definition of "point source" to include virtually all-human created soil disturbances, contrary to the clear intent of Congress in drafting Sec 319 of the Clean Water Act. Thus, we caution EPA about moving in this direction without meaningful dialogue with the affected public. Absent this, the mining community would have little recourse but to vigorously oppose the imposition of new regulatory requirements created outside of the legally mandated process.	EPA notes that it is not "imposing" a watershed analysis as a "standard for gathering data for future NPDES permits." Rather, the Source Book recognizes that a watershed approach provides a useful scale on which to assess impacts and to remediate past problems.
166	Northwest Mining	C-4.4.5	This section discusses the utility of various extraction methods and indicates that EPA method 13 12 (SPLP) is best suited to mining wastes. The text provided in the Mining Source book then discusses ways to modify this standard method. In 1995, EPA published Applicabilitv of the TCLP to Mineral Processing Wastes, in which it identifies TCLP as superior to SPLP in characterizing mine wastes. This issues is the subject of ongoing regulatory discussion. If the SPLP is the appropriate method, why does the document offer means of altering it? The guidance is unclear within the document and inconsistent with other EPA guidance.	EPA has modified the text to clarify the recommendation of SPLP. As noted in the text, in some areas, precipitation can be more acid than in others, and this may make a more acid lixiviant appropriate.
167	Northwest Mining	C-6.2	All of the possible approaches to determining a representative level of sampling are discussed, but guidance is not offered to the operator on which approach to use. Why does EPA present the BC sampling nomograph if it agrees that the level of sampling for larger projects is unrealistic and in its words, prohibitive? Experience of many operators shows that regardless of which method they choose, the regulatory community will suggest that the alternative method might have been preferable. Specific, consistent guidelines on how sampling are needed, not an academic discussion of possible means of determining the number of samples.	The text has been clarified somewhat, but the variety of approaches that are used simply emphasizes that there is no simple answer to the complex questions regarding a representative level of sampling.
168	Northwest Mining	F-3.0	Section 3.0 references recent contaminant releases that emphasize the importance of comprehensive geochemical testing. What contaminant release in Region 10 is EPA referring to?	At mines in Region 10 and elsewhere in the country, contaminants have been released via seepage from waste rock piles, seepage through tailings dams, leaks in liners, and other mechanisms.

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169	Northwest Mining	General	The commenter, which represents many companies, expressed the concern that EPA staff takes an overly academic approach to developing discharge limits and setting water quality standards. For example, a long standing, major concern …. is the "ridiculously low detection limits" being mandated by EPA in an attempt to "measure" a discharge limit that is immeasurable. We are unaware of any competent practitioner outside of EPA who thinks much of this really makes any practical sense.	EPA notes the comment.
170	Northwest Mining	General	[The commenter] desires additional opportunities to work constructively with EPA on water quality issues, among others. [They] must encourage EPA to make its processes for developing policy and technical standards more transparent. Not only would this strengthen the science, but it would help to enhance the working relationship between the Agency and those in the regulated community.	EPA notes the comment and appreciates the comments on this Source Book. This is one way in which EPA makes its procedures more transparent, as the commenter encourages.
171	Center for Science in Public Policy	A-4.1	The number of modern mines with water balance problems, many of which led to major environmental problems, are too numerous to quote. One of the most common problems that has led to miscalculating water balance is assuming, rather than actually measuring, the precipitation at the minesite. In section 4.1 it is stated "Actual measurements of precipitation and runoff within the specific watershed of a mine *are <u>preferred</u> and <u>should</u> be used <u>whenever</u> <u>possible</u>* to develop probabilistic storm frequency and design hydrological structures." [p. A-6, *emphasis added*] Taking this 'soft' approach is not likely to prevent the worst cases of miscalculation, e.g. where a mine proponent is trying to save money, or is using an inexperienced contractor. EPA should take a stronger and proactive position with regard to data collection, e.g. requiring a minimum of one year's data at the minesite, which can then be correlated to longer term precipitation records from nearby stations. Data should be collected at the minesite, not just in the watershed. (See Section 4.5 Groundwater, where the basic requirements for data collection are clearly laid out.)	EPA believes that such a prescriptive approach is not necessary in all cases. EPA recognizes that there may be "cases of miscalculation" but emphasizes that data and evaluations are reviewed and assessed for adequacy.
172	Center for Science in Public Policy	B Table B-2	You might consider adding thallium to the list of "Other Metals." There is a water quality standard for thallium, and exceedance of the human health standard is a problem at the Kendall Mine in Montana.	EPA has added thallium to the list.

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173	Center for Science in Public Policy	C-6.2.1	In the discussion of the BC AMD Task Force recommended minimum number of samples appropriate for a rock unit, the following statement is made: "This approach can lead to extensive sampling requirements for large facilities and result in inordinately high sampling costs." [pp. C-33, 34]. I believe it would be more correct to say that "This approach can lead to … ~~inordinately~~ high sampling costs." The key is in demonstrating the statistical-geochemical uniformity of a "rock unit." I believe that the sampling guideline is projecting that with the recommended number of samples, the statistical uniformity of the resulting data should be demonstrated. If it can be demonstrated that an acceptable level of statistical uniformity can be demonstrated with fewer samples (i.e. the defined geologic unit has a higher-than-expected degree of uniformity), then fewer total samples will be needed to define the geochemical characteristics of the material. EPA could perhaps offer more guidance in this Appendix as to when it expects the Runnells approach, or the BC AMD Task Force approach, to be utilized.	EPA has revised the discussion concerning sampling cost. EPA leaves it to applicants to choose the appropriate approach.
174	Center for Science in Public Policy	E-8.2	Suggest you add several additional points to the discussion here: 1. Application Rate The land application of mine effluent will be managed so that the amount of water applied would be tied to the agronomic rate of uptake of the plants (plus evaporative loss). It should be stated that land application will be governed by the agronomic uptake – this information is commonly available through agricultural support agencies. The land application plan should specify exactly how this would be accomplished. 2. Use of lysimeters to monitor application rates. We are finding that it is appropriate to use lysimeters to check the theoretical application rate to insure that the applied solution is not migrating down into groundwater. 3. Cation Exchange Capacity EPA has recommendation for total loading for metals of concern for land application of municipal sludge. If these are matched with loading rates calculated from the geochemical makeup of the land application solution, and the cation exchange capacity of the soil, which can be determined from soil samples, metal loading for the soils for the life of the LAD operation can be determined. This analysis should be performed as a part of land application planning.	EPA agrees and has added these points to the list of information needs.

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175	Center for Science in Public Policy	F-3.0	After working on a number of reclamation projects, it has become evident that an accurate record of the timing and source of waste rock that is placed in a waste rock dump or heap leach pad is often essential to designing the reclamation plan for a mining facility. This is especially relevant when problems arise with acid mine drainage in waste piles or heaps. EPA should, at a minimum, strongly recommend that mine operators keep accurate and easily interpretable records of the source, amount, and location of all waste placed in waste storage facilities, and for ore material placed on heap leach pads. Reclamation design can then be facilitated, especially if it is shown that the original geochemical characterization of the waste (or the altered state of leached ore) is different than predicted.	EPA agrees and has added this recommendation.
176	Center for Science in Public Policy	F-4.1.2	In the discussion on the different types of embankments on page F-12, it might be appropriate to mention that upstream construction is virtually used [unused?] in modern mine design because of the risks associated with seismic failure.	EPA has added a statement concerning seismic failure risks.
177	Center for Science in Public Policy	F-4.1.3	This section mentions cyanide and radioactive materials as substances that might require a liner. Metals might also be considered if they pose a risk to groundwater resources.	EPA has revised the text accordingly.
178	Center for Science in Public Policy	F-4.1.3	a sentence in this section says: "Tailings pond liners can be composed of compacted clay, synthetic materials, or *tailings slimes*." [p. F-18, *emphasis added*] Using non-engineered material, e.g. tailings slimes, has failed to produce the desired liner-effect in many instances. It would be better to stay away from suggesting tailings slimes in particular, and non-engineered materials in general, for use as a liner material.	EPA does not believe this "suggests" tailings slimes as a liner material, but rather identifies slimes as a material that has been and is used. EPA notes that clay and synthetic liners have also failed to produce the desired liner-effect in many instances. The point that should be emphasized is that liners should be selected and evaluated carefully.