EIA Guidelines for Mining

Environmental Impact Assessment Guidelines for New Source NPDES Permits

ORE Mining and Dressing

and

Coal Mining and Preparation Plants Point Source Categories

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U.S. Environmental Protection Agency
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1. INTRODUCTION

The National Environmental Policy Act of 1969 (NEPA, 42 U.S.C §4321 *et seq.*) was the first of what has come to be an array of statutes whose individual and collective goals are the protection of the human and natural environment from a variety of impacts that human activity can have. NEPA introduced the requirement that Federal agencies consider the environmental consequences of their actions and decisions as they carry out their mandated functions. For "major Federal actions significantly affecting the quality of the human environment," the Federal agency must prepare a detailed environmental impact statement that assesses not only the proposed action but also reasonable alternatives.

The Federal Water Pollution Control Act (33 U.S.C. §§1251-1387), better known as the Clean Water Act, seeks to restore and maintain the chemical, physical, and biological integrity of the Nation's waters. One of the major mechanisms by which the Clean Water Act is to attain that goal is the requirement that all point source discharges of pollutants to waters of the United States be controlled through permits issued under the National Pollutant Discharge Elimination System (NPDES).

The Clean Water Act [§511(c)(1)] also requires that the issuance of a NPDES permit by the Environmental Protection Agency (EPA) or authorized States for a discharge from a new source be subject to NEPA. In 1979, EPA established the regulations by which it applies NEPA in such cases: "Environmental Review Procedures for the New Source NPDES Program," 40 CFR 6 Subpart F. These procedures require EPA to prepare a written environmental assessment based on information provided by the new source NPDES permit applicant and other available documentation. If the environmental assessment concludes that no significant impacts will result from issuance of the new source NPDES permit, EPA issues a Finding of No Significant Impact (FNSI). If the assessment concludes that there may be significant environmental impacts that cannot be eliminated by changes in the proposed project, EPA must prepare (or participate in the preparation of) an environmental impact statement that contains the information and analyses described in 40 CFR Part 6 Subpart B and conforms with Council on Environmental Quality regulations (40 CFR Part 1502) governing NEPA compliance.

In preparing the environmental assessment, EPA relies on information and analyses provided by the applicant for the new source NPDES permit in an "environmental information document," or EID. The scope and content of an EID is determined by EPA in consultation with the applicant, with the regulatory caution that EPA "...keep requests for data to the minimum consistent with his responsibilities under NEPA" [40 CFR 6.604(b)].

1.1 PURPOSE OF ENVIRONMENTAL IMPACT ASSESSMENT GUIDELINES

Following the promulgation of New Source Performance Standards for new source discharges in the late 1970s and early 1980s, EPA prepared a series of "Environmental Impact Assessment Guidelines" for use in determining the scope and contents of EIDs for new source NPDES permits for facilities in specific industries. The guidelines also were intended to assist EPA staff in reviewing and commenting on applicants' EID information and in preparing, overseeing the preparation of, or commenting on environmental assessments and environmental impact statements.

Three of the environmental impact assessment guidelines prepared by EPA addressed the mining industry; one[1] addressed facilities that mine and beneficiate ores and minerals to recover metals, another[2] addressed underground coal mines and coal cleaning facilities, and a third[3] addressed surface coal mines. EPA's Office of Federal Activities, in cooperation with other EPA offices and Regions, is now revising and updating these guidelines to incorporate new information and to make them more widely useful in identifying and evaluating the potential environmental impacts that proposed mining projects may have. Because many of the potential impacts, and the information and analyses needed to assess impacts, are common to metal and coal mining, the topics covered by the three previous guidelines documents have been combined into this single document.

These guidelines are expressly intended to provide background information for EPA staff to assist them in consulting with and directing new source NPDES permit applicants in the scope and contents of EIDs and as a reference to assist them in identifying and evaluating the potential impacts of proposed mining projects. EPA anticipates several other audiences for these guidelines: EPA staff who review and comment on other Federal agencies' environmental impact statements and regulations pursuant to §309 of the Clean Air Act; other EPA staff who deal with the mining industry and its environmental impacts; new source NPDES permit applicants who must prepare EIDs for EPA; other Federal agencies responsible for regulating or overseeing the mining industry; and State, local, and foreign government environmental officials. Officials in States that have been authorized to implement the NPDES program may also find these guidelines useful in their reviews of permit applications. All audiences should be aware that this document provides background information and general guidance, but does not constitute an official EPA position on laws or regulations, or represent Agency policy.

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[1] U.S. Environmental Protection Agency, Office of Environmental Review. 1981 (December 16). *Environmental Impact Assessment Guidelines for New Source Ore Mining and Dressing Facilities*. Prepared for EPA by Wapora Inc. under contract 68-01-4157.

[2] U.S. Environmental Protection Agency, Office of Federal Activities. 1981 (October). *Environmental Impact Assessment Guidelines for New Source Underground Coal Mines and Coal Cleaning Facilities*. EPA-130/6-81-002.

[3] U.S. Environmental Protection Agency, Office of Environmental Review. 1979 (December). *Environmental Impact Assessment Guidelines for New Source Surface Coal Mines*. EPA-130/6-79-005.

These guidelines supplement the more general document, *Environmental Impact Assessment Guidelines for Selected New Source Industries*, which provides general guidance for preparing environmental impact assessments (EIAs) and presents impact assessment considerations that are common to most industries, including mining.

1.2 SCOPE OF THE MINING INDUSTRY

The ore mining and dressing (or beneficiation) industry is composed of mining facilities that remove raw mineral ores from the earth, and of mill facilities that separate the mineral ores from overburden and waste rock removed during mining activities. The industry also includes mill facilities that further concentrate and purify metals in the ore to a condition specified for further processing (smelting and/or refining) or for incorporation as a raw material by another industry. The mining and beneficiation of various mineral ores occurs nationwide, and is viewed as critically important to the Nation's economy since it provides the raw materials on which many other industries rely.

The metal mining industry is identified as Standard Industrial Classification (SIC) Major Group 10. This industrial group includes facilities engaged in mining ores for the production of metals and also includes all ore dressing (or beneficiation) operations, whether performed at mills operating in conjunction with mines or at mills operated separately. These include mills that crush, grind, wash, dry, sinter, or leach ore, or that perform gravity separation or flotation operations.

EPA has promulgated effluent limitation guidelines for discharges of pollutants from existing and new sources in the Ore Mining and Dressing Point Source Category (40 CFR Part 440). These effluent limitation guidelines provide numeric limitations for discharges from mines and mills in various industry subcategories (see also Chapter 5). Exhibit 1-1 shows the SIC categories covered by this industrial group and the subcategories for which EPA has promulgated effluent limitation guidelines.

The coal mining industry is composed of facilities that mine coal of any rank from the earth, and of preparation plants that clean or otherwise prepare the coal for combustion and other uses. The coal mining industry is identified as Standard Industrial Classification (SIC) Major Groups 11 (anthracite) and 12 (bituminous and lignite). These industrial groups include facilities that are engaged in mining coal and preparation plants that operate in conjunction with mines or separately.

EPA has promulgated effluent limitation guidelines for discharges of pollutants from existing and new sources in the Coal Mining and Preparation Plant Point Source Category (40 CFR Part 434). These effluent limitation guidelines provide numeric limitations on discharges from mines (with separate standards for acid and for alkaline discharges), preparation plants, and areas of mines that are being reclaimed.

Exhibit 1-1. Standard Industrial Classification Codes for the Metal Mining Industry

SIC	Type of Ore	Subpart Within 40 CFR Part 440
1011	Iron Ores	Subpart A
1021	Copper Ores	Subpart J
1031	Lead and Zinc Ores	Subpart J
1041	Gold Ores	Subpart J (lode) Subpart M (placer)
1044	Silver Ores	Subpart J
1051	Bauxite and Other Aluminum Ores	Subpart B
1061	Ferroalloy Ores, except Vanadium	Tungsten: Subpart F Nickel: Subpart G Molybdenum: Subpart J
1092	Mercury Ores	Subpart D
1094	Uranium, Radium, and Vanadium Ores	Subpart C Subpart H (vanadium when mined alone–reserved)
1099	Other Metal Ores	Antimony: Subpart I Platinum: Subpart K (reserved) Titanium: Subpart E

1.3 ORGANIZATION OF GUIDELINES

The remainder of this document is organized as follows. Chapter 2 describes NEPA requirements and provisions as they apply to issuance of new source NPDES permits. Chapter 3 presents information on the mining industry. This chapter is intended to give the reader background information on the operations that take place on mine sites. The apparent simplicity of mining—removing ores from the earth and then concentrating the valuable product from the ores—disguises what is in reality a formidable complexity. As a result, some understanding of the nature of mining operations is necessary in any assessment of the potential environmental impacts and in identifying the information and analyses that are necessary to conduct such an assessment. Metal mining and beneficiation are described in the first three subsections of Chapter 3. The first two describe, respectively, mining and beneficiation operations that are common to the industry; the third describes each of the major industry sectors, with particular regard to the mining and beneficiation operations that are unique to the individual sector. This third subsection focusses on the industry sectors which are most important to the U.S. mining industry, including gold, copper, iron, lead-zinc, and uranium.

Sectors for which EPA has promulgated effluent limitation guidelines but in which there are currently very few active mines (e.g., aluminum, molybdenum, platinum, tungsten) or no active or anticipated mines (e.g., antimony, mercury) are also described, but in less detail. Following the subsections on metal mining are two subsections that describe coal mining and coal preparation, respectively. All of the subsections in this chapter describe the major operations that take place and identify the major environmental concerns of these operations.

Chapter 4 then describes in some detail several of the major environmental issues and impacts that are of most concern when evaluating the potential major impacts of proposed mining operations. Separate subsections in this chapter describe each of a number of major potential impacts and the circumstances that can lead to their occurrence. These sections also describe the types of information and analyses that are necessary to identify whether these impacts are of concern for a particular operation, to evaluate these potential impacts and their significance, and to identify and evaluate possible mitigation measures.

The process of analyzing impacts within the context of NEPA and new source NPDES permits is described in Chapter 5. Separate subsections describe each of the major steps in the impact analysis. Chapter 6 then provides information on the major Federal environmental and natural resource management statutes that directly affect or that regulate mining operations. The purposes and broad goals of each of these statutes are described, along with a brief indication of the requirements imposed by the statute and the implementing agency's regulatory or consultation programs.

Finally, references cited in the document are listed in Chapter 6, as are a number of other valuable references. Appendix A presents an outline, in the form of a "checklist," of the types of information and analyses that should go into an environmental information document. Appendix B presents a glossary of terms.

2. NEPA REQUIREMENTS AND PROVISIONS

2.1 OVERVIEW

NEPA serves as the basic national charter for environmental protection. Section 102 of NEPA establishes environmental review requirements for Federal actions. These reviews or impact assessments are required to be broad in scope, addressing the full range of potential effects of a proposed action on the human and natural environment. A general framework for implementing these requirements is presented in regulations issued by the Council on Environmental Quality (CEQ). Federal agencies, in turn, have developed their own rules for NEPA compliance that are consistent with the CEQ regulations but address their specific missions and program activities. 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.

Congress has determined that most EPA activities are exempt from impact assessment requirements under NEPA. In the case of EPA's water quality programs, Section 511(c) of the Clean Water Act (CWA) clearly specifies that actions taken by EPA under the Act shall not "be deemed a major Federal Action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969." However, Congress did make two important exceptions to this exemption:

(1) the provision of financial assistance for the construction of publicly owned treatment works
(2) the issuance of NPDES permits for new sources as defined in Section 306 of the CWA.

The specific reference to NPDES new source permits makes clear EPA's responsibility to review proposed permit issuance actions from the broader perspective of the NEPA environmental assessment framework.

Since EPA does have responsibility for conducting environmental reviews for some types of proposed activities, the Agency has developed and codified its own set of NEPA procedures. These procedures, which are found at 40 CFR Part 6, have been revised a number of times. Some of the relevant steps in the course of the development of EPA's current regulations are as follows:

- Initial EPA proposed rulemaking setting forth procedures for the preparation of EISs (37 *FR* 879; January 20, 1972)
- Interim EPA regulations for Part—Preparation of Environmental Impact statements (38 *FR* 1696; January 17, 1973)

- Notice of proposed rulemaking—Preparation of EISs (39 *FR* 26254; July 17, 1974). This proposed rulemaking reflects substantial public comment on the interim regulations as well as additional CEQ requirements. The rulemaking addresses EPA's nonregulatory programs only.

- Final EPA regulations on the preparation of Environmental Impact statements (40 *FR* 16814, April 14, 1975). Although procedures for new source NPDES permits are not included in this rulemaking, EPA notes in the preamble that such regulations will be subsequently issued in 40 CFR Part 6.

- Preparation of Environmental Impact Statements, New source NPDES permits (42 *FR* 2450, January 11, 1977). Presents an outline for the preparation of EISs for proposed new source permitting action.

- Proposed rule—Implementation of Procedures on the National Environmental Policy Act (44 *FR* 35158; June 18, 1979). In response to major revision of CEQ's regulations in 1978, EPA revises its procedures accordingly. The revised procedures include streamlining and clarification of procedures in general. In addition, requirements for NPDES new source permitting actions were substantially revised and presented as Subpart F of the proposed rule.

- Final rule—Implementation of Procedures on NEPA (44 *FR* 64174, November 6, 1979). Issues raised during promulgation include limitation of construction activities during permitting process and environmental review and the conditioning or denying or permits based on factors identified during the NEPA review process.

- Minor changes to Subpart F, involving the changing of citations, were made on September 12, 1986 (51 *FR* 32606).

2.1.1 EPA Requirements for Environmental Review Under NEPA

EPA's current National Environmental Policy Act Procedures (40 CFR 6) outline the Agency's policies and processes for meeting environmental review requirements under NEPA. 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)**, which is a document prepared by applicants, grantees, or permittees and submitted to EPA. This document must be sufficient in scope to enable EPA to prepare an environmental assessment.

- **Environmental Assessment (EA)**, which is a concise document prepared by EPA that provides sufficient data and analysis to determine whether an EIS or finding of no significant impact is required.

- **Notice of Intent (NOI)**, which 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 and that these impacts can not be eliminated by making changes in the project.

- **Environmental Impact Statement (EIS)**, which is a formal and detailed analysis of alternatives including the proposed action, is undertaken according to CEQ requirements and EPA procedures.

- **Finding of No Significant Impact (FNSI)**, which announces 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)**, which is 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**, which refers to EPA's responsibility to ensure 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 of the text specifies format and the 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 on threatened and endangered species and potential impacts on historic or archaeological resources.

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; 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). 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. (A more detailed discussion of the environmental review process and triggers for certain specific environmental assessment requirements are presented later in this chapter.)

The remaining Subparts of the EPA Procedures (i.e., Subparts E, G, H, I, and J) address aspects of EPA's environmental review procedures that are not relevant to these guidelines for the proposed issuance of new source NPDES permits.

2.1.2 Environmental Review Process for New Source NPDES Permits

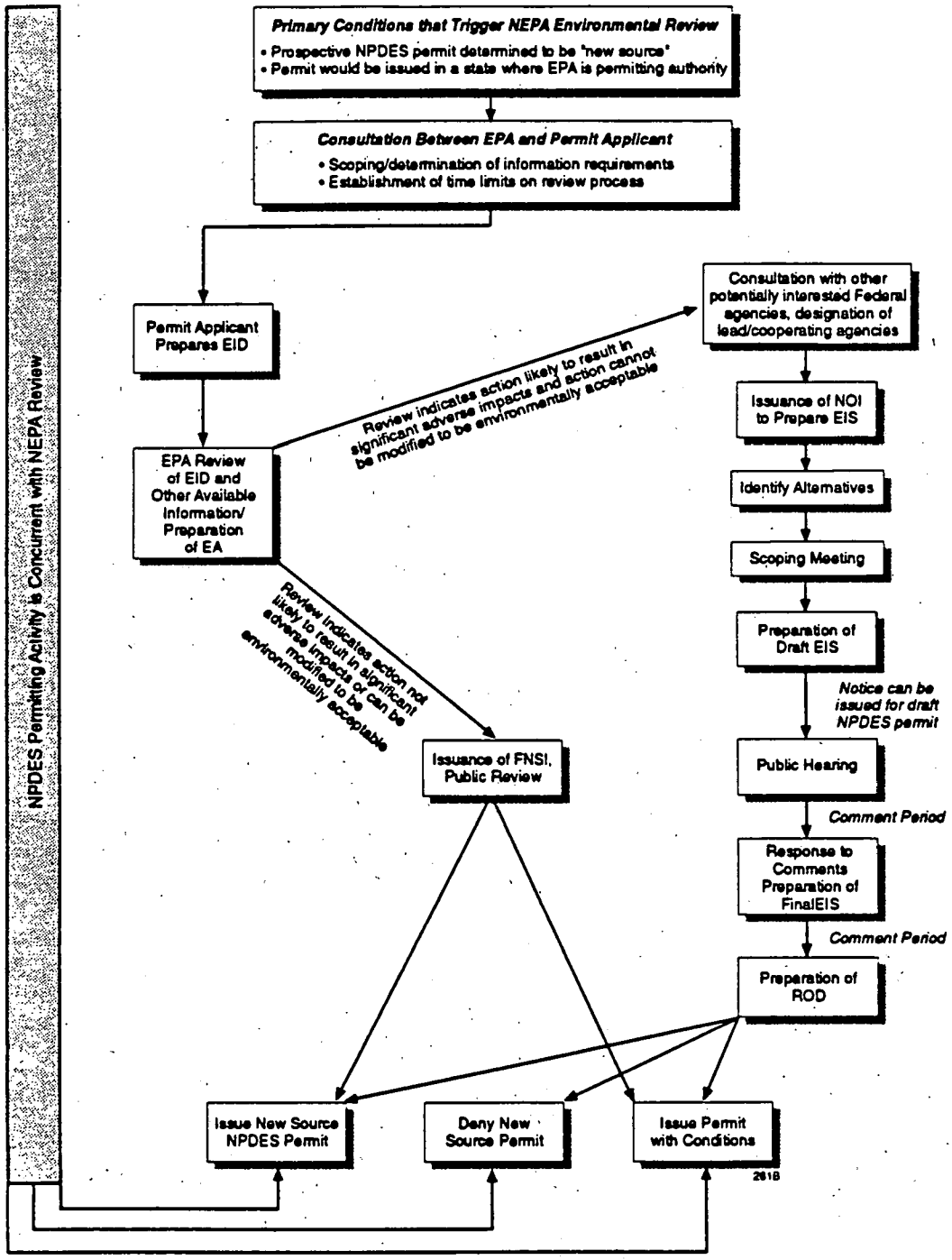
As illustrated by Exhibit 2-1, the NEPA review of proposed new source permitting actions and the process of NPDES permit issuance are to occur concurrently. However, completion of the environmental review—either through the issuance of a FNSI or the issuance of a ROD—is to precede actual permit issuance or denial.

As discussed in detail in a following section, EPA first must ensure that the two primary conditions that trigger NEPA environmental review have been met. EPA Regional office staff then would consult with the permit applicant to determine the scope of the information document; and upon request by the permit applicant, to set time limits on the completion of the review process consistent with 40 CFR 1501.8. (Information required from permit applicants is addressed in more detail later in this chapter.)

Once the permit applicant has submitted the EID, EPA Regional office staff must review the information provided by the applicant along with any other available information that is relevant. EPA Regional staff then must prepare a written EA which identifies alternatives, including the proposed action, presents a concise analysis of the potential impacts of these alternatives, and identifies any mitigation measures that could be (or will be) undertaken to address potential significant impacts.

The EA will result in one of two possible outcomes. If the review indicates that the proposed issuance of the new source permit is likely to result in "significant" adverse impacts that cannot be avoided through changes in the proposal, then EPA must initiate the more formal process of EIS preparation. Should the EA review indicate that the proposed action would be unlikely to result in significant adverse impacts or that those impacts could be avoided by modifying the proposal, EPA would issue a FNSI.

Exhibit 2-1. NEPA Environmental Review Process for Proposed Issuance of New Source NPDES Permits



A FNSI, which identifies any mitigation measures necessary to make a project environmentally acceptable, must be made available for public review (typically through publication in the *Federal Register*) and comment before issuing the permit.

The process of preparing an EIS is a more complex and formal process that begins with EPA's consultation with any other Federal agencies that may be involved in the project. Should EPA be designated as "lead" agency for the EIS, EPA would then begin the process through the publication through EPA's Office of Environmental Review of an NOI in the *Federal Register*. EPA also may consult with the permit applicant at this point to discuss the option of preparing the EIS through a "third-party method." If the applicant and EPA agree on this method (and this agreement must be expressed in writing), the applicant would then engage and pay for the services of a third-party contractor to prepare the EIS. Such an agreement will eliminate the need for further independent preparation of EIDs by the applicant. EPA, in consultation with the applicant, would choose the contractor, which must provide appropriate disclosure statements attesting to a lack of financial or other conflicting interest in the outcome of the EIS. EPA would manage the contractor and would have sole authority for approval and modification of EIS conclusions.

At this early stage of the process, a preliminary set of alternatives would be identified, based on several perspectives:

- Alternatives considered by the applicant
- Alternatives available to EPA
- Alternatives available to other agencies with jurisdiction over the facility.

Next is the scoping process, which involves identifying key issues, refining the list and description of alternatives, and setting general parameters for the data and analyses that will be required to complete the assessment. Public involvement and interagency coordination are important parts of the scoping process, which typically involves the convening of a scoping meeting attended by interested parties. If a third-party contractor is to prepare the EIS, the contractor is not to begin work until after the scoping meeting is held.

Following the scoping process, the potential impacts of alternatives, including the proposed action, are analyzed and a Draft EIS (DEIS) is prepared in accordance with strict format and content requirements. In the course of DEIS preparation, a number of specific coordination and consultation requirements must be met. These include formal consultation with the U.S. Fish and Wildlife Service (and/or the National Marine Fisheries Service) regarding threatened and endangered species issues as well as formal consultation with the State Historic Preservation Offices (SHPO) on any relevant cultural and historic resource issues.

After the DEIS is reviewed internally by EPA, the public and interested parties are notified of its availability through a *Federal Register* notice, notices in local newspapers, and letters to participants in the scoping process. EPA also would conduct one or more public hearings to further solicit comments on the DEIS.

Following the comment period for the DEIS, EPA (or the third-party preparers as directed by EPA) would respond to all comments and would prepare the final EIS (FEIS). After internal EPA review of the FEIS, notification again is made through the *Federal Register*, notices, and letters to interested parties. A final review period allows for any additional comments by the public and interested government agencies.

The last step in the EIS process is the preparation of the ROD, which summarizes the permitting action that will be taken, as well as any mitigation measures that will be implemented to make the selected alternative environmentally acceptable. (A discussion of the relationship between the NEPA review and the permitting procedures is presented later in this chapter.)

2.2 TRIGGERS FOR NEPA REVIEW ACTIVITIES

2.2.1 PRIMARY CONDITIONS THAT TRIGGER NEPA REVIEW

As noted earlier in this chapter, the following two major conditions must be met before NEPA review requirements apply.

2.2.1.1 New Source Determination

A proposed NPDES permittee must be determined to be a "new source" before NEPA review requirement apply. The determination is made by the EPA Region in accordance with NPDES permit regulations under 40 CFR 122.21(l) and 122.29(a) and (b).

2.2.1.2 EPA is the Permitting Authority

The second major condition that must be met before NEPA review requirements apply is that EPA is the permitting authority. Under NPDES, States and Native American tribes with an approved program may administer the permitting program. In such cases, the proposed issuance of a new source permit would not be a Federal action (unless EPA issues a permit in an approved-program State pursuant to 40 CFR 123.44(h)). Thus, NEPA requirements would not apply. As of mid-1994, the NPDES permit program is administered in 40 States. In addition to tribal lands, States and other jurisdictions where EPA is the permitting authority and where NEPA review requirements would apply are listed below:

- Alaska
- Arizona
- District of Columbia
- Florida
- Idaho
- Louisiana
- Maine
- Massachusetts
- New Hampshire
- New Mexico
- Oklahoma
- Texas
- American Samoa
- Guam
- Puerto Rico

2.2.2 When is An EIS Required?

NEPA requires that an EIS be prepared for "major" Federal actions "significantly affecting the human environment." Generally, the determination of the need for an EIS hinges on a 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 EIS, 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 groundwater 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 new source would have a **significant** direct adverse impact on a property listed or eligible for listing in the National Register of Historic Places.

- Any part of the new source will have **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.

In his review of legal issues associated with NEPA, Mandelker (1992) summarizes judicial criteria for significance. He cites the results of *Hanly v. Kleindienst (II)*, where the court stated four criteria that could be used to make a significance determination:

> "First, did the agency take a 'hard look' at the problem, as opposed to bald conclusions, unaided by preliminary investigation? Second, did the Agency identify the relevant areas of environmental concern? Third, as to problems studied and identified, does the agency make a convincing case that the impact is insignificant? ... If there is an impact of true 'significance,' has the agency convincingly established that changes in the project have sufficiently minimized it?"

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, they can be quite controversial. Several of the more commonly raised issues surrounding whether the impacts of a given mining operation could be considered significant are described below.

2.2.2.1 Impacts to Already-degraded Environments and Cumulative Impacts

Mining operations are often proposed in areas where previous mining has occurred, sometimes directly on sites that have been mined in the past. Many of these areas have been severely impacted by past mining activity, and the impacts of a modern mine would occur within the context of pre-existing conditions (it should be noted that "remining" previously degraded sites can lead to net improvements in the long-term environmental conditions of a site). In these cases, there are three fundamental approaches for using baseline conditions to evaluate the significance of impacts:

- Define natural background conditions as the baseline in assessing significance: this approach emphasizes that additional impacts to already-affected environments are even more serious than to more resilient undisturbed environments.

- Define existing conditions as the baseline in assessing significance, but adjust the definition of significance according to the current quality of the resource that would be affected (i.e., environmental effects that would be considered "significant," and thus would trigger an EIS, in an undisturbed natural environment may not be considered "significant" in one where the resource affected is already degraded, and the degree of degradation also influences the determination).

- Define existing conditions as baseline but use a consistent definition of "significant."

CEQ regulations require descriptions of the affected environment in EISs (40 CFR 1502.15) but do not address the issue of how or what pre-existing conditions should be taken into account in assessing significance. The courts have addressed the issue and come to various conclusions. In practice, existing conditions have assumed a central place both in assessing significance and in considering mitigation measures in EAs and EISs. Environmental effects that would be considered significant in one environment may not be considered significant in another. This has allowed impacts to particularly "valuable" environments to be assigned a significance differently than similar or more serious impacts in degraded environments. This is by no means absolute, however, since the assessment of significance is generally made on a case-by-case basis.

It should be noted that the Clean Water Act provides less flexibility: discharges to waters of the United States that do not meet their State-designated beneficial uses and water quality standards are not allowed to further degrade these waters. This has proven to be a problem in some areas where waters affected by prior mining activities already fail to attain the beneficial uses and water quality standards that have been assigned to them by the State. A proposed operation in such areas could "threaten a violation of Federal, State, or local law or requirements imposed for the protection of the environment" (40 CFR 1508.27(b)(10)) and this would be a factor for consideration in determining the significance of the proposed action. This also points out the need for sufficient technical documentation of the basis for determination of how a project will ensure compliance with applicable water quality standards.

In addition, CEQ regulations include "cumulative" impacts among the environmental impacts that must be assessed under NEPA. CEQ defines (40 CFR 1508.7) cumulative impacts as "the incremental impact[s] of the action when added to other past, present, and reasonably foreseeable future actions...." This is important for proposed mining operations for two reasons. First, new mines are often located in areas--or directly on sites--where mining took place in the past, and where there are residual impacts from that mining. As noted above, this can complicate the process of establishing baseline conditions, and make it extremely expensive. Second, metal mining operations in particular almost invariably evolve and expand during their active lives. The nature and extent of

future operations depends on the experience gained with the initial operation and on information that is not obtained until operations begin.

For example, the sizes of and gold concentrations in ore bodies are never fully understood until the ore body is mined, so the ultimate success in recovering the gold, and the ultimate extent of mining, are simply not known at the time initial environmental evaluations must be conducted. Typically, facility design and operations evolve as more and better information is gained during mining operations, and the evolution is captured in proposals for major expansions. Such proposed major expansions usually trigger new evaluations of potential and actual environmental impacts. These evaluations are limited by similar information gaps at the time the evaluations are made. However, there is always much more detailed site-specific information (both environmental and operational) at the time of a planned expansion, since these types of information are gained during operations. This information could be used to assess the adequacy of the initial environmental evaluation, and thus to guide the evaluation for the expansion, but this is not always the case. Indeed, it is not uncommon for secondary environmental evaluations to be confined to incremental effects of the expansion, not to the total impacts of the evolving operation. Thus, assessments of potential environmental impacts of expanding operations may sometimes be less comprehensive even than initial evaluations. In assessing impacts under NEPA, however, CEQ regulations make it clear that an environmental assessment or EIS consider the sum total of impacts (i.e., the cumulative impacts).

2.2.2.2 Uncertain Impacts

As noted above, CEQ regulations (40 CFR 1508.27) indicate that assessing significance requires considerations of "context" and "intensity." Intensity, in turn, "refers to the severity of impacts," and the regulations list a number of factors that should be considered in evaluating intensity. These include consideration of "the degree to which the possible impacts . . . are highly uncertain or involve unique or unknown risks" (§1508.27(b)(6)). Uncertainty regarding both immediate and ultimate impacts is a characteristic of most mining operations, particularly metal mining.

In some cases, there may be a relatively low (but to some extent quantifiable) probability that a mining operation will cause a significant environmental effect, but the effect, were it to occur, could be severe. Whether such risks "require an impact statement has received surprisingly little attention" by the courts (Mandelker, 1992). Mandelker cited one case that addressed the issue, in which it was found that effects which were "only a possibility" could indeed be considered in an impact statement, and that the agency would have "some latitude" in making a determination that an EIS was or was not necessary ((*Conservation Law Foundation v. Air Force*, 26 Env. Rep. Cas. 2146 (D. Mass. 1987)).

This can be an important issue in the case of mining. Acid generation potential, and the development of acid drainage, for example, can be extremely difficult to predict. There are some mines where acid generation can be predicted with some confidence, and others where there is only a remote or no

chance of acid generation. For many (perhaps most) mines, however, there is substantial uncertainty as to its ultimate occurrence, as described in Chapter 4. Often, acid generation is considered unlikely but possible, or likely but not certain, based on information available at the time. Other active and abandoned mines in a particular area may give some idea of the possibility or probability that acid generation will occur, and any such information should always be assessed. Uncertainty regarding future acid generation is very common at the time of mine permitting (or approval). As the geology and geochemistry of the ore body and of waste materials are better understood during the life of the mine, more accurate predictions can be made; periodic testing and prediction are sometimes required throughout the life of a mine by States or Federal regulators. There are some cases, however, where substantial uncertainty exists even at mine closure/reclamation.

When acid drainage develops, it can have catastrophic effects on water quality and aquatic resources in particular environments. It is nearly always possible to assess the potential impacts on water quality should acid drainage occur, using various reasonable (and/or worst case) assumptions as to flow rates and frequency, pH, metals concentrations, etc. This information could be used together with information on existing surface water or groundwater quality and on aquatic resources, to assess the significance of acid drainage should it develop. The assessment of acid generation potential (in terms of its probability) could then provide guidance as to whether an EIS should be prepared for new source permit issuance (or for other agencies' actions that authorize development of a mine).

When potential impacts could have catastrophic consequences, even if the probability of occurrence is low, they should be analyzed. This analysis should be undertaken even if information is incomplete or unavailable, and CEQ regulations (40 CFR 1502.22) guide how an agency is to proceed in such cases. These regulations apply to situations where an EIS is being prepared. In general, the regulations require that incomplete or unavailable information be obtained and included in the EIS unless the cost would be "exorbitant." When costs would be "exorbitant," the EIS must include a statement that the information is incomplete or unavailable, a statement describing the relevance of the information to the evaluation, a summary of relevant credible evidence, and the agency's evaluation of potential impacts based on "theoretical approaches of research methods generally accepted in the scientific community." Any such analyses must be "supported by credible scientific evidence," must not be "based on pure conjecture," and must be "within the rule of reason."

2.2.2.3 Delayed Impacts

Indirect impacts, as defined by CEQ regulations (§1508.8(b)), include those "caused by the action and later in time or farther removed in distance, but still reasonably foreseeable." Such impacts must be considered in an EA, and significant delayed impacts can trigger an EIS. An example of a delayed impact in the context of mining would be acid drainage whose onset occurs years or decades after the mine opens (or closes). However, there must be a causal relationship between the Federal action (in this case, permit issuance or other approval) and the indirect effect: the action must be "proximately

related to a change in the physical environment" (*Metropolitan Edison v. People Against Nuclear Energy*, 460 U.S. 7866 (1983)). This would be the case in the case of a new source permit (or other approval), since the changes in the earth's surface in excavating a pit or an underground mine, or the placement of materials in a location and in a configuration that can lead to acid drainage, would be the direct result of issuing the permit (or approving the plan) and thus allowing the operation to go forward. For at least some mines, however, it is not clear if acid generation is "reasonably foreseeable," since there can be substantial uncertainty as to its ultimate development. Any prediction of acid drainage would seem to have to be quantifiable (or otherwise supportable) to some extent, since at least one court has determined that "unquantified speculation" (*American Public Transit Association v. Goldschmidt* 485 F. Supp. 811 (D.D.C. 1980)) that subsequent events would occur is not sufficient to qualify an action as significant.

2.2.2.4 Duration of Impacts

In general, temporary impacts are not considered significant, but generally the operations of all but the most ephemeral placer or coal mines would not be considered temporary. Specific activities associated with mine development, operation, and closure/reclamation are indeed temporary (e.g., construction activities associated with mine development), but would have to be considered in terms of the cumulative impacts of all the effects that result from the Federal action.

2.2.2.5 Transfer of Responsibility for Facility

The possession of (or responsibility for) a mining facility can change hands several times over the active life of the facility. In some cases, EPA (or another agency) may have reason to believe that the new responsible party (i.e., the new permittee) will be less able or less willing to carry through on commitments made by the previous party. For example, the site, and the responsibility for implementing mitigation measures, can become the responsibility of an owner or operator with less experience in dealing with issues faced by the mine, smaller in size and/or financial resources, with a worse history of environmental performance, and/or with differences in other regards that give rise to the concern. The transfer itself would not be a "major Federal action" (certainly, it would not involve issuance of a new source permit unless site conditions/operations changed). It is not clear if a transfer accompanied by material changes in stipulated mitigation measures (e.g., a change in the type or amount of bonding required by a State or Federal agency) would allow for any intervention by EPA, even though this could have major environmental implications.

2.2.2.6 Controversial Actions and Impacts

CEQ regulations (40 CFR Part 1508.27(b)(4)) provide that agencies are to consider whether environmental effects are "likely to be highly controversial" in assessing their significance, and thus determining whether an EIS must be prepared. Mandelker cites the leading case that addresses this issue, *Hanly v. Kleindienst (II)* (471 F.2d 823 (2d Cir. 1972)): "the term 'controversial' apparently

refers to cases where a substantial dispute exists as to the size, nature or effect of the major federal action," not to "neighborhood opposition." Many or most proposed mining operations are subject to some opposition, which would not by itself then seem to be a trigger for an EIS. However, for many proposed mines there can be substantial scientific and engineering uncertainty regarding the "size, nature or effect" of the potential impacts, or all three. This uncertainty can be particularly acute as to the ultimate extent of the operation (this occurs at many metal mines, since the full extent of the ore body is seldom known at the time the mine begins operation) and to the potential impacts of a given operation (given the uncertain extent of the operation in the case of metal mines and the difficulty in predicting the course of reclamation and ultimate performance of mitigation in the case of both metal and coal mines).

2.2.3 The Relationship between NEPA Review and NPDES Permitting Activities

How the NEPA review process affects NPDES permitting activities is a complex issue. EPA regulations clearly establish procedural and timing relationships between the two processes. However, how the findings of a NEPA review can affect the substantive outcome of the permitting process is less certain. In particular, there is a gray area as to how EPA should address NEPA review findings that are not related to water quality. As summarized by Mandelker (1992), in a recent court case it was held that NEPA does not confer on EPA the authority to impose conditions in effluent discharge permits that are not related to water quality or to other areas within the purview of the Clean Water Act.[1] However, the court held that NEPA authorized EPA to impose NEPA-inspired water-related conditions on permits for effluent discharges and to rely on NEPA to deny a discharge permit. Thus, for example, if a NEPA review indicated that construction associated with a proposed new source discharge would adversely affect a significant historic resource, EPA would not be authorized to include in the NPDES permit any conditions that related to that construction. However, EPA would be authorized to deny issuance of the permit based on a finding that was not strictly related to water quality.

It should be noted that most States in which mining occurs have assumed responsibility for administering the NPDES program. Consequently, EPA now issues very few NPDES permits to mining operations (new sources or otherwise) and thus is not responsible for NEPA compliance for such permit issuance very often (neither State issuance of new source NPDES permits, nor EPA's concurrence in such issuance, triggers NEPA). However, other Federal agencies are frequently responsible for preparing EAs or EISs on new mines. Mining often occurs on Federal lands in the west, thus requiring NEPA compliance by the Bureau of Land Management, Forest Service, or other land management agency. Also, new mines often require issuance of a Clean Water Act §404 permit, thus requiring NEPA compliance by the Army Corps of Engineers. When an EIS is prepared in such cases, EPA often participates as a cooperating agency in the NEPA process pursuant to 40 CFR Part

[1]Natural Resources Defense Council, Inc. v. Environmental Protection Agency, 859 F.2d 156 (D.C. Cir. 1988).

1501.7. Even where EPA does issue a new source permit, another Federal agency may be the lead agency in preparing the EIS, again with EPA participating as a cooperating agency.

2.3 LEVELS OF REVIEW

Environmental analysis under NEPA is a process that is attended by extensive internal, interagency, and public review. In particular, NEPA involves a strong mandate to involve the public in the environmental analysis process. As discussed below, document review is an element of all major aspects of the analysis process. The formality and intensity of review increases with each escalation in the hierarchy of NEPA documentation. So, EIDs are subject to the least formal and extensive review; while EISs are subject to the greatest level of review.

2.3.1 ENVIRONMENTAL INFORMATION DOCUMENT (EID)

The EID, which is prepared by the permit applicant, is reviewed by the EPA Region. Although no formal public notice is involved at this stage, documents prepared as part of the NEPA review process are intended to be readily available for public review. The applicant may request confidential treatment of certain types of business information that is provided as part of the EID.

2.3.2 ENVIRONMENTAL ASSESSMENT DOCUMENTS (EA)

The EA, which is prepared by EPA Regional office staff (or by contractors or the permit applicant under EPA's auspices), is reviewed and approved by the EPA Regional Administrator or designee. The Regional Administrator is formally the "responsible official" for EPA's action.

The Regional Administrator is required to give notice and make EAs and FNSIs available for public inspection. EAs and FNSIs are reviewed by staff responsible for making permitting decisions prior to those decisions. Copies of EAs and FNSIs are included in the official administrative record for those permitting actions.

2.3.3 ENVIRONMENTAL IMPACT STATEMENTS (EISS)

Notices, determinations and other reports and documentation related to an EIS are reviewed internally by EPA to the level of the Regional Administrator, who serves as the "responsible official," or the Regional Administrator's designee. Through consultation processes with cooperating and other interested agencies, EPA provides opportunities for joint decision making and review. These consultation activities take place throughout the EIS preparation process, beginning with initial discussions regarding the determination of the appropriate Federal lead agencies through review and comment on the (EIS) ROD.

The public, too, is provided many opportunities for review and participation in the assessment process. These opportunities include the following:

- Publication of the NOI in the *Federal Register* provides an opportunity for parties to express their interest in an EIS action.
- A scoping meeting is held early in the process to solicit public and government agency advice on the issues that should be addressed and any relevant information that should be considered in the assessment process.
- Draft EISs are made available for review by the public and interested government agencies. Cooperating and interested parties are provided review copies of Draft EISs. Other copies are provided in easily accessible areas, such as public libraries in the local area of the proposed action. EPA must respond formally to all comments made on the Draft EIS. Comments and responses are represented in a special section of the final EIS.
- Similar notice is provided of the availability of Final EISs and RODs and copies are sent to interested parties for their review.
- The Office of Federal Activities (OFA) also maintains copies of EISs for public review and also provides a copy to CEQ for its review and consideration.

Draft final EISs and RODs are subject to internal review at the regional level, prior to release. Coordination of the internal review is by the lead branch among the regional program branches. Depending upon the nature of the specific issue, EPA's Office of General Counsel (OGC), OFA, the Office of the Administrator, or other EPA offices may also be included in the internal review cycle.

As is noted elsewhere, EPA's authorization of most States to administer the NPDES system has resulted in only occasional issuance by EPA of new source NPDES permits for mining operations. Even then, EPA Regions more often act as a cooperating or oversight agency on EISs prepared by other Federal agencies (e.g., Federal land managers or the Army Corps of Engineers). In these case, EPA reviews preliminary drafts and other EIS-related documents. The jurisdictional and other reasons for determining lead vs. cooperating agency roles are discussed in CEQ regulations at 40 CFR Part 1501. Under these circumstances, the EPA Region typically drafts a memorandum of agreement (MOA) with the lead Federal agency, defining respective roles. EPA participates to varying levels in the preparation of the EIS document (with the objective of adopting the EIS), and issues an EPA ROD. As would be the case if EPA were the lead agency, the EIS is part of the administrative record for the NPDES permit and should be complete with regard to documenting the basis for the decision to issue the permit.

2.4 INFORMATION REQUIRED FROM PERMIT APPLICANTS

In accordance with EPA NEPA procedures, the nature and extent of information required from applicants as part of the EID are bounded by two separate requirements:

- EIDs must be of sufficient scope to enable EPA to prepare its environmental assessment.
- In determining the scope of the EID, EPA must consider the size of the new source and the extent to which the Applicant is capable of providing the required information. EPA must not require the Applicant to gather data or perform analyses which unnecessarily duplicate either existing data or the results of existing analyses available to EPA. EPA must keep requests for data to the minimum consistent with the Agency's responsibilities under NEPA.

The EPA procedures call for EPA to consult with the applicant to determine the scope of the EID at the outset of the process. As discussed in more detail in Chapter 5 of these guidelines, elements of the EID will be consistent with general requirements for the contents of NEPA documents.

Among the types of information required for EIDs is a balanced description of each alternative considered by the applicant. These discussions should include the size and location of facilities, land requirements, operation and maintenance facilities, waste management units, auxiliary structures such as pipelines or transmission lines, and construction schedules.

2.5 TIME INVOLVED IN PREPARING AND PROCESSING NEPA DOCUMENTS

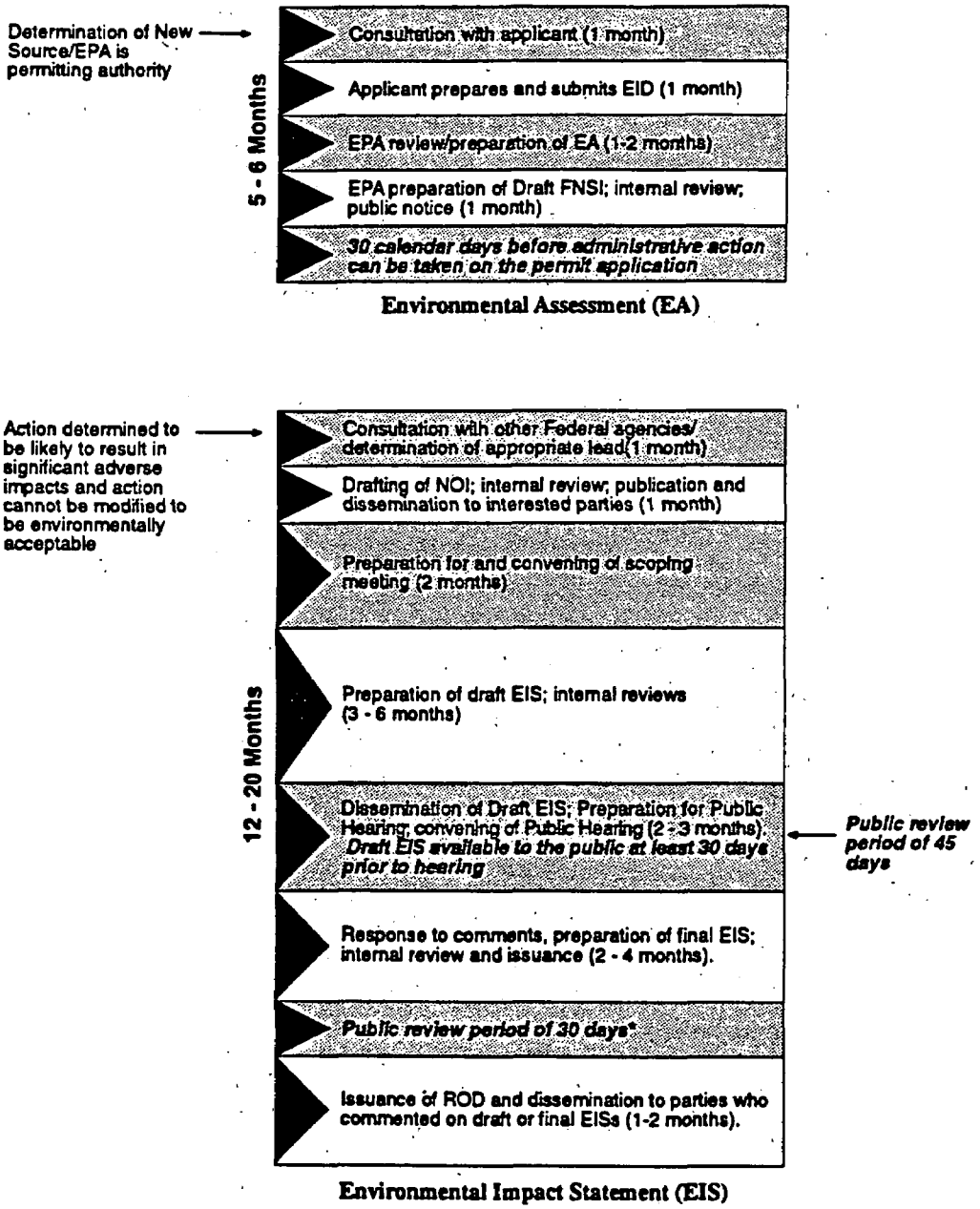
The time required to complete NEPA documentation requirements will vary considerably depending upon the complexity of issues, public controversy, and other factors. As shown on Exhibit 2-2, completion of the EA process generally requires at least 5 to 6 months; while completion of the EIS process ideally requires between 12 to 20 months but usually takes somewhat longer. As noted on this exhibit, some elements of the schedule (e.g., public review periods) are established by regulation, while others are more flexible.

Under EPA's NEPA procedures, the Applicant may request that EPA establish time limits for the environmental review process consistent with 40 CFR 1501.8.

2.6 LIMITATIONS ON PERMIT APPLICANT ACTIONS DURING THE REVIEW PROCESS

EPA NEPA procedures state that actions undertaken by the applicant or EPA shall be "performed consistent with the requirements" of 40 CFR 122.29(c) (see amendment in 51 *FR* 32609, September 12, 1986). In his treatise on NEPA law and litigation, Mandelker (1992) cites a key case that bears on this issue. In *Natural Resources Defense Council, Inc. v. EPA* the court held that, provided no discharge occurred, EPA could not prohibit construction of a new source.

Exhibit 2-2. Model Schedules for EAs and EISs for Proposed Issuance of New Source NPDES Permits



No EPA permitting decision can be made until the later of the following dates: (1) 90 days from the beginning of the Draft EIS public review period; (2) 30 days from the beginning of the Final EIS public review period*.*

* The review period officially starts on the Friday following the Federal Register reporting week when OFA receives 5 bound copies of a Draft or Final EIS.

** These are representative schedules. Schedules for specific cases may vary based on the complexity of issues, availability of data, and other factors. Items shown in bold are mandatory in accordance with EPA NEPA procedures.

3. OVERVIEW OF MINING AND BENEFICIATION

This chapter presents an overview of the processes and activities associated with metal ore and coal mining and beneficiation as currently practiced in the United States. The activities and processes for mining and beneficiating many metal ores are quite similar in many regards, so the first sections (3.1 and 3.2) describe general concepts of ore mining and ore beneficiation which apply to one or more of the commodity sectors. These general overviews are followed by commodity-specific profiles (Section 3.3), which discuss in greater detail those aspects of mining and beneficiation that are particularly important within each of the commodity sectors. These profiles emphasize the process variations that are unique to that ore, the chemical reagents typically used in beneficiation of each ore, and physical/chemical properties that result in the discharge of unique waste streams. Coal mining and coal processing are then addressed in individual sections (3.4 and 3.5).

3.1 ORE MINING

Mining activities generally consist of exploration, site development, ore extraction (including drilling and blasting, surface mining, and underground mining), and restoration/reclamation. Processes typical of these activities are discussed below.

In developing effluent limitation guidelines for discharges from mines, a mine was defined by EPA (1982) as an area of land upon or under which minerals or metal ores are extracted from natural deposits in the earth by any means or methods. The mine includes the total area upon which such activities occur or where such activities disturb the natural land surface. A mine also includes land affected by ancillary operations that disturb the natural land surface, and can include any adjacent land the use of which is incidental to any such activities; all lands affected by the construction of new roads or the improvement or use of existing roads to gain access to the site of such activities; all lands associated with haulage and excavations, workings, impoundments, dams, ventilation shafts, drainage tunnels, entryways, refuse banks, dumps, stockpiles, overburden piles, spoil banks, tailings, holes or depressions; and all repair areas, storage areas, and other areas upon which are sited structures, facilities, or other property or materials resulting from or incident to such activities.

Similarly, in developing effluent limits for discharges from mills, a mill was defined by EPA (1982) as a preparation facility within which the mineral or metal ore is beneficiated by being cleaned, concentrated or otherwise processed prior to shipping to the consumer, refiner, smelter or manufacturer who will extract or otherwise use the metal contained in the ore. This ore preparation includes such operations as crushing, grinding, washing, drying, sintering, briquetting, pelletizing, nodulizing, leaching, and concentrating by gravity separation, magnetic separation, flotation or other means. A mill includes all ancillary operations and structures necessary for the cleaning and concentrating of the mineral or metal ore, such as ore and gangue storage areas and loading facilities.

3.1.1 EXPLORATION

In the ore mining industry, exploration is defined as all activities and evaluations performed to locate and define mineral deposits for the purpose of extraction now or in the future. Exploration activities range from efforts of a one-man prospector to use of sophisticated ground and airborne sensing equipment, and extensive sampling and testing programs. A typical exploration program consists of four principal stages (Bureau of Mines, 1977):

- Regional appraisal
- Detailed reconnaissance of favorable areas
- Detailed surface appraisal of target areas
- Detailed sampling and analysis.

A regional appraisal (Stage 1) typically consists of a review of aerial photographs, geologic maps, geophysical maps, published reports, and other available literature and may cover an area from 2,600 to more than 260,000 square kilometers (km) (1,000 to 100,000 square miles). The detailed reconnaissance of favorable areas (Stage 2) typically covers 26 to 260 km (10 to 100 square miles), and involves more extensive geologic and geophysical surveys using techniques such as geologic mapping; stream, sediment, and rock sampling; and non-destructive ground and airborne magnetic, electromagnetic, radiometric, and remote-sensing imagery studies (Bureau of Mines, 1977a). Stage 3, the detailed appraisal of target areas, may involve all of the non-destructive evaluation methods used in Stage 2, and often includes destructive sampling efforts such as drilling and the excavation of test pits and trenches. These target area examinations usually cover from 3 to 130 km (1 to 50 square miles), and may identify the existence of mineral deposits that constitute potential ore bodies. If further definition of the potential ore appears warranted, then a three-dimensional sampling and preliminary evaluation program (Stage 4) will be conducted. A Stage 4 investigation typically covers from 1 to 25 km (0.4 to 10 square miles). Its purpose is to identify the study boundary or limits, as well as the depth, size, shape, mineralization, and grade of the potential ore deposit. Testing activities may involve extensive drilling; excavation of test pits, trenches, shafts, and adits; groundwater pumping tests; blasting tests; and many other forms of destructive testing, as well as the non-destructive techniques already described. The extent of these tests will depend greatly upon the location, accessibility, geologic setting, and types of minerals under investigation. In addition, support activities such as the construction of access roads and the building of temporary living quarters may be undertaken.

The first two principal stages include very limited destructive testing, if any. The potential for adverse environmental impact is thus limited to those impacts associated with gaining access to the areas. The last two stages, however, involve destructive testing activities which may be undertaken before or after permit applications are filed. Therefore, construction activities and destructive exploratory testing that may result in adverse environmental impacts can occur prior to the filing of

applications for NPDES, PSD, and other Federal, State, and local permits. The exploratory tasks conducted by the permit applicant, and the known environmental impacts (adverse and beneficial) resulting from the exploratory activities, should be well documented within the EID.

3.1.2 SITE DEVELOPMENT

Once a mineral deposit of commercial value has been defined by exploration activities, it is necessary to construct facilities for extracting the ore, beneficiating it if necessary, and transporting it to market. The site development process has many possible stages depending on the type of mine projected and its relation to the surrounding transportation system. Site development activities may include the following.

3.1.2.1 Construction of Access Roads, Rail Lines, or Ship/Barge Terminals

Road and rail lines will require clearing a right-of-way, filling or excavating to a desired grade, and paving or laying rail. This may involve the use of earthmoving equipment such as graders, scrapers, bulldozers, power shovels or backhoes. These operations may result in the destruction of vegetation along the right-of-way, and possibly the production of excess earth from excavation or the requirement that borrow pits be created for obtaining fill material. Overburden or waste rock from the developing mine may be used in road or other construction. In a few cases, acid-generating waste rock used for various purposes has caused significant problems. In previously undeveloped terrain, the removal of vegetation and/or soil cover may cause an increase in the rate of local erosion, and, where terrain is steep, increase the potential for mass wasting processes such as slumps, landslides, and mud flows. If excavation extends into hard materials, blasting may be employed. It can be expected that these operations will produce brush and timber debris which must be removed, buried, or burned if permitted. There will also be dust generated during earthmoving. Development of ship/barge loading facilities may require dredging and construction activities that disturb bottom sediment.

3.1.2.2 Construction of Mining Facilities

Initial work at most mines involves obtaining access to the ore bodies. At surface mines, topsoil and overlying rock must be removed; at underground mines, shafts or adits must be driven. These operations involve the operation of earth moving and construction equipment, the erection of structures, and, possibly, major excavation. Waste rock dumps must be provided and topsoil may be stockpiled for future use in restoration activities.

Also, ancillary facilities such as maintenance and office buildings may be constructed during this stage. At many larger mining operations, living facilities for mine personnel may involve the construction of major housing, shopping, and recreational developments.

3.1.2.3 Construction of Mill Facilities

Unless the ore is of such a high grade that it can be economically shipped for offsite beneficiation, a mill must be constructed in order to beneficiate the ore to a marketable grade. Usually the mill will be located as close to the mine as is practicable in order to reduce the costs of transporting the raw ore. However, in some cases, conditions dictate construction of a mill at a considerable distance from the mine and sites at lower elevation are always preferred. Roads, railway lines, and/or conveyors must be constructed from the mine to the mill. The impacts of mill construction itself will generally be similar to those incurred in the construction of any industrial/manufacturing facility. Land must be cleared of vegetation and prepared by excavation and grading. Materials must be transported to the site and assembled by a sizeable labor force. These operations may result in the production of vegetation and construction debris, emission of fugitive dust, generation of noise from construction machinery, and increased sediment loading to local streams, as well as secondary effects caused by the influx of construction laborers.

3.1.2.4 Other Pre-Mining Activities

Other aspects of mine/mill development may include the need for installing utilities (i.e., electrical transmission lines or water lines) to the site, or in remote areas constructing a power plant and/or water supply system. In very remote regions, it may even be necessary to construct a settlement (i.e., living quarters and support facilities) for the mill construction and operation personnel.

3.1.3 MINING

Minerals are extracted from the earth by a wide variety of techniques. In general, mining consists of removing the ore from the host rock or matrix and transporting it away from the mined site. In the interests of economic efficiency, the extraction process is designed to remove ore of a predetermined grade or higher, leaving behind lower-grade ore and barren rock if this is practicable. In practice, such an ideal separation is not always possible, so that some lower-grade rock is mined and some higher-grade ore left behind. (As noted below, the distinction between waste rock, "subore," and ore is an economic one that varies from mine to mine and can vary in time at specific mines.) Most extraction processes result in the removal of ore and associated rock or matrix in bulk form from the deposit, using various mechanical means to break the ore into pieces of manageable size or to separate the ore minerals from unwanted material.

Mechanical techniques include the use of explosives or heavy machinery to break up or to excavate the ore-bearing rock or matrix; high-pressure streams or jets of water, to disaggregate beds of sediment; sluices, riffles and other hydraulic devices to separate placer minerals from the bedload of streams. Some (copper and uranium) ore deposits are suitable for extraction by *in situ* solution techniques, in which the ore minerals are dissolved in the ore body by solvents and pumped to processing areas in solution.

Although mining processes may be classified according to the numerous techniques that are employed in removing ore, they can be broken down into two broad categories that are associated with the general setting of the running operation. These are: (1) surface mining or open-pit processes; and (2) underground mining processes. Specific techniques and applications within this framework are discussed below.

3.1.3.1 Surface Mining

Surface mining is the major type of mining operation for most of the major metallic ores in the United States. This is the method of choice when the ore deposit is near the surface, or is of sufficient size to justify removing overburden. At present, this is the most economical way of mining highly disseminated (lower-grade) ores. Generally, ore deposits must be within 150 meters (approximately 500 feet) of the surface for surface mining methods to be economically feasible. Surface mining methods typically used for ore extraction are discussed in the following paragraphs.

3.1.3.2 Open Pit Mining

This method involves excavation of an area of ground and removal of the ore exposed in the resulting pit. Depending on the thickness of the ore body, it may be removed as a single vertical interval or in successive intervals or benches. If the ore is mined as a single vertical interval, it may be feasible to place waste rock from one area in the space (pit) left by previous mining of the adjacent area. However, the ore body generally is mined in benches after the overburden has been completely removed from the mine area. In resistant materials, the procedure usually employed involves mining each bench by drilling vertical shot holes from the top of the bench, and then blasting the ore onto the adjacent lower level. The broken ore and waste rock then is loaded into rail cars or trucks for transport to the mill or waste rock dumps, as the case may be. In less resistant materials, the ore may be excavated by scrapers or digging machinery without the use of explosives. A variation of open pit mining involves use of a central shaft (or glory hole) into which ore from an open pit is dropped. The ore is allowed to move downward through the vertical or inclined shaft to an underground level where it is loaded into cars for transport to the surface. This method is especially favored if the ore body is relatively deep and narrow.

3.1.3.3 Dredging

Placer deposits are concentrations of heavy metallic minerals which occur in sedimentary deposits associated with watercourses or beaches (either current or ancient). These deposits can be mined by surface open pit methods, but in some cases can be better handled by dredging. For this method, the mine area is flooded and the excavating/mining equipment mounted on a barge. In hard materials the dredge uses a mechanical digging system to break up and excavate the deposit, while soft deposits can be removed by hydraulic suction alone. Mechanical dredges can use individual digging buckets (clamshells) to excavate the material; or, if conditions permit, will use a chain of buckets which dig

as a continuous sequence and transport material steadily into the dredge for processing. Suction dredges essentially operate as "vacuum cleaners" to mine out the alluvial material, although some have a revolving cutter head to aid in breaking up the material prior to its removal by suction. Placer deposits can also be worked with small portable suction units and by traditional hand sluicing and panning; however, these portable suction and panning methods can handle only limited volumes of material. There are no commercial dredges operating in the United States as of the 1990s, although the technology may be in use elsewhere. Also, suction dredging in the United States is mainly practiced by recreational miners or very small commercial miners.

3.1.3.4 Underground Mining

Underground mining has been the major method for production of several metals but is increasingly less common in the United States. Underground mining activities typically have significantly less impact on the surface environment than do surface methods. This is due both to the fact that less waste rock is mined with ores that are mined underground, and the fact that waste material can be used to backfill mined out spaces. However, large underground openings such as stopes can cause subsidence or caving at the surface, resulting in significant disturbance to structures, roads, drainages, etc. Drainage from underground mines also may cause significant alteration to the quality of surface water and can affect groundwater quantity and quality.

Several underground mining procedures rely on the natural support of the ground, including:

- **Room and Pillar.** This method is suitable for level deposits that are fairly uniform in thickness. It consists of excavating drifts (horizontal passages) in a rectilinear pattern so that evenly spaced pillars are left to support the overlying material. A fairly large portion of the ore (40%-50%) must be left in place. Sometimes the remaining ore is recovered by removing or shaving the pillars as the mine is vacated, allowing the overhead to collapse or making future collapse more likely.

- **Open Stope.** In competent rock, it is possible to remove all of a moderate sized ore body, resulting in an opening of considerable size. Such large, irregularly-shaped openings are called stopes. The mining of large inclined ore bodies often requires leaving horizontal pillars across the stope at intervals in order to prevent collapse of the walls.

Some other degree of support is required in most underground mines. The basic concepts of the methods described above can be extended to permit working in less competent rock to allow extraction of a greater percentage of the ore, by using various methods of permanent or temporary support in order to prevent or delay collapse.

Underground mining methods that use these temporary or permanent methods of support include the following:

- **Longwall.** In level, tabular ore bodies it is possible to recover virtually all of the ore by using this method (in the United States, only coal is known to have been mined using longwall methods). Initially, parallel drifts are driven to the farthest boundary of the mine area. The ore between each pair of drifts is then mined along a continuous face (the longwall) connecting the two drifts. Mining proceeds back toward the shaft or entry, and only enough space for mining activities is held open by moveable steel supports. As the longwall moves, the supports are moved with it and the mined out area is allowed to collapse. Various methods can be used to break up and remove the ore. In many cases, the rock stresses that are caused by the caving of the unsupported area aids in breaking the material in the longwall face.

- **Shrinkage Stoping.** In this method, mining is carried out from the bottom of an inclined or vertical ore body upwards, as in open stoping. However, most of the broken ore is allowed to remain in the stope in order both to support the stope walls and to provide a working platform for the overhead mining operations. Ore is withdrawn from chutes in the bottom of the stope in order to maintain the correct amount of open space for working. When mining is completed in a particular stope, the remaining ore is withdrawn, and the walls are allowed to collapse.

- **Cut and Fill Stoping.** If it is undesirable to leave broken ore in the stope during mining operations (as in shrinkage stoping), the lower portion of the stope can be filled with waste rock and/or mill tailings. In this case, ore is removed as soon as it has been broken from overhead, and the stope filled with waste to within a few feet of the mining surface. This method eliminates or reduces the waste disposal problem associated with mining as well as preventing collapse of the ground at the surface.

- **Square-set Stoping.** Ore bodies of irregular shape and/or that occur in weak rock can be mined by providing almost continuous support as operations progress. A squareset is a rectangular, three-dimensional frame usually of timber, which is generally filled with waste rock after emplacement. In this method, a small square section of the ore body is removed, and the space created is immediately filled by a square-set. The framework provides both lateral and vertical support, especially after being filled with waste. Use of this method may result in a major local consumption of timber and/or other materials utilized for construction of the sets.

- **Top Slicing.** Unlike the previously described methods in which mining begins at the bottom of an ore body and proceeds upward, this procedure involves mining the ore in a series of slices from the top downward, first removing the topmost layer of the ore and supporting the overhead with timber. Once the top layer of an area is completely removed, the supports are removed and the overlying material allowed to settle onto the new top of the ore body. The process is then repeated, so that as slices of ore are removed from the ore body, the overburden repeatedly settles. Subsequent operations produce an ever-thickening mat of timber and broken supports. This method consumes major quantities of timber.

Additional methods of underground mining involve procedures in which ore is broken by removing its support, allowing the forces produced as the ore mass subsides to break the ore into manageable pieces. Methods based on this principal include:

- **Block Caving.** Large massive ore bodies may be broken up and removed by this method with a minimum of direct handling of the ore required. Generally, these deposits are of such a size that they would be mined by open-pit methods if the overburden were not so thick. Application of this method begins with the driving of horizontal crosscuts below the bottom of the ore body, or below that portion which is to be mined at this stage. From these passages, inclined raises are driven upward to the level of the bottom of the mass which is to be broken. Then a layer is mined so as to undercut the ore mass and allow it to settle and break up. Broken ore descends through the raises and can be dropped into mine cars for transport to the surface. When waste material appears at the outlet of a raise it signifies exhaustion of the ore in that interval. If the ore extends to a greater depth, the entire process can be continued by mining out the mass which contained the previous working passage.

- **Sublevel Caving.** In this method, relatively small blocks of ore within a vertical or steeply sloping vein are undercut within a stope and allowed to settle and break up. The broken ore is then scraped into raises and dropped into mine cars. This method can be considered as an intermediate between block carving and top slicing.

Naturally there are many variations and combinations of the basic methods discussed above. For example, a stope which is not quite capable of standing open without support may be maintained by a series of single timbers (or stulls) placed from wall to wall in a system called stull stoping. Many of the variations and combinations of underground mining utilized today have been developed in response to specific or unusual characteristics of the ore being mined. Mining methods used in the production of specific ores are presented by ore subcategory in subsequent sections of this chapter.

3.1.3.5 *In Situ* Solution Mining

This is a method of underground mining that is applicable to certain ores under certain geohydrologic conditions. In principal, a series of wells are drilled into the ore body and a solvent is circulated through the ore-bearing formation by injection through some of the wells and withdrawal through others. Use of the method has obvious geochemical restrictions based upon the amenability of the ore minerals to solution and the cost and practicality of solvents, and based on concerns related to groundwater quality. Hydrologic requisites include: (1) the host rock must be permeable to circulating fluids; and (2) the host rock must be overlain and underlain by impermeable formations or rock units that restrict the vertical flow of fluids. *In situ* solution mining is at present applied most widely to uranium and copper deposits in suitable geohydrologic settings.

Although there is little disturbance of the bulk properties of the surface and underground materials at an *in situ* solution mine, the effects of the operation on the quality of underground water can be enormous. In order to solubilize the ore minerals, the chemistry of the groundwater must be

drastically altered by the introduced solvents. In addition to the ore minerals, other materials are dissolved by the solvent action and these, too, enter the groundwater, generally rendering it unacceptable for human or animal consumption and often presenting a hazard of further contamination if the altered groundwater moves out of the mine area and into surrounding areas. Provisions for emergency cleanup and post-mining restoration of the groundwater often are required prior to issuance of permits for this type of operation.

3.1.4 Mining Wastes and Waste Management

The wastes generated by mining operations (as opposed to mills) in the largest quantities, and that present the most significant environmental impacts during and after mining, are mine water and waste rock. These are described in the following two subsections. Other wastes are generated in much smaller quantities, and they generally have much less environmental significance. Many of these wastes are described in the commodity-specific discussions in Section 3.3. (It should be noted that the use of the terms "mining waste" and "waste management unit" in this document does not imply that the materials in questions are "solid wastes" within the meaning of the Resource Conservation and Recovery Act.)

3.1.4.1 Mine Water

Mine water is water that must be removed from the mine to gain or facilitate access to the ore body. For surface mines, mine water can originate from precipitation, flows into the pit or underground workings, and from groundwater aquifers that are intercepted by the mine. Mine water can be a significant problem at many mines, and enormous quantities may have to be pumped continuously from the mine during operations. Dewatering can result in significant groundwater drawdowns, and this in turn can result in the loss of streamflows as well as wetland and riparian habitat in some areas. Uses of mine water can include:

- Dust control on the mine site (with or without prior treatment, depending on its quality and regulatory requirements).
- Process water in the mill circuit (again, with or without prior treatment).
- Discharge to surface water pursuant to an NPDES permit, which would include effluent limits on the discharge (limits would be either the 40 CFR Part 440 effluent limits on mine drainage or more stringent limits if those were necessary to protect water quality).

When a mine closes, removal of mine water from the mine generally ends. Underground mines can then fill (or partially fill) and mine water may be released through adits, or through fractures and fissures that reach the surface. Surface mines that extend below the water table fill to that level when pumping ceases, either forming a "lake" in the pit or inundating and saturating fill material. Recovery of groundwater to or near pre-mining levels following the cessation of pumping can take

substantial amounts of time, however, and effects that result from groundwater drawdown (e.g., reduction or elimination of surface water recharge) may continue to be felt for decades or centuries.

Mine water can have environmentally significant concentrations of heavy metals and TDS, elevated temperatures, and altered pH, depending on the nature of the ore body and local geochemical conditions. In addition, mine water can acidify over time as sulfide minerals are exposed to water and air, and release of mine water during active operations and for decades afterward can present enormous problems to surface and groundwater resources.

3.1.4.2 Waste Rock

The primary waste generated by both underground and surface mining is waste rock. Waste rock consists of non-mineralized and low-grade mineralized rock removed from above or within the ore body during extraction activities (Hutchison, 1991). Waste rock includes granular, broken rock and soils ranging in size from fine sand to large boulders, with fines content largely dependent on the nature of the formation and the methods employed during mining.

Depending on the nature of and depth to the ore deposit, mine waste rock may constitute the largest volume waste stream generated by a mining project. The quantity of waste rock generated relative to ore extracted from a mine is typically larger for surface mines than underground mines, reflecting the greater costs of underground mining operations. The ratio of waste rock to ore, described as the stripping ratio, may range as high as 10:1 for some areas, with typical values ranging from 1:1 to 3:1 for most mineral types.

Waste rock geochemistry varies widely from mine to mine, and may vary significantly at individual mines over time as differing lithologic units are exposed. Generally, waste rock at metal mines will always contain some concentration of the target mineral along with other metals. The mobility of any particular constituent of waste rock is highly dependant on site specific conditions such as climate, hydrology, geochemistry of the disposal unit and its foundation, mineralogy, etc. Waste rock from metal mines often contains sulfidic materials as components of the host rock. The concentration of sulfide minerals, and of neutralizing minerals, are important factors in the potential for waste rock to generate acid rock drainage (ARD), which is discussed in detail in Section 4.1.

Waste rock is typically disposed in large piles or dumps in close proximity and down-slope of the point of extraction. Waste rock dumps may be loosely categorized as valley fills, cross valley fills, side-hill fills, or heaped fills (or piles) (British Columbia Mine Dump Committee, 1991). Each of these names derives from the particular topographical feature exploited for waste containment. As the name implies, valley fills partially or completely fill the topographical depression formed by valley walls, with the walls providing stability and containment. Cross-valley fills span the mouth of a valley but do not completely fill the up-slope volume of the depression. Side-hill fills are formed by

disposing of waste rock down slope from the crest of a ridge and represent the most common form of waste rock dumps (BCMDC, 1991). Heaped fills or waste piles are constructed in areas of flat terrain where available topography and other factors require.

Regardless of the layout of the unit, waste rock dumps are generally constructed on unlined terrain, with underlying soils stripped, graded, or compacted as regulations and engineering consideration require. Such conditions may include steep foundations of unconsolidated material or partially saturated terrain that may not support the weight of fill material. Rock is hauled to the face of the unit in trucks or by conveyor systems and dumped. Surface grading of fill material is typically performed to provide haulage trucks access to the working face. Most commonly, waste rock is deposited at the angle of repose. If multiple lifts are constructed, or if stability of the dump is a concern, side slopes may be graded. Additionally, final dump slopes may be graded during reclamation activities.

Depending on site hydrology and regulatory constraints, drainage systems may be incorporated into dump foundations. In areas of ground water intrusion or where catchment areas channel substantial surface water flows into the dump, drainage systems help to prevent instability due to foundation failures from saturation (BCMDC, 1991). Drainage systems may be constructed of gravel-filled trenches or gravel blankets, with capacity and configuration determined according to site-specific conditions. Dump toe drains may be particularly favored to reduce pore pressure near the face of the structure to prevent toe spreading or local slumping.

Equally important are surface water and run-on controls. Such controls are often necessary to maintain stability and prevent mobilization of fines as well as erosion of exposed slopes. Upstream surface water diversion ditches and rock drains are options often incorporated into design for these purposes.

3.1.5 Restoration and Reclamation

Restoration activities often are conducted during surface mining activities in order to reduce environmental impacts and enhance visual aesthetics in the mining area. Although these restoration activities do prove valuable, they do not replace or lessen the necessity for full and comprehensive land reclamation at the completion of various staged mining activities. Temporary restoration activities may involve tasks such as landscaping in non-mining areas, soil stabilization by replacement of native grasses on spoil bank slopes, and using temporary vegetation covers on topsoil and other stockpiles.

Restoration activities conducted during underground mining operations are similar to those used in conjunction with surface mines, but are more limited since the waste piles developed as a result of underground mining are relatively smaller. Restoration activities conducted during underground

mining activities include landscaping and erosion control measures around the mining site, and the periodic sealing of drift entryways to prevent mine drainage.

Full-scale land reclamation activities begin upon completion of mining or of planned unit mining stages. These stages can be three to five year plans for large mines, or one- to three-month events for very small mining operations. Land reclamation activities are not temporary restoration measures taken to reduce impacts of daily mining activities, but represent permanent measures that are taken to restore the earth's surface to some level of productivity and to reduce to the greatest extent possible the permanent effects of the mining operation.

Surface mining activities involve massive disturbance. Thus, any reclamation activity itself is a major undertaking. Reclamation of some sort is required by Federal land managers and nearly all States. The specific reclamation that is undertaken by a given mine depends on the anticipated future uses of the land and regulatory agency requirements.

Closure and reclamation of waste rock piles and dumps have three major purposes: isolating toxic or reactive materials from the environment, providing for long-term stability, and returning as much of the pile or dump to some semblance of long-term beneficial use. The latter two objectives have received the most attention in the past, and techniques to achieve them are better understood. The first has begun to receive much more attention, but techniques are as yet generally unproven. The following techniques can be used alone and in combination to reclaim waste rock dumps. The specific techniques that are used to reclaim particular waste rock dumps are based on site-specific factors and regulatory requirements.

- Grading the top surface of sidehill dumps so that it slopes gently back toward the hillside, away from the face of the dump. When combined with prepared ditches (e.g., rip-rap) where the hillside meets the dump, this minimizes erosion and reduces flows down the steep face of the dump. For valley dumps, grading of the top surface should result in gentle slopes that direct and control flows so as to reduce uncontrolled runoff over the face of the dump. For freestanding piles, grading is generally intended to direct precipitation flows to prepared channels that convey flow over and down the sides of the dump in a controlled fashion. If the waste rock has no acid generation potential, some infiltration may be encouraged by creating shallow topographic lows in the top surface. Infiltration near an angle-of-repose slope should be avoided, since it could lead to saturation of surface materials and cause slumping and slope failure.

- Compacting the top surface of the dump, covering with stockpiled topsoil (possibly amended with organic matter such as sewage sludge and/or mulch), and seeding with native plant species. This minimizes both erosion and infiltration. Drought-resistant plant species may be appropriate since the substrate is generally unsaturated. Revegetation should be monitored for at least several years following reclamation to ensure that plant communities become well-established.

- Removing waste rock and using it as backfill in underground workings or the open pit. This can be prohibitively expensive, and is generally not an economic option after the waste rock has already been placed in dumps. In addition, nonreactive (i.e., not acid forming) waste rock can be used as construction material during successive stages of mine development (e.g., roads, tailings dams, water diversion berms, building foundations, underdrains) and for off-site construction.

- Regrading steep slopes of the dump to slopes less than the angle of repose, thus enhancing long-term stability. Regrading can include incorporating flat benches at intervals of the slope to reduce runoff velocity and provide another surface suitable for revegetation. Depending on the size of the waste rock, it may be appropriate to cover slopes with topsoil and revegetate.

- If the dump contains acid-generating waste rock, reducing infiltration becomes even more important. This can be accomplished by lining the top surfaces of dumps with synthetic materials or clay. Then, the cap or liner is covered with a protective layer of fine-grained material, covered with topsoil, and revegetated; alternatively, the surface can be covered with large rocks and boulders. When revegetating, particular care must be taken in selecting the plant species, since they must resist extreme cycles of drought and saturation. In addition, species must be shallow-rooted to avoid penetrating clay caps.

3.2 ORE DRESSING (BENEFICIATION)

Most ores contain the valuable metals disseminated in a matrix of less valuable rock called gangue. The purpose of ore beneficiation is the separation of valuable minerals from the gangue to yield a product which is much higher in content of the valued material. To accomplish this, ore generally must be crushed and/or ground small enough so that each particle is composed predominantly of the mineral to be recovered or of gangue. This separation of the particles on the basis of some difference in physical or chemical properties between the ore mineral and the gangue yields a concentrate high in values, as well as waste (tailings) containing very little value. Overall recovery is optimized according to the value (and marketability) of the concentrate produced.

Many properties are used as the basis for separating valuable minerals from gangue, including: specific gravity, conductivity, magnetic permeability, affinity for certain chemicals, solubility, and the tendency to form chemical complexes. Processes for effecting separation may be generally considered as: gravity concentration, magnetic separation, electrostatic separation, flotation, and leaching. Amalgamation and cyanidation are variants of leaching which bear special mention. Solvent extraction and ion exchange are widely applied techniques for concentrating metals from leaching solutions, and for separating them from dissolved contaminants.

3.2.1 GRAVITY CONCENTRATION

Gravity-concentration processes exploit differences in density to separate ore minerals from gangue. Several techniques (e.g., jigging, tabling, spirals, sink/float separation) are used to achieve the

separation. Each is effective over a somewhat limited range of particle sizes, the upper bound of which is set by the size of the apparatus and the need to transport ore within it, and the lower bound by the point at which viscosity forces predominate over gravity and render the separation ineffective. Selection of a particular gravity-based process for a given ore will be strongly influenced by the size to which the ore must be crushed or ground to separate values from gangue, as well as by the density difference and other factors.

Gravity concentration typically involves three general steps, the first to remove grossly oversized material from the smaller fraction that contains the valuable mineral (generally gold), the second to concentrate the mineral, and the third to separate the fine values from other fine, heavy minerals. The same type of equipment is often used in more than one step; for example, an array of jigs may be employed to handle successively finer material (Flatt, 1990).

Classification (sizing) is the initial step in the beneficiation operation. Large, oversized material (usually over 3/4 inch) is removed. A rough (large diameter) screen is usually used. This step may be fed by a bulldozer, front-end loader, backhoe, dragline or conveyor belt. Within the gold placer industry, this step is also referred to as roughing (EPA, 1988a). Previous studies have indicated that the practice improves the efficiency of gold recovery and reduces water consumption (Bainbridge, 1979).

After the initial removal of the larger material during sizing, ore is subject to a coarse concentration stage. This step, also referred to as cleaning, may employ trommels or screens. Other equipment used in the coarse concentration stage includes sluices, jigs, shaking tables, spiral concentrators and cones. Depending on the size of the particles, cleaning may be the final step in beneficiation (Flatt, 1990; Silva, 1986).

Fine concentration is the final operation used to remove very small values from the concentrate generated in the previous stages. Many of the previously identified pieces of equipment can be calibrated for finer separation sensitivity. Final separation uses jigs, shaking tables, centrifugal concentrators, spiral concentrators or pinched sluices.

The following is a summary of the equipment commonly used in beneficiation. One of the key determinants in selecting equipment is the volume of material that will pass through each step within a given time period. Rates for ore handling for the equipment discussed below are included where the information was available.

3.2.1.1 Sizing

Sizing is the physical separation of material based strictly on size. The sizing step removes large rocks prior to additional beneficiation. The waste generated is usually solid and is much lower in

volume compared to the ore that passes through. Discharge material may be used for other applications including road aggregates. This step typically involves the ore being loaded into a grizzly, trommel or screen, or a combination thereof.

A typical grizzly consists of a large screen or row of bars or rails set a specific distance apart (2 to 6 inches) such that undersized (gold-bearing) material can readily pass through while oversized material is rejected. Typically, the grizzly would be inclined to ease the removal of the rejected material. Water is usually used to move material through the grizzly and wash off any fines that may be attached to larger fragments before they are discarded. The undersized material drops onto a trommel, screen, or sluice depending on the operation. Grizzlies may be stationary or vibrating (EPA, 1988a).

Trommels are wet-washed, inclined, revolving screens. They usually consist of three chambers, the first uses a tumbling action and water to break up aggregated material. Successive chambers are formed of screens or punched metal plates (smaller holes first) that allow the selected sized material to pass through. The screens are typically 3/8 inch in the second chamber and 3/4 inch in the final chamber. Material passing through the screens is directed for further concentration. Material passing through the trommel may be returned for a second pass or discarded (Cope and Rice, 1992; EPA, 1988a).

A fixed punchplate screen (also called a Ross Box) consists of an inclined plate with holes ranging from 1/2 to 3/4 inches. Ore is placed onto the plate where nozzles wash the material with a high-pressure water stream. The undersized (desirable) material is washed to the outside of the plate where it is fed into a sluice designed to handle 3/4 inch material. The oversized material is directed down the plate which typically has riffles to collect coarser gold. Oversized material passing off the plate is discarded.

Screens function to separate oversized, undesirable material from the ore. Screen size (usually 1/2 to 3/4 inch) is selected based on ore characteristics. Screens may be fixed or vibrating. The action of both is similar although vibrating screens speed the rate of particle separation. The concentrate continues for further concentration while the oversized material is removed via a chute or stacker conveyor belt. Different sized screens may be used to sort material into different sizes for use as road construction aggregate or other purposes.

3.2.1.2 Coarse Concentration

Separation in the coarse concentration step involves particle density rather than size. Sluices are the pieces of equipment most commonly used by gold placer mines in the coarse concentration step although jigs and screens may also be employed. The wastes are discharged to a tailings pond, also called a recycle pond or settling pond. Most of the material that enters the sluice exits as waste. The

gold and other heavy minerals settle within the lining material while the lighter material is washed through. Coarse concentration generates the largest volume of waste during beneficiation.

A sluice consists of a long, narrow, inclined trough lined with riffles, perforated screens, astroturf, corduroy, burlap, or a combination thereof. The sluice mimics the conditions that caused the formation of the placer deposit initially. Ore is placed at the high end of the trough and washed with a stream of water. Gold and other dense minerals settle between the riffles or in the lining while the lighter material is carried through the sluice. Longer sluices are used for preliminary concentration. Shorter, wider sluices are used following preliminary separation to separate fine gold from black sands. The length, grade, riffles and lining are adjusted to suit the nature of the ore. However, slopes of one to two inches per foot are typical.

Riffles are bars, slats, screens or material that act to create turbulence and variation of water flow within the sluice. This action increases the efficiency of gravity separation. Riffles have ranged in size from 12 inches wide, 12 inches high and 12 inches apart to 1 inch high, 1 inch wide and 2 inches apart.

Hungarian riffles are angle irons mounted perpendicular to the sluice box. The vertical angle of the angle irons may be adjusted to affect the degree of turbulence generated and maximize gold deposition. Astroturf, carpet or coconut husks are sometimes placed between and under the riffles to maximize their efficiency. The units are usually constructed so that sections of the riffles may be removed so the gold can be recovered from the turf. As mentioned above, the height, spacing and construction of the riffles may be adjusted to maximize efficiency of separation depending on the character of the ore.

Other material has also been tested and/or used as riffles and liners. Expanded metal riffles are employed at some operations. Like the hungarian riffles, the height, size and spacing is determined by the ore and sections are removable for cleaning. Miscellaneous materials including longitudinal or horizontal wooden poles, blocks, rocks, railroad ties, cocoa mats, rubber and plastic strips have also been documented as being used as riffles by different placer operations (EPA, 1988a).

3.2.1.3 Fine Concentration

After the ore is concentrated, typically through a trommel and sluice, most waste material has been removed leaving a fine concentrate. The concentrate may then be subjected to fine concentration methods including jigs, shaking tables and pinched sluices. Depending on the nature of the concentrate and the equipment, 80 to 95 percent of gold can be recovered from the concentrate at this stage. The waste at this stage is a slurry (often called slimes), and is low in volume compared to that generated in the other stages.

Jigs are settling devices that consist of a screen through which water is pulsed up and down via a diaphragm or plunger numerous times per second. A layer of rock or steel shot referred to as ragging may be placed on the screen to accentuate the up and down motion. Slurry is fed above the screen. The agitation keeps the lighter material in suspension which is then drawn off. The heavier material falls onto or through the screen and is collected as concentrate. Efficiency is increased by varying the inflow rate, pulse cycles and intensity. Jigs may handle from 7 to 25 tons per hour, and can handle particles ranging from 75 mm to 25 mm. At some operations, jigs are also employed in the cleaning stage. (Macdonald, 1983; Silva, 1986).

Shaking tables consist of small riffles over which a slurry containing fine ore is passed. The gold settles into the riffles and, through a vibrating action, is directed to one side of the table where it is collected. The tails are passed across the middle of the table or remain in suspension. Middlings, material that is partially settled, may be collected. Heads and middlings are commonly reprocessed on multi-stage tables. Shaking tables can handle materials from 15 *um* to 3.0 mm (EPA, 1988a; Macdonald, 1983).

Spiral concentrator is a generic term referring to a method of separation rather a specific piece of equipment. Ore concentrated from previous steps is fed with water into the top of the spiral and spins down through the spiral. The heaviest materials are concentrated toward the center of the spiral while lighter material moves to the outside. Concentrates are collected from the center of the spiral while the tails pass down the entire spiral. Large operations may employ multiple spiral concentrators in series to handle a wide range of sizes. Humphreys concentrators, as one example, can be used to separate particles between 100 *um* and 2 mm in diameter. These machines can handle low feed rates (1.5-2 tons per hour) and low feed density (EPA, 1988a).

Centrifugal concentrators or bowls were typically used in dredges but may also be used in other operations. Slurry is fed into the top of the circular machine. Driven from the bottom, the interior portion spins on its vertical axis, driving the slurry against a series of concentric circular riffles or baffles. The lighter material (tails) is driven up the side of the bowl while the heavy material (concentrate) collects on the bottom or in the riffles (Cope and Rice, 1992).

Pinched sluices work on the concept that as a fine feed is exposed to an opening, the arc formed by the heaviest particles dropping will be much narrower than the arc formed by the lighter materials. A divider placed perpendicular to and below the pinched outfall lets heavy materials (concentrate) collect on one side while lighter material (tails) can be collected and reprocessed separately or directed out of the operation completely. Reichert cones, which are based on the pinched sluice principle, can handle 75 tons per hour and recover particles in the minus 10 to plus 400 mesh range (45 *um* to 0.5 mm) (Gomes and Martinez, 1983).

Magnetic separation (see Section 3.22) is not commonly used in gold placer mining but may be employed when magnetite is a component of the black sand. This technique is used to remove electrostatically charged tails from the neutral gold. To be effective, the method should involve multiple magnetic treatments followed by demagnetization steps so that the magnetite is removed slowly, not in a 'magnetically coagulated' form that may bind gold particles within it. Magnetic separation, when used, is one of the final steps of beneficiation.

3.2.1.4 Sink/Float Separation

Sink/float (heavy media separation) separators differ from most gravity methods in that buoyancy forces are used to separate the various minerals on the basis of density. The separation is achieved by feeding the ore to a tank containing a medium whose density is higher than that of the gangue and less than that of the valuable ore minerals. As a result, the gangue floats and overflows the separation chamber, and the denser values sink and are drawn off at the bottom, often by means of a bucket elevator or similar contrivance. The size of material separated by this method varies, and is dependent on the density and viscosity of the medium. Because the separation takes place in a relatively still basin and turbulence is minimized, effective separation may be achieved with a more heterogeneous feed than for most gravity-separation techniques. Viscosity does, however, place a lower bound on particle size for practicable separation, since small particles settle very slowly, limiting the rate at which ore may be fed. Further, very fine particles must be excluded, since they mix with the separation medium, altering its density and viscosity. Media commonly used for sink/float separation in the ore milling industry are suspensions of very fine ferrosilicon or galena (PbS) particles. Ferrosilicon particles may be used to achieve medium specific gravities as high as 3.5, and are used in "heavy-medium separation." Galena allows the achievement of somewhat higher densities of ore concentrate.

3.2.2 Magnetic Separation

Magnetic separation is widely applied in the ore milling industry, both for extraction of values from ore and for separation of different valuable minerals recovered from complex ores. Magnetic separation is used in beneficiating ores of iron, columbium and tantalum, and tungsten. Separation is based on differences in magnetic permeability (which, although small, is measurable for almost all materials) and is effective in handling materials not normally considered magnetic. The basic process involves transport of ore through a region of high magnetic-field gradient. The most magnetically permeable particles are attracted to a moving surface, behind which is the pole of a large electromagnet, and are carried by it out of the main stream of ore. As the surface leaves the high-field region, particles are released into a hopper or onto a conveyor leading to further processing.

For large-scale applications, particularly in the iron-ore industry, large rotating drums surrounding the magnet are used. Although dry separators are used for rough separations, these drum separators are most often run wet on the slurry produced in grinding mills. Wet and crossed-belt separators are frequently employed where smaller amounts of material are handled.

3.2.3 Electrostatic Separation

Electrostatic separation is used to separate minerals on the basis of their conductivity. It is an inherently dry process using very high voltages. In a typical application, ore is charged at 20,000 to 40,000 volts, and the charged particles are dropped onto a conductive rotating drum. The conductive particles lose their attractive charge very rapidly and are thrown off and collected, while the non-conductive particles keep their charge and adhere by electrostatic attraction. They may then be removed from the drum separately.

3.2.4 Flotation

Basically, flotation is a process where the addition of chemicals to an ore slurry causes particles of one mineral or group of minerals to adhere preferentially to air bubbles. When air is forced through a slurry of mixed minerals, the rising bubbles carry with them the particles of the mineral(s) to be separated from the matrix. If a foaming agent is added which prevents the bubbles from bursting when they reach the surface, a layer of mineral-laden foam is built up at the surface of the flotation cell which may be removed to recover the mineral. Requirements for success of the operation are that particle size be small (typically flour-sized or less), that reagents compatible with the mineral to be recovered be used, and that water conditions in the cell not interfere with the attachment of reagents to minerals or to air bubbles.

Flotation concentration has become a mainstay of the ore milling industry because it is adaptable to very fine particle sizes of less than 0.01 mm (.0004 in.). It also allows for high rates of recovery from slimes, which are inevitably generated in crushing and grinding and which are not generally amenable to physical processing. As a physico-chemical surface phenomenon, it can often be made highly specific, allowing production of high-grade concentrates from very low-grade ore (e.g., over 95% MoS_2 concentrate from 0.3% ore). Its specificity also allows separation of different ore minerals (e.g., CuS, PbS, and ZnS) where desired, and operation with minimum reagent consumption since reagent interaction typically occurs only with the particular materials to be floated or depressed.

Details of the flotation process (e.g., exact type and dosage of reagents, fineness of grinds, number of regrinds, cleaner-flotation steps) differ at each operation where it is practiced and may often vary with time at a given mill. A complex system of reagents is generally used, including five basic types of compounds: pH conditioners (regulators, modifiers), collectors, frothers, activators, and depressants. Collectors serve to attach ore particles to air bubbles formed in the flotation cell. Frothers stabilize

the bubbles to create a foam which may be effectively recovered from the water surface. Activators enhance the attachment of the collectors to specific kinds of particles, while depressants prevent such attachment. Activators are frequently used to allow flotation of particular minerals that have been depressed at an earlier stage of the milling process. In almost all cases, use of each reagent in the mill is low, being generally less than 0.5 kg (approximately 1 lb) per ton of ore processed; at large-capacity mills, the total reagent usage can be high, since tens of thousand of tons of ore per day may be beneficiated. The bulk of the reagent adheres to tailings or concentrates.

Sulfide minerals are all readily recovered by flotation using similar reagents in small doses, although reagent requirements and ease of flotation do vary throughout the class. Sulfide flotation is most often carried out at alkaline pH. Collectors are most often alkaline xanthates having two to five carbon atoms—for example, sodium ethyl xanthate (NaS_2COC_2H). Frothers are generally organics with a soluble hydroxyl group and a "non-wettable" hydrocarbon. Sodium cyanide is widely used as a pyrite depressant. Activators useful in sulfide-ore flotation may include cuprous sulfide and sodium sulfide. Other pyrite depressants which are less damaging to the environment may be used to replace the sodium cyanide. Sulfide minerals of copper, lead, zinc, molybdenum, silver, nickel, and cobalt are commonly recovered by flotation.

Minerals in addition to sulfides may be recovered by flotation (e.g., oxidized ores of iron, copper, manganese, the rare earths, tungsten, titanium, and columbium and tantalum). Generally, these flotation processes are more sensitive to feed-water conditions than sulfide floats; consequently, oxidized ores can less frequently run with recycled water. Flotation of these ores involves very different reagents from sulfide flotation and may require substantially larger dosages. Reagents used include fatty acids (such as oleic acid or soap skimmings), fuel oil, and various amines as collectors; and compounds such as copper sulfate, acid dichromate, and sulfur dioxide as conditioners.

3.2.5 LEACHING

Leaching is the process of extracting a soluble metallic compound from an ore by selectively dissolving it in a suitable solvent such as water, sulfuric hydrochloric acid, or sodium cyanide solution. The desired metal is then removed from the "pregnant" leach solution by chemical precipitation or other chemical or electrochemical process. When ores are (or can be) so fractured or shattered in texture that air and water can be made to percolate through them as they exist in the ground, then the ores can be profitably leached *in-situ* (in place) without being mined. Ores that are mined, but are too low in grade to justify the cost of milling, can be recovered by placing the ore rock in large piles on an impermeable surface and treating them with the leach solution, which is collected through a drain system at the bottom of the pile. This method is termed "heap" or "dump" leaching. Heap leaching is widely used in the gold industry, dump leaching in the copper industry. Vat or tank leaching is similar to heap leaching, with the exception that the ore rock is placed in a

container (vat) equipped for agitation, heating, aeration, pressurization, and/or other means of facilitating the leaching of the target mineral.

Ores can be leached by dissolving away either the gangue or the value in aqueous acids or base, liquid metals, or other special solutions. Typical leaching situations include:

- Water-soluble compounds of sodium, potassium, and boron which are found in arid climates or under impervious strata can be mined, concentrated, and separated by leaching with water and recrystallizing the resulting brines.
- Vanadium and some other metals form anionic species (e.g., vanadates) which occur as insoluble ores. Roasting of such insoluble ores with sodium compounds converts the values to soluble sodium salts (e.g., sodium vanadate). After cooling, the water-soluble sodium salts are removed from the gangue by leaching in water.
- Uranium ores are only mildly soluble in water, but they dissolve quickly in acid or alkaline solutions.
- Native gold which is found in a finely divided state is soluble in mercury and can be extracted by amalgamation (i.e., leaching with a liquid metal).
- Nickel can be concentrated by reduction of the nickel with ferrosilicon at a high temperature and extraction of the nickel metal into molten iron. This process, called skip-ladling, is related to liquid metal leaching.
- Certain solutions (e.g., sodium cyanide) dissolve specific metals (e.g., gold) or their compounds, and leaching with such solutions immediately concentrates the values.

Leaching solutions can be categorized as strong, general solvents (e.g., acids) and weaker, specific solvents (e.g., cyanide). The acids dissolve certain metals present, which often include gangue constituents (e.g., calcium from limestone). They are convenient to use, since the ore does not have to be ground very fine, if at all (i.e., approximately 5 to 30 cm (2 to 12 inches) in diameter), and then separation of the tailings from the value-bearing (pregnant) leach solution is not difficult. In the case of sulfuric acid, the leach is cheap but gangue constituents in addition to the value are dissolved.

Specific solvents attack only one (or, at most, a few) ore constituent(s), including the one being sought. Ore must often be crushed or finely ground to expose the values, although this is not always necessary.

Countercurrent leaching, preneutralization of lime in the gangue, leaching in the grinding process, and other combinations of processes that simplify or improve the effectiveness of the leaching

procedure are often seen in the industry. The values contained in the pregnant leach solution are recovered by one of several methods, such as:

- **Precipitation.** The process of separating mineral constituents (i.e., values) from a solution by chemical means, by evaporation, or by changing the temperature and/or pH of the solution.

- **Electrowinning.** The recovery of metal values from solutions by an electrochemical process similar to electrolytic refining. Insoluble (long-life) anodes are used, with the desired metal produced as or on a cathode.

- **Carbon Adsorption.** The target mineral is adsorbed onto activated carbon and further concentrated.

- **Cementation.** The process by which a metal is precipitated or "cemented" out of solution as a finely divided metallic product by replacement with less active metal. For example, when a copper solution (CuSO4) is brought into contact with scrap iron plates, (Fe), the copper replaces the iron on the scrap plates and the iron goes into solution (FeSO4). The copper is then removed by washing the scrap plates.

Amalgamation represents a special application of leaching and/or the recovery of the leached mineral. Amalgamation is a process by which mercury, in its natural liquid state, is alloyed with some other metal to produce an "amalgam" (a solution containing mercury and another metal(s) in liquid form). This process is applicable to free milling precious metal ores, which are those in which the ore is free, relatively coarse, and has clean surfaces. The current practice of amalgamation in the United States is limited to small-scale barrel amalgamation of a relatively small quantity of high-grade, gravity-concentrated gold ore. The gravity concentrate is ground in an amalgam barrel with steel balls or rods before mercury is added. This mixture is then gently ground to bring the mercury and gold into intimate contact. The resulting amalgam is collected in a gravity trap. Although the amalgamation process has, in the past, been used extensively for the extraction of gold and silver from pulverized ores, in recent years it has largely been superseded by cyanidation processes, as described in Section 3.3.1.

3.2.6 Beneficiation Wastes and Waste Management

Tailings are the wastes generated in by far the largest quantities by beneficiation operations that use flotation and gravity separation. This section describes the most common method of managing and disposing of tailings from metal mines. Tailings from gravity separation are described in the discussion of gold placer mining in Section 3.3.2. Leaching operations also generate enormous quantities of spent ore and small quantities of process solutions: the management of wastes from heap leaching is described in the discussion of gold mining (Section 3.3.1), the industry sector in which heap leaching is most commonly practiced; the management of wastes from dump leaching is

described in the discussion of copper mining (Section 3.3.4), the industry sector in which dump leaching is most commonly practiced.

Tailings are the coarsely and finely ground waste portions of mined material that have been separated from the valuable minerals during beneficiation (crushing, grinding and concentration). By far the larger proportion of ore mined in most industry sectors ultimately becomes tailings that must be disposed of. In the gold industry, for example, only a few hundredths of an ounce of gold may be produced for every ton of dry tailings generated. Similarly, the copper industry and others typically mine relatively low-grade ores that contain less than a few percent of metal values; the residue becomes tailings. Thus, tailings disposal is a significant part of the overall mining and milling operation. The physical and chemical nature of tailings varies according to the ore being milled and the milling operations used to beneficiate the ore. The method of tailings disposal is largely controlled by the percent water content of the tailings. Generally, three types of tailings may be identified based on their water content: wet, thickened and dry.

Most ore milling processes require the use of water to classify (grinding stage) and concentrate the valuable minerals. Although dewatering of tailings is a common final step prior to the transport and disposal of the tailings, an equal or greater weight of water remains with the solids in a slurry mixture. These tailings are known as wet tailings. More recently, some mills have begun to significantly dewater tailings to where only 40 percent of their total weight is water. These tailings are known as thickened tailings.

A few beneficiation operations, such as magnetic separation, may require little or no water for preparing the ore. Tailings beneficiated with these methods are normally known as dry tailings. Magnetic separation extracts magnetic minerals, such as iron, from the nonmagnetic particles, which remain as tailings. Although tailings from beneficiation operations may be considered dry tailings, they may contain a small weight percentage of water. In addition to the specific beneficiation operations that produce dry tailings, belt filtering (which removes liquids from tailings by transporting the tailings on a cloth belt over a vacuum box) results in tailings with only 20 to 30 percent total weight in water. These tailings are also considered to be dry tailings.

3.2.6.1 Mine Backfilling

Slurry tailings are sometimes disposed in underground mines as backfill to provide ground or wall support. This decreases the above-ground surface disturbance and can stabilize mined-out areas. For stability reasons, underground backfilling requires tailings that have a high permeability, low compressibility, and the ability to rapidly dewater (i.e., a large sand fraction). As a result, only the sand fraction of whole tailings is generally used as backfill. Whole tailings may be cycloned to separate out the coarse sand fraction for backfilling, leaving only the slimes to be disposed in an

impoundment. To increase structural competence, cement may be added to the sand fraction before backfilling (Environment Canada, 1987).

3.2.6.2 Subaqueous Disposal

Subaqueous disposal in a permanent body of water such as a lake, the ocean, or an engineered structure (e.g., a pit or impoundment) is also a possible disposal method. The potential advantage to underwater disposal is that it may prevent the oxidation of sulfide minerals in tailings, thus prohibiting acid generation. However, there is substantial uncertainty regarding other short- and long-term effects on the water body into which the tailings may be disposed (Rawson Academy 1992; U.S. Bureau of Mines 1992). Canada's Mine Environment Neutral Drainage (MEND) program is currently studying subaqueous disposal.

In a bench-scale 16-year simulation of deep-lake disposal using Ottawa River water by CANMET (Canadian Centre for Mineral and Energy Technology), Ritcey and Silver (1987) found that the tailings had little effect on pH when using ores with a low sulfide content. Ripley, et al. (1978), found that the tailings can cover large areas on the ocean or lake floor and cause turbidity problems if the disposal practice is not designed correctly. There are little data on the long-term efficacy and environmental effects of subaqueous disposal (Environment Canada, 1987), although this issue is being intensively studied in Canada.

Subaqueous disposal recently has been practiced by eight mines in Canada, where its use predated current regulations. Three of these mines still were active and disposing of their tailing underwater (two in lakes, one in the ocean) as of 1990 (Environment Canada, 1992), as were a number of mines elsewhere in the world. In the United States, regulations under the Clean Water Act (e.g., the effluent limitation guidelines for mills that beneficiate base and precious metal ores) effectively prohibit subaqueous disposal of tailings in natural water bodies (i.e., any discharge to "waters of the U.S."). The use of subaqueous disposal in engineered structures has not been tried in the U.S., although it has been proposed in at least one case.

3.2.6.3 Tailings Impoundments

Because mine tailings produced by the mill are usually in slurry form, disposal of slurry tailings in impoundments made of local materials is the most common and economical method of disposal. There are four main types of slurry impoundment layouts; valley impoundments, ring dikes, in-pit impoundments, and specially-dug pits (Ritcey, 1989). The impoundment design choice is primarily dependent upon natural topography, site conditions, and economic factors. Because costs are often directly related to the amount of fill material used in the dam or embankment (i.e., its size), major savings can be realized by minimizing the size of the dam and by maximizing the use of local materials, particularly the tailings themselves. Leakage from tailings impoundments is a serious and

ongoing environmental problem at many operating mines. Any leakage can transport contaminants to ground or surface water; uncontrolled leakage can threaten the integrity of the impoundment structure itself. Increasing numbers of impoundments are lined, with or without leachate collection systems. Although this reduces the risk of leakage, at least in the short term, the long-term integrity of liners is as yet untested, particularly following mine closure when routine inspections and maintenance may be reduced or eliminated.

There are two general classes of impounding structures: water-retention dams and raised embankments. The choice of impounding structure is influenced by economics and site-specific factors including the characteristics of the mill tailings and effluent. In general, impoundments are designed to move, or control the movement of, fluids both vertically and horizontally.

Water retention dams are constructed to their final height before the impoundment begins to receive tailings. The design and construction of these impoundments is similar to conventional earth dam technology. A typical design includes an impervious core, downstream filter and drainage zone and upstream riprap. Upstream slopes are often steeper than those required for a water storage dam because rapid drawdown is not experienced. This impoundment type is best suited for tailings impoundments which must retain large water volumes. Ponds which may require this type of impoundment construction include those that receive large volumes of storm water runoff or store mill effluent not recirculated back to the mill process.

Raised embankments are constructed over the life of the impoundment and are initially begun as a starter dike constructed of native soils or borrow materials including waste rock and tailings. Embankment raises are constructed to keep pace with the rising elevation of the tailings and floodwater storage allowance. The embankment raises may be constructed using a variety of materials including tailings, overburden and native soil and may be positioned downstream, upstream or directly on top of the starter dike.

The three most common methods used to construct tailings embankments are upstream, downstream and centerline. Upstream construction begins with a starter dam constructed at the downstream toe of the planned impoundment, with tailings discharged peripherally from the crest of the starter dam using spigots or cyclones. This deposition develops a dike and wide beach area composed of coarse material which in turn becomes the foundation of the next dike. Some type of mechanical compaction of the dike is typically conducted before the next stage of the dam is constructed.

As in upstream construction, downstream construction also begins with a starter dam constructed of compacted borrow materials; however, this starter dam may be constructed of pervious sands and gravels or with predominantly silts and clays to minimize seepage through the dam. The downstream method is so named because subsequent stages of dike construction are supported on top of the

downstream slope of the previous section, shifting the centerline of the top of the dam downstream as the dam stages are progressively raised. Peripheral spigotting and on-dam cycloning and spreading are common depositional methods used for downstream embankments. Again, some type of mechanical compaction is typically performed.

Centerline construction is similar to both the upstream and downstream construction methods in that the embankment begins with a starter dam and tailings are spigotted off the crest of the dam to form a beach. The centerline of the embankment is maintained as fill and progressive raises are placed on both the beach and downstream face. The tailings placed on the downstream slope are typically compacted to prevent shear failure.

Other things being equal, it is economically advantageous to use natural depressions to contain tailings. Among other advantages are reduced dam size, since the sides of the valley or other depression serve to contain tailings. In addition, tailings in valleys or other natural depressions present less relief for air dispersion of tailings material.

Valley impoundments (and variations) are the most commonly used impoundments. There are several variations of valley-type impoundments. The Cross-Valley design is frequently used because it can be applied to almost any topographical depression in either single or multiple form. Laid out similarly to a conventional water-storage dam, the dam is constructed connecting two valley walls, confining the tailings in the natural valley topography. This configuration requires the least fill material and consequently is favored for economic reasons. The impoundment is best located near the head of the drainage basin to minimize flood inflows. Side hill diversion ditches may be used to reduce normal runon if topography allows, but large flood runoff may be handled by dam storage capacity, spillways, or separate water-control dams located upstream of the impoundment.

Other types of valley impoundments may be employed when there is an excessively large drainage catchment area and/or there is a lack of necessary valley topography. Two variations are the side-hill impoundment and the valley-bottom impoundment. The side-hill layout consists of a three-sided dam constructed against a hillside. This design is optimal for slopes of less than 10% grade. Construction on steeper slopes requires much more fill volume to achieve sufficient storage volume.

If the drainage catchment area is too large for a cross-valley dam and the slope of the terrain is too steep for a side-hill layout, then a combination of these two designs, the valley-bottom impoundment, may be considered. Valley-bottom impoundments are often laid out in multiple form as the valley floor rises, in order to achieve greater storage volume. Because the upstream catchment area is relatively large, it is often, or usually, necessary to convey upstream flows around (and/or under) valley-bottom impoundments.

Where natural topographic depressions are not available, the Ring-Dike configuration may be appropriate. Instead of one large embankment (as in the valley design), embankments (or dikes) are required on all sides to contain the tailings. Construction can be similar to valley dams, with tailings, waste rock, and/or other native materials typically used in later phases of construction. Because of the length of the dike/dam, more materials are necessary for this configuration, and material for the initial surrounding dikes is typically excavated from the impoundment area.

Open-pit backfilling is also practiced, where tailings are deposited into abandoned pits or portions of active pits. The Pinto Valley tailings reprocessing operation, located in Arizona, uses this method to dispose of copper tailings. In active pits, embankments may be necessary to keep the tailings from the active area. However, since seepage from the tailings can adversely affect the stability of the pit walls or embankments, it is unusual to see disposal in active pits. Williams (1979), for example, discusses a failure due to pore water pressure in the floor of a pit in Australia. Ritcey (1989) notes that the hydrogeological parameters affecting the migration of seepage and contaminants are poorly understood, so tailings with toxic contaminants or reactive tailings may be poor candidates for this type of impoundment. This method is much less common than the valley and ring-dike impoundments. Since the tailings are protected by pit walls, wind dispersion is minimized. Good drainage can be incorporated into the design. Many of the failure modes common to tailings embankments (e.g., piping, liquefaction) do not apply to this design. The lack of dam walls reduces the possibility of slope failure, but the stability of the pit slopes do have to be checked.

Specially dug pit impoundments are fairly unusual and involve the excavation of a pit specifically for the purpose of tailings disposal. The impoundment consists of four or more cells with impermeable liners surrounded by an abovegrade dam. Material removed from the pit is used in construction of the dam. This dug pit/dam design has some of the same advantages as the ring-dike design, including site independence and uniform shape. Site independence benefits the design, since less effort and cost are needed to counteract topographic obstacles, soil conditions, climatic conditions, and construction obstacles. The uniform layout, shape, and flat terrain prevents surface runoff from entering the impoundment and decreases the requirements for flood control measures.

Irrespective of the layout of the impoundment, at most facilities, water may be decanted from tailings ponds and recirculated to the mill for reuse in beneficiation processes. In general, two methods are available for decanting pond water; decant towers and pumping (usually from floating barges). Decant towers are vertical concrete risers with intake ports that rise from the bottom of the impoundment upward through the tailings. A concrete conduit extends from the bottom of the decant tower to beyond the dam toe. Decant towers may not be a preferred method for decanting due to the potential for conduit rupture and the resulting potential for internal erosion and collapse of the dam. Floating barges offer flexibility for relocation to various parts of the pond and may not present a potential for dam failure.

Tailings slurry (wet tailings and thickened tailings) is usually abrasive and highly viscous, which presents complications for the design, construction, operation and maintenance of tailings transport systems. Slurried tailings may be transported from the mill to the tailings pond by gravity flow and/or pumping through open conduits or pipes. Pipe wear is a significant problem that may be mitigated by the use of rubber lined steel pipes or high-density polyethylene pipe. The transport system may become plugged with settling solids if the minimum flow velocity is not maintained or if provisions are not made for pipe drainage during mill shutdowns. Tailings may be discharged from the conveyance system to any location along the impoundment perimeter; however, as discussed previously, tailings (particularly sand tailings) spigotted along raised embankments may provide additional stability.

Siting of tailings impoundments may be influenced by a number of factors, including location and elevation relative to the mill, topography, hydrogeology and catchment area, geology and groundwater. Layout of impoundments may be virtually independent of the type of embankment used to confine it. Essentially any of the embankment types or raising methods discussed previously may be used, provided that the embankment type is compatible with site-specific conditions and the characteristics of mill tailings and effluent.

3.2.6.4 Dry Tailings Disposal

In some cases, as noted above, tailings are dewatered (thickened to 60 percent pulp density or more) or dried (to a moisture content of 25 percent or below) prior to disposal. The efficiency and applicability of using thickened or dry tailings depends on the ore grind and concentrations of gypsum and clay as well as the availability of alternative methods. Except under special circumstances, these methods may be prohibitively expensive due to additional equipment and energy costs. However, the advantages include minimizing seepage volumes and land needed for an impoundment or pile, and simultaneous tailings deposition and reclamation (Vick, 1990).

Tailings piles are non-impounding structures that are designed for the disposal of dry tailings or thickened tailings. Dry tailings piles are considerably different from tailings piles created as a result of thickened tailings disposal. Dry tailings may be disposed of in piles that may be constructed in a variety of configurations. These include: a valley-fill, where tailings are simply dumped to in-fill a valley; side hill disposal, where tailings are disposed on a side of a hill in a series of piles; and level piles that may grow as lifts are added through out the life of the mine. The maximum slope of tailings piles is determined by the physical and chemical characteristics of the tailings.

Thickened tailings are typically spigotted as a very viscous slurry from a permanent discharge line, creating a conical pile. No embankments are needed with the exception of a small dam constructed down stream from the piles to intercept and collect seepage. This method of disposal may be best suited for areas close to the mill and with low relief topography.

3.3 COMMODITY-SPECIFIC MINING AND BENEFICIATION PROCESSES

The remainder of this section describes the mining and milling of specific metal ores, with individual ores discussed in separate subsections. The ores and industry sectors discussed in the following subsections include gold and silver (Section 3.3.1), gold placer (3.3.2), lead-zinc (3.3.3), copper (3.3.4), iron (3.3.5), uranium (3.3.6), and other ores (3.3.7). The industry sectors discussed in more detail (in Sections 3.3.1 through 3.3.6) are those representing the most mining activity in the United States as of the early 1990s. Although EPA has developed effluent limitations guidelines for other industry sectors, there are few (and in some cases, no) actives mines for the other sectors, including molybdenum, tungsten, and mercury.

3.3.1 GOLD AND SILVER

Historically, gold has been the principal medium of international monetary exchange, although its role has changed significantly in recent years. Between 1934 and 1972, the United States monetary system was on a gold standard at a fixed rate of $35 per troy ounce (a troy ounce equals 1.09714 avoirdupois ounces, so there are 14.6 troy ounces per pound). After leaving the gold standard in 1975 and allowing private ownership of the metal, the U.S. gold market grew rapidly and the price of gold peaked at $850 per ounce in January 1980. Prices are notoriously volatile and gold prices are set on a number of world exchanges. In the 1990s, gold has generally traded in the $300 to $400 per troy ounce range.

In 1992, U.S. gold operations produced an estimated 10.3 million troy ounces of gold from ore, valued at $3.6 billion. This represented an increase of 10 percent over 1991 production and nearly a tenfold increase over production in the early 1980s, which averaged less than 1.5 million troy ounces annually. An estimated 70 percent of 1992 gold production was used for jewelry and art (including coinage), 23 percent for industrial purposes (primarily in the electronics industry), and 7 percent in dentistry (Bureau of Mines, 1986a and 1993).

Many new gold mines opened in the United States throughout the 1980s (24 in 1989), and mines continue to expand their production capabilities. The United States is now the second largest gold producer in the world. According to the Bureau of Mines, there are about 200 lode gold mines in the United States, primarily in the west, and a dozen or more large placer mines in Alaska (plus hundreds of small commercial placer mines in Alaska). In addition, there are hundreds or thousands of "recreational" lode and placer gold mines that may operate periodically (Bureau of Mines, 1993).

Gold has been mined in virtually every State but production has been concentrated in 15: Alaska, Arizona, California, Colorado, Idaho, Michigan, Montana, Nevada, New Mexico, North Carolina, Oregon, South Carolina, South Dakota, Utah, and Washington. According to the Bureau of Mines, approximately 10 percent of gold production is produced as a by-product of other mining, with the

remainder produced at gold mines. In 1991, about 61 percent of newly mined domestic gold from gold mines (or 5.7 million troy ounces) was mined in Nevada, 10 percent in California, 6 percent in both Montana and South Dakota, and 1 percent in Colorado, Arizona, Alaska, and Idaho. The 25 leading domestic gold-producing mines in 1991 are identified in Exhibit 3-1. These mines accounted for 68 percent of all domestically produced gold in that year. (Bureau of Mines, 1992 and 1993).

Like gold, silver has been a principal medium of international monetary exchange. Silver, however, is also an important metal in many other applications. Mine production in 1992 exceeded 57 million troy ounces. Nevada mines produced over 34 percent of the total, followed by Idaho (16 percent), Montana (11 percent), and Arizona (7 percent). About 50 percent of silver is used in manufacturing photographic products, 21 percent in electrical and electronic products, and 20 percent for a variety of other uses (Bureau of Mines, 1993). Exhibit 3-2 identifies the U.S. mines that produced the most silver in 1991; several of these have since closed, either permanently or temporarily.

Prices for silver also peaked in the early 1980s, but have been severely depressed in recent years. This depressed price (generally in the range of $4 to $5 per ounce) has resulted in a significant reduction in silver mining: although silver is produced by over 150 U.S. mines (Bureau of Mines, 1993), it is mined now only in conjunction with other metals, notably gold and copper. At the present time, there is essentially no mining in the U.S. whose primary target is silver. This section focusses on gold since silver is now recovered by U.S. operations only with gold or with other metals that are discussed in separate sections. (Although Exhibit 3-2 identifies several mines whose silver is derived from "silver ore," in every case only the other metals recovered make recovery of silver economic. Beneficiation processes for silver include flotation similar to other metals and cyanidation similar to gold (although with higher cyanide concentrations), and silver mining presents no unique operational or environmental issues.)

3.3.1.1 Geology of Gold Ores

Estimates of average abundance of gold in the Earth's crust are on the order of 0.003 to 0.004 parts per million (ppm) (U.S. Geological Survey, 1973). Deposits considered to be economically recoverable at current market prices may contain as little as 0.69 to 1.37 ppm (0.02 to 0.04 troy ounces of gold per ton of rock [oz/t]), depending on the mining method, total reserves, and the geologic setting of the deposit. (In absolute terms, 0.04 troy ounces of gold per ton translates to a gold:ore ratio of 1:729,150.)

All gold deposits, except placer deposits, were formed by hydrothermal processes. Hydrothermal systems form in numerous geologic environments, ranging from dynamic systems associated with magmatic intrusives to low-energy systems associated with deep fluid circulation heated by geothermal heat flow. Deposits formed from hydrothermal systems flowing at or near the surface (1,000 to 2,500 feet deep) are called epithermal deposits, while those formed deeper are called mesothermal

Exhibit 3-1. Twenty-Five Leading Gold-Producing Mines in the United States, 1991

Rank	Mine	County and State	Operator	Source of Gold
1	Nevada Mines Operations	Elko and Eureka NV	Newmont Gold Co.	Gold Ore
2	Goldstrike	Eureka NV	Barrick Mercury Gold Mines Inc.	Gold Ore
2	Bingham Canyon	Salt Lake UT	Kennecott-Utah Copper Corp.	Copper Ore
4	Jerritt Canyon (Enfield Bell)	Elko NV	Freeport-McMoran Gold Co.	Gold Ore
5	Smoky Valley Common Operation	Nye NV	Round Mountain Gold Corp.	Gold Ore
6	Homestake	Lawrence SD	Homestake Mining Co.	Gold Ore
7	McCoy and Cove	Lander NV	Echo Bay Mining Co.	Gold Ore
8	McLaughlin	Napa CA	Homestake Mining Co.	Gold Ore
9	Chimney Creek	Humboldt NV	Gold Fields Mining Co.	Gold Ore
10	Fortitude and Surprise	Lander NV	Battle Mountain Gold Co.	Gold Ore
11	Bulldog	Hye NV	Bond Gold, Bullfrog, Inc.	Gold Ore
12	Mesquite	Imperial CA	Goldfields Mining Co.	Gold Ore
13	Getchell	Humboldt NV	FMG Inc.	Gold Ore
14	Sleeper	Humboldt NV	Amax Gold Inc.	Gold Ore
15	Cannon	Chelan WA	Asamera Minerals (U.S.) Inc.	Gold Ore
16	Ridgeway	Fairfield SC	Ridgeway Mining Co.	Gold Ore
17	Jamestown	Tuolumne CA	Sonora Mining Corp.	Gold Ore
18	Paradise Peak	Nye NV	FMC Gold Co.	Gold Ore
19	Rabbit Creek	Humboldt NV	Rabbit Creek Mining Inc.	Gold Ore
20	Barney's Canyon	Salt Lake City UT	Kennecott Corp.	Gold Ore
21	Continental	Silver Bow MT	Montana Resources	Copper Ore
22	Zortman-Landusky	Phillips MT	Pegasus Gold Inc.	Gold Ore
23	Golden Sunlight	Jefferson MT	Golden Sunlight Mines Inc.	Gold Ore
24	Wind Mountain	Washoe NV	Amax Gold Inc.	Gold Ore
25	Foley Ridge & Annie Creek	Lawrence SD	Wharf Resources	Gold Ore

Source: Bureau of Mines, 1992.

Exhibit 3-2. Twenty-Five Leading Silver-Producing Mines in the United States, 1991

Rank	Mine	County and State	Operator	Source of Silver
1	McCoy and Cove	Lander NV	Echo Bay Mining Co.	Gold Ore
2	Greens Creek	Admiralty Island AK	Greens Creek Mining Co.	Zinc Ore
3	Rochester	Pershing NV	Coeur Rochester Inc.	Silver Ore
4	Bingham Canyon	Salt Lake UT	Kennecott-Utah Copper Co.	Copper Ore
5	Troy	Lincoln MT	ASARCO Inc.	Copper ore
6	Red Dog	NW Arctic AK	Cominco Alaska	Zinc Ore
7	Sunshine	Shoshone ID	Sunshine Mining Co.	Silver Ore
8	Lucky Friday	Shoshone ID	Hecla Mining Co.	Lead-Zinc Ore
9	DeLamar	Owybee ID	NERCO De-Lamar Co.	Gold Ore
10	Paradise Peak	Nye NV	FMC Gold Co.	Gold ore
11	Galena	Shoshone ID	ASARCO Inc.	Silver Ore
12	Montana Tunnels	Jefferson MT	Montana Tunnels Mining Inc.	Zinc Ore
13	Mission Complex	Pima AZ	ASARCO Inc.	Copper Ore
14	White Pine	Ontonogon MT	Copper Range Co.	Copper ore
15	Candelaria	Mineral NV	NERCO Metals Inc.	Silver Ore
16	Continental	Silver Bow MT	Montana Resources Inc.	Copper Ore
17	Ray Unit	Pinal AZ	ASARCO Inc.	Copper ore
18	Denton-Rawhide	Mineral AZ	Kennecott Rawhide Mining Co.	Gold Ore
19	Zortman-Landusky	Phillips MT	Pegasus Gold Inc.	Gold ore
20	Morenci	Greenlee AZ	Phelps Dodge Corp.	Copper Ore
21	Bagdad	Yavapai AZ	Cyprus Bagdad Copper Co.	Copper ore
22	San Manuel	Pinal AZ	Magma Copper Co.	Copper ore
23	Battle Mountain Complex	Lander NV	Battle Mountain Gold Co.	Gold Ore
24	Chino	Grand NM	Phelps Dodge Corp.	Copper Ore
25	Pinto Valley	Gila AZ	Magma Copper Co.	Copper ore

Source: Bureau of Mines, 1992.

deposits. Combinations of the various types of hydrothermal systems in various host rocks create variations in deposit morphology, grade ranges (variation in gold content), and wall rock alteration. Deposit morphology ranges in a continuum from veins several feet thick and hundreds to thousands of feet in vertical and lateral dimensions (formed by mineral precipitation in voids in the host rock) to disseminated mineralization (essentially micro veinlets) pervading through the host rock in irregular pods up to several hundred feet in dimension.

Gold deposits may be categorized based on similarities in geologic environment and generic hydrothermal factors. Recent data show that the 25 largest gold producing mines in the U.S. may be grouped into four types: sediment-hosted disseminated gold (examples are the Goldstrike and Gold Quarry mines), volcanic-hosted epithermal deposits (McLaughlin, Chimney Creek), porphyry copper-related deposits (Bingham Canyon), and greenstone gold-quartz vein deposits (Homestake). (Bureau of Mines, 1990c).

Grades range in all deposit types from subeconomic margins to high-grade ores. The term "high grade" varies with mining methods but usually refers to ores greater than 0.1 or 0.2 oz/t. Likewise, average deposit grades are economic distinctions. Deposits requiring high-cost mining and milling methods may require bulk averages of 0.25 oz/t or more, at 0.15 or higher cutoffs. Those deposits that are amenable to the lowest-cost mining and milling methods may average 0.03 to 0.04 oz/t or less with an ore-to-waste separation grade of about 0.01 oz/t.

The mineral content or assemblage of a deposit is the result of reactions between hydrothermal solutions and the wall rock, influenced by wall rock chemistry, solution chemistry, temperature, and pressure. Most gold ores contain some amount of sulfur-bearing minerals; carbonate deposits may also contain carbonaceous material. The weathering environment affecting the ore body following deposition is determined mainly by the location of the water table (either present or past) in relation to the deposit. Ores above the water table, in the vadose or unsaturated zone, will tend to be oxidized (referred to as "oxide ores"), while ores below the water table will usually be unoxidized (referred to as "sulfide ores").

Gold ores may contain varying amounts of arsenic, antimony, mercury, thallium, sulfur, base metal sulfides, other precious metals, and sulfosalts. The amount of these constituents depends on the nature of the deposit and the amount of weathering that has occurred. Subsequent alteration of the ore by oxidation influences both gold recovery and the byproducts of extracting the ore. Sulfide minerals oxidize to form either oxides or sulfosalt minerals. Leaching of sulfides or other minerals may occur in association with oxidation. Sulfide ores retain their original composition. Zones of secondary enrichment may form at the oxidized/unoxidized interface.

The minerals found in gold ores, and elements associated with them, vary with the type of ore. Sulfide ores contain varying amounts of native gold and silica (SiO_2), as well as sulfur-bearing minerals, including, but not limited to, sphalerite (ZnS), chalcopyrite ($CuFeS_2$), cinnabar (HgS), galena (PbS), pyrite (Fe_2S), sylvinate ($[Au,Ag]Te_2$), realgar (AsS), arsenopyrite (FeAsS), ellisite (Tl_3AsS_3), and other thallium-arsenic antimony-mercury-bearing sulfides and sulfosalt minerals. Oxide ores may contain varying amounts of these minerals, as well as silica (SiO_2), limonite ($FeO{\cdot}OH{\cdot}nH_2O$), calcite ($CaCO_3$), clay minerals, and iron oxides (Hurlbut and Klein, 1977).

The mineral assemblage of the ore deposit is an important factor in the beneficiation method to be used. In general, the percent recovery of gold from sulfide ores using various cyanidation techniques is lower and more costly than from oxide ores. Recovery is reduced because the cyanide solution also reacts with constituents such as sulfides in addition to gold. Increasingly, sulfide ores may be oxidized in roasters or autoclaves. This is the result both of the development of more cost-effective oxidation techniques and of the fact that oxide ores are becoming increasingly scarce (Weiss, 1985).

3.3.1.2 Mining

Gold ore may be mined by either surface or underground techniques. Mining methods are selected based on maximum ore recovery, efficiency, economy, and the character of the ore body (including dip, size, shape, and strength) (Whiteway, 1990). With notable exceptions (e.g., the Homestake mine), most gold ore in the United States is mined using surface mining techniques in open-pit mines. This is primarily because of economic factors related to mining large-volume, low-grade ores and the improvement of cyanide leaching techniques. In 1988, a total of 160 million short tons of crude ore (97.8 percent of the total) was handled at surface lode mines. In contrast, underground mines mined only 3.56 million short tons (2.2 percent) (Bureau of Mines, 1991a). Exhibit 3-3 summarizes the amounts of crude ore, waste, and marketable product generated by surface, underground, and placer operations in 1988.

Exhibit 3-3. Materials Handled at Surface and Underground Gold Mines, 1988

Material	Lode			Placer
	Surface	Underground	Total	
Material handled (1,000 short tons):				
Total	553,000	4,890	558,000	32,900
Crude Ore	160,000	3,560	163,560	15,000
Waste	394,000	1,340	395,000	17,900
Marketable Product (1,000 Troy oz.)	5,250	241	5,490	153

Source: EPA, compiled from Bureau of Mines, 1990b.

The quantity and composition of waste rock generated at mines vary greatly by site. This material can contain either oxides or sulfides (or, more likely, both), depending on the composition of the ore body. Constituents include mercury, arsenic, bismuth, antimony, and thallium, and other heavy metals. These may occur as oxides, carbonates, and sulfides with varying degrees of solubility. Sulfur-bearing minerals, such as pyrite and pyrrhotite, can oxidize to form sulfuric acid (Bureau of Mines, 1984). Factors that influence acid generation by sulfide wastes include the availability of oxygen and water; the presence and availability of acid-generating and/or neutralizing minerals in the rock; and the design of the disposal unit. Overburden and waste rock are generally disposed of in unlined piles known as mine rock dumps or waste rock dumps (occasionally, they can be called "low-grade ore" or "subore" stockpiles). Waste dumps are generally unsaturated. Waste rock also is used in constructing tailings dams, roads, and for other onsite purposes. Waste rock with high sulfide content and sufficient moisture content, and without adequate neutralization potential or other controls in the dump itself (e.g., encapsulation or segregation of sulfide material within the dump), has led to significant problems associated with acid drainage, both from waste rock dumps and from roads and other onsite construction made of sulfide waste rock.

Mine water consists of water that collects in mine workings, both surface and underground, as a result of inflow from rain or surface water, and groundwater seepage. Mine water may be used and recycled in the beneficiation circuit, pumped to tailings impoundments, or discharged to surface water under an NPDES permit. During the life of the mine, if necessary, water is pumped to keep the mine dry and allow access to the ore body. This water may be pumped from sumps within the mine or from interceptor wells surrounding the mine. Interceptor wells are used to withdraw groundwater and create a cone of depression in the water table around the mine, thus reducing groundwater inflow. Surface water is most often controlled using engineering techniques to prevent water from flowing into the mine.

The quantity and chemical composition of mine water generated at mines vary by site. The chemistry of mine water is dependent on the geochemistry of the ore body and surrounding area. After the mine is closed and pumping stops, the potential exists for mines to fill with water. Water exposed to sulfur-bearing minerals in an oxidizing environment, such as open pits or underground workings, may acidify and mobilize metals in the rock matrix. In contrast, flooding of some mine workings may, in some unusual situations, serve to slow or stop acidification by reducing or eliminating the source of oxygen.

In addition to wastes generated as part of gold mining and beneficiation, facilities also store and use a variety of chemicals required by the mine and mill operations. Exhibit 3-4 presents a list of chemicals used at gold mines, compiled from data collected by the National Institute for Occupational Safety and Health (NIOSH, 1990).

Exhibit 3-4. Chemicals Stored and Used at Gold Mines

Acetic Acid	Diisobutyl Ketone	Methyl Acetylene-Propadiene Mixture	Sucrose
Acetone	Ethanol	Methyl Alcohol	Silica, Sand
Acetylene	Fluoride	Methyl Chloroform	Silica, Crystalline
Ammonia	Graphite	Mineral Oil	Silver
Argon	Hexone	Molybdenum	Silver Nitrate
Asbestos	Hydrogen Bromide	Nitric Acid	Sodium Cyanide
Butyl Acetate	Hydrogen Chloride	Nitrogen	Sodium Hydroxide
Calcium Carbonate	Hydrogen Peroxide	Nitrous Oxide	Stoddard Solvent
Calcium Oxide	Iron Oxide Fume	Oxalic Acid	Sulfuric Acid
Carbon Dioxide	Kerosene	Phosphoric Acid	Tin
Chlorine	Lead	Portland Cement	Vanadium Pentoxide
Coal	Lead Nitrate	Potassium Cyanide	Xylene
Copper	Litharge	Propane	2-Butanone
Diatomaceous Earth	Mercuric Chloride	Pyridine	Diesel Fuel No. 1
Dichlorodifluoromethane	Mercury		

Source: National Institute for Occupational Safety and Health, 1990.

Surface Mining

Surface mining methods associated with the extraction of gold include open-pit and placer (including dredging, which is often considered separately). Placer mining is used to mine and concentrate gold from alluvial sand and gravels and is described in Section 3.3.2.

Surface mining of gold is generally more economical than underground methods, especially in cases when the ore body being mined is large and the depth of overburden covering the deposit is limited. The primary advantage of surface mining is the ability to move large amounts of material at a relatively low cost, in comparison with underground operations.

The predominant surface mining method used to extract gold ore is open-pit. Surface mining practices follow a basic mining cycle of drilling, blasting, and mucking. The depth to which an ore body is mined depends on the ore grade (and the extent of oxidation), nature of the overburden, and the stripping ratio. The stripping ratio is the amount of overburden and waste rock that must be removed for each unit of crude ore mined and varies with the mine site and the ore being mined.

Stripping ratios can range up to 5 to 10 tons of overburden and waste rock per ton of ore or higher at open-pit mines; it usually ranges around 1 to 3 tons per ton. These materials become wastes that must be disposed of, primarily in waste rock dumps. Because ore grades in mined material are continuous, waste rock with gold concentrations just below the "cut-off" grade (i.e., the grade at which gold can be recovered economically) may be stockpiled separately from other waste rock—this materials is often referred to as "subore" or "low-grade ore." In addition, the cut-off grade at a given mine may change with the price of gold, thus leading to more or less waste rock being disposed as the stripping ratio changes.

Underground Mining

Underground mining operations use various mining methods, including caving, stoping, and room and pillar. In general, underground mining involves sinking a shaft or driving a drift near the ore body to be mined and extending horizontal passages (levels) from the main shaft at various depths to the ore. Mine development rock is removed, while sinking shafts, adits, drifts, and cross-cuts, to access and exploit the ore body. From deep mines, broken ore (or muck) is removed from the mine either through shaft conveyances or chutes and hoisted in skips (elevators). From shallow mines, ore may be removed by train or conveyor belt. Waste rock, mine development rock, or mill tailings may be returned to the mine to be used as fill for mined-out areas (EPA, Office of Water, 1982). The ratio of waste rock to ore is much lower at underground mines than at surface mines, reflecting the higher cost of underground mining. Because of the higher costs, underground mining is most suitable for relatively higher-grade ores. This in turn reduces the amount of beneficiation wastes (i.e., tailings) generated (and disposed) per troy ounce of gold produced.

In Situ Mining

In situ leaching, although increasingly common in the copper industry, is only an experimental procedure in the gold industry and is not used in commercial operations. It involves blasting an underground deposit in place to fracture the ore and make it permeable enough to leach. Subsequently, 20 to 25 percent of the broken ore is removed from the mine to provide "swell" space for leaching activities. In buried ore bodies, cyanide solution is then injected through a well into the fractured ore zone. At surface ore bodies, the solution can simply be sprayed over the deposit. Recovery wells are used to collect the gold-cyanide solution after it percolates through the ore. Groundwater and surface water concerns are commonly raised in discussions of potential *in situ* operations. *In situ* leaching has only been tested at the Ajax Mine near Victor, Colorado (Bureau of Mines, 1984).

3.3.1.3 Beneficiation

Four main techniques are used to beneficiate gold ore: cyanidation, flotation, amalgamation, and gravity concentration. Exhibit 3-5 illustrates the common methods used to beneficiate gold. The method used at a given operation depends on the characteristics of the ore and economic considerations (Bureau of Mines, 1984). Each of the four techniques is described below. Base-metal flotation is described only briefly, since gold is produced only as a byproduct at these operations. Amalgamation also is discussed only briefly, since this method is primarily of historic significance in the United States. Gravity concentration methods are generally used only in placer-type operations and are discussed in a separate section (Section 3.3.2). Cyanidation operations are by far the most common, and are described in more detail below. The two basic types of cyanidation operations, heap leaching and tank leaching, are described separately.

Exhibit 3-5. Gold Mining and Beneficiation Overview
(Adapted from various sources)

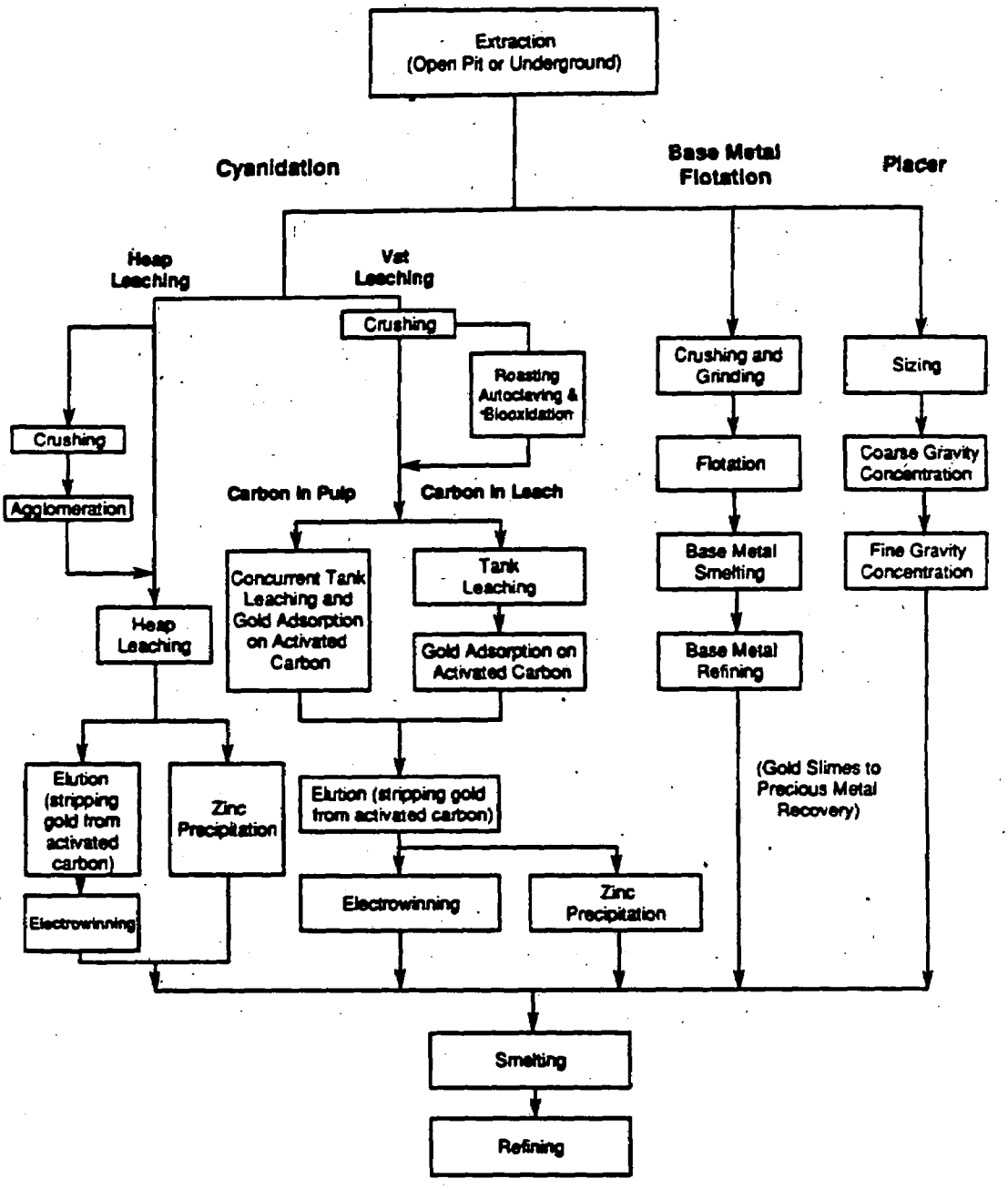


Exhibit 3-6 presents a comparison of gold ore treated and gold product produced by the various beneficiation methods in 1991. As can be seen, cyanidation and direct processing (smelting of precious metals recovered as a by-product from base metal mining) were used to produce 89 percent and 10 percent of all domestic recovered lode gold, respectively. Placer mining accounted for 1 percent of the total gold produced. Amalgamation was used to beneficiate much less than 1 percent of all lode gold in 1986, the last year for which complete data were reported (Bureau of Mines, 1990a).

Exhibit 3-6. Gold Ore Treated and Gold Produced, By Beneficiation Method, 1991

Beneficiation Method	Gold Ore Treated		Gold Produced	
	Percent	Short Tons (000s)	Percent	Troy oz.
Cyanidation (All)	51	227,271	89	8,235,820
Heap Leaching	36	159,985	33	3,037,084
Tank Leaching	14	67,285	56	5,198,736
Amalgamation[a]	0.5	0.9	0.3	33,694
Smelting (ore and concentrates)[b]	49	221,507	10	909,736
Total Lode	100	449,920	99	9,227,187
Placer (gravity)	100	5,500,000 cubic meters	1	92,851

Source: Bureau of Mines, 1992.

Notes:

Due to rounding and unit conversions, totals may not match exactly.

a Values for amalgamation are for 1986 production, the last year for which complete information was available.

b Smelting of base metal ores and concentrates, mainly copper and lead ores. Production information is not available specifically for flotation, but Bureau of Mines personnel have suggested that these production figures approximate byproduct gold production by the base metal industry.

By-Product Gold (Flotation)

As described above, flotation is a technique in which particles of a single mineral or group of minerals are made to adhere, by the addition of reagents, preferentially to air bubbles (EPA, Office of Water, 1982). This technique is chiefly used on base metal ore that is finely disseminated and generally contains extremely small quantities of gold in association with the base metals. Gold is recovered as a byproduct of the base metal recovery (for example, recovered from electrowinning sludges or slimes).

Ore is milled and sorted by size in preparation for flotation. The ore is then slurried with chemical reagents of four main groups: collectors (promoters), frothers, activators, and depressants. In a typical operation, the ore slurry and reagents are mixed in a conditional cell so the reagents coat the target mineral. The conditional slurry is pumped to a flotation cell, and air is injected. Air bubbles adhere to the reagents and carry the target mineral to the surface, away from the remaining gangue, for collection. In the flotation technique, the target mineral is not necessarily the precious metal or other value. Depending on the specific gravity and the reagents used, the values may be recovered from the top or bottom of the flotation cell.

In general, there would be little or no incremental environmental concerns as a result of byproduct gold recovery. Any significant concerns would be related to the base metal mine and mill.

Amalgamation

In amalgamation operations, metallic gold is wetted with mercury to form a solution of gold in mercury, referred to as an amalgam. This method of beneficiation is most effective on loose or free coarse gold particles with clean surfaces (EPA, 1982). Because of its high surface tension, mercury does not penetrate into small crevices of ore particles, so the ore generally must be crushed finely enough to expose the gold material. Use of this method of gold beneficiation has been greatly restricted in the U.S. in the recent past because of its high costs, inefficiency in large-scale operations, and the scarcity of ores amenable only to this technique. In addition, environmental concerns related to mercury contamination have contributed to its limited use. It is still used in other parts of the world, particularly remote areas such as the upper Amazon, where its suitability for small-scale operations and limited environmental concerns have not restricted its use.

Ore preparation consists of grinding, washing, and/or floating the ore. The ore is then fed into a ball mill along with mercury to form an amalgam. The amalgam is then passed over a series of copper plates where it collects. When fully loaded with amalgam, the plate is removed and the amalgam is scraped off. Upon heating the hardened amalgam in a retort furnace, the mercury is vaporized and the gold material remains. The mercury driven off by heating is captured, condensed, and reused. Alternatively, hot dilute nitric acid may be applied to the amalgam, dissolving the mercury and leaving the gold material. Amalgamation has traditionally been used in conjunction with other beneficiation methods such as cyanidation, flotation, and gravity concentration (Beard, 1987).

Wastes generated as a result of amalgamation activities consist of gangue in the form of coarse- and fine-grained particles and a liquid mill water component in the form of a slurry. The constituents of the waste are similar to those found in the ore body (or gravel) plus any mercury lost during amalgamation. This material can then be directed to a tailings impoundment. In the past, some U.S. operations (as well as current operations in other parts of the world) simply directed the tailings to nearby streams or valleys. In some areas, the amount of mercury lost during historic mining has

been significant, and has led to widespread mercury contamination. For example, modern placer operations in California have recovered substantial amounts of mercury from stream sediments contaminated by past amalgamation operations.

Cyanidation

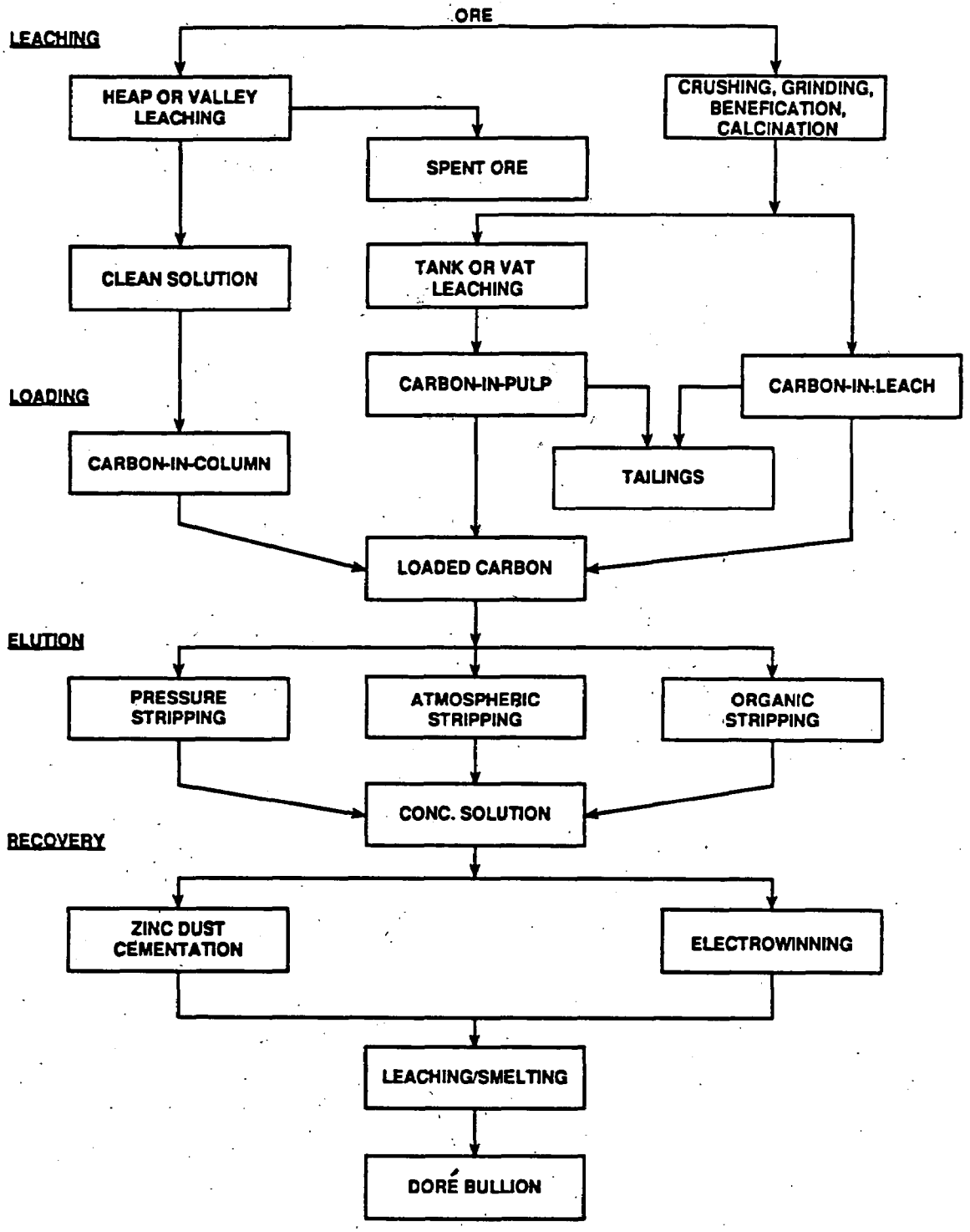
As noted previously, the predominant methods used in the U.S. and the developed world to beneficiate gold ore involve cyanidation. This technique uses solutions of sodium or potassium cyanide as lixiviants (leaching agents) to recover precious metals (including gold and silver) from the ore. Cyanide heap leaching is a relatively inexpensive method of recovering gold from lower-grade ores while tank leaching is used for higher grade ore. Although other lixiviants are currently being tested, none are known to be used in commercial operations. Alternative lixiviants include malononitrile, bromine, urea, and copper-catalyzed thiosulfate (Bureau of Mines, 1985; Bureau of Mines, undated(a)).

The cyanidation-carbon adsorption processes most commonly used involve four steps: leaching, loading, elution, and recovery (van Zyl et al., 1988) (see Exhibit 3-7). In leaching, the cyanide reacts with the ore to liberate gold material and form a cyanide-gold complex in an aqueous solution. Precious metal values in this solution are then loaded onto activated carbon by adsorption. When the loading is complete, the values are eluted, or desorbed from the carbon, and recovered by electrowinning or zinc precipitation prior to smelting. An alternative to cyanidation/carbon adsorption is cyanidation/zinc precipitation. The cyanidation-zinc precipitation technique also involves four steps: leaching, clarification, deaeration, and precipitation. The precipitate (a solid) is smelted directly.

Cyanidation is best suited to fine-grain gold in disseminated deposits. Cyanidation techniques used in the gold industry today include:

- Heap or valley fill leaching followed by carbon adsorption (carbon-in-column, or CIC, adsorption)
- Carbon-in-pulp (CIP) operations, where the ore pulp is leached in an initial set of tanks with carbon adsorption occurring in a second set of tanks
- Carbon-in-Leach (CIL) operations, where leaching and carbon recovery of the gold values occur simultaneously in the same set of tanks
- Cyanide leaching in heaps or tanks (CIP) followed by zinc precipitation (the Merrill-Crowe process).

Exhibit 3-7. Steps for Gold Recovery Using Carbon Adsorption
(Adapted from various sources)



As noted previously, *in situ* cyanide leaching to recover gold directly from ore bodies is a subject of research by the Bureau of Mines and others, but is not used commercially at this time. Other methods to recover the precious metal from the cyanide solution following leaching include solvent extraction and direct electrowinning; these methods are not common in the industry and are not discussed here.

Heap or valley fill leaching is generally used to beneficiate ores containing an average of less than 0.04 troy ounces of gold per ton of ore. CIP and CIL techniques, commonly referred to as tank or vat methods, are generally used to beneficiate ores averaging more than 0.04 oz/t. Gold beneficiation cut-off values are dependent on many factors, including the price of gold and an operation's ability to recover the precious metal (van Zyl et al., 1988). At many heap leach operations, the lower cut-off grade is around 0.01 to 0.02 oz/t.

The sections below describe gold beneficiation using the various cyanidation techniques. The first subsection describes ore preparation that may take place before cyanidation. This is followed by sections that describe heap leaching and tank leaching, respectively, with carbon adsorption and zinc precipitation discussed in the heap leaching section. In each section, the discussion focusses on the operations, the waste generated, and the major environmental concerns during and after operations.

Ore Preparation

Depending on the type of ore (sulfide or oxide), the gold concentration in the ore, and other factors, the mine operator may prepare the ore by crushing, grinding, and/or oxidation (roasting, autoclaving, or bio-oxidation) prior to cyanidation or flotation. Crushing and grinding are described briefly below, as is oxidation.

Crushing and Grinding. In most cases, ore is prepared for leaching or flotation by crushing and/or grinding. These operations produce relatively uniformly sized particles by crushing, grinding, and wet or dry classification. Factors that determine the degree of ore preparation include the gold concentration and the mineralogy and hardness of the ore, the mill's capacity, the next planned step in beneficiation, and general facility economics. Run-of-mine ores with very low gold concentrations may be sent directly for heap leaching with no prior crushing or classification.

Milling begins when ore material from the mine is reduced in particle size by crushing and/or grinding. A primary crusher, such as a jaw type, is used to reduce ore into particles less than 150 millimeters ($\approx$ 6 inches) in diameter. Generally, crushing continues using a cone crusher and an internal sizing screen until the ore is less than 19 mm ($\approx$ 3/4 inch). Crushing in jaw and cone crushers is a dry process, with water spray applied only to control dust.

From the cone crusher, ore to be leached in tanks is fed to the grinding circuit where milling continues in the presence of water, often with cyanide added to begin the leaching process (ore to be leached in heaps or valley fills is routed from the crusher directly to the heap/fill). Water is added to form a slurry containing 35 to 50 percent solids. Grinding then occurs in ball or rod mills to further reduce the ore particle size. In some cases, ore and water are fed directly into an autogenous mill (where the hard ore itself serves the grinding medium) or a semiautogenous mill (where the ore supplemented by large steel balls are the grinding media). Between each grinding unit operation, hydrocyclones are used to classify coarse and fine particles, with coarse particles returned to the circuit for further size reduction and fine particles continuing through the process. Milled ore is in the form of a slurry, which is pumped to the next unit operation (Weiss, 1985; Stanford, 1987). Fugitive dust generated during crushing and grinding activities is usually controlled by water sprays, although there may be other air pollution control devices whose blowdown streams may be recirculated into the beneficiation circuit.

Oxidation of Sulfides (Roasting, Autoclaving, and Bio-Oxidation). Beneficiation of sulfide ores may include oxidation of sulfide minerals and carbonaceous material by roasting, autoclaving, bio-oxidation, or chlorination (chlorination is not commonly used because of the high equipment maintenance costs caused by the corrosive nature of the oxidizing agent). Roasting involves heating sulfide ores in air to convert them to oxide ores amenable to cyanidation. In effect, roasting oxidizes the sulfur in the ore, generating sulfur dioxide that can be captured and converted into sulfuric acid. Roasting temperatures depend on the mineralogy of the ore, but range as high as several hundred degrees Celsius. Roasting of ores that contain carbonaceous material oxidizes the carbon that otherwise interferes with leaching and reduces gold recovery efficiency. Autoclaving (pressure oxidation) is a relatively new technique that operates at lower temperatures than roasting. Autoclaving uses pressurized steam to start the reaction and oxygen to oxidize sulfur-bearing minerals. Heat released from the oxidation of sulfur then sustains the reaction. Roasting and autoclaving are being used more frequently in the U.S. as the technologies become more cost-effective and as oxide ores become increasingly difficult to find and/or mine economically.

Bio-oxidation of sulfide ores employs bacteria to oxidize the sulfur-bearing minerals. This technique is currently used on an experimental basis at the Congress Gold Property in Canada and at the Homestake Tonkin Springs property in Nevada. The bacteria used in this technique are naturally occurring and typically include *Thiobacillus ferrooxidans*, *Thiobacillus thiooxidans*, and *Leptospirillum ferrooxidans*. In this technique, the bacteria are placed in a vat with sulfide gold ore. The bacteria feed on the sulfide minerals and ferrous iron components of the gold ore. Research is currently being conducted on other bacteria that can grow at higher temperatures; high-temperature bacteria are thought to treat the ore at a much faster rate (Bureau of Mines, 1990a). Although more time is required for bio-oxidation, it is considered to be less expensive than roasting or autoclaving (Hackel, 1990).

Heap Leaching

Since the late 1970s, heap leaching has developed into an cost-effective way to beneficiate a variety of low-grade, oxidized gold ores. Compared to conventional cyanidation (i.e., tank agitation leaching), heap leaching has several advantages, including simplicity of design, lower capital and operating costs, and shorter startup times. Depending on the local topography, a heap or a valley fill method may be employed. Where level ground exists, a heap is constructed; the heap consists simply of a flat-topped pile of the ore to be leached. In rough terrain, a valley may be dammed and filled with the ore. Sizes of heaps and valley fills can range from a few acres up to several hundred. The design of these leaching facilities and their method of operation are quite site-specific and may vary over time at the same site. Gold recovery rates for heap and valley fill leaching generally range from 60 to 80 percent, but may be higher in some cases.

Leaching. Heap leaching activities may involve any or all of the following steps (Bureau of Mines, 1978 and 1984; van Zyl, 1988; many others):

- Preparation of a "pad" (or base under the heap) with an impervious liner on a 1° to 6° slope or greater for drainage. No gold heap or valley fill leaches are known to operate without a liner (Hackel, 1990). Some liners may simply be compacted soils and clays, while others may be of more sophisticated design, incorporating clay liners, french drains, and multiple synthetic liners.

- Placement of historic tailings or other relatively uniform and pervious material on the liner to protect it from damage by heavy equipment or other circumstances.

- Mining ore (or, as has been practiced in Cripple Creek, Colorado, and elsewhere, taking material containing gold values from old waste piles or coarse tailings).

- Crushing and/or agglomerating the ore (agglomeration is discussed below), typically to between 1/2 and 1 inch in size if necessary and cost-effective; some operations may leach run-of-mine ore.

- Placing the ore on the pad(s) using trucks, bulldozers, conveyors, or other equipment.

- Applying cyanide solution using drip, spray, or pond irrigation systems, with application rates generally between 0.5 and 1.0 pounds of sodium cyanide per ton of solution. This is known as the "barren" solution because it contains little or no gold.

- Collecting the solution intercepted by the impervious liner via piping laid on the liner, ditches on the perimeter of the heap, or pipes/wells through the heap into sumps at the liner surface. The recovered solution, now "pregnant" with gold (and silver), may be stored in "pregnant" ponds or routed directly to tanks for gold recovery, or it may be re-applied to the heap for additional leaching.

- Recovering the gold from the pregnant solution.

Two common types of pads are used in gold heap leaching: permanent heap construction on a pad where ore is placed, leached, and left in place; and on-off pads, where ore is placed on the pad, leached, and removed to a permanent disposal site, after which more ore is placed on the pad for a new cycle. Permanent heaps are typically built in successive lifts, with each lift composed of a 5- to 30-foot layer of ore. Each lift is then leached, a new lift is added to the top and leached, and so on, until the heap reaches its final height, which can range up to 200 feet or more. On-off pads are much less common in the industry (Lopes and Johnston, 1988).

Pad and liner construction methods and materials vary with the type of pad, site conditions, and perhaps most importantly, regulatory requirements. Construction materials may include compacted soil or clay, asphaltic concrete, and low-permeability synthetic membranes such as plastic or geomembrane (van Zyl et al., 1988). As noted above, sand, historic tailings, or crushed ore may be placed on top of the synthetic liner to provide a pervious medium for leachate collection as well as to protect the pad. Older pads tend to be made of compacted clay, with little or no other site preparation. Newer pads are usually constructed of synthetic materials, typically installed over a compacted layer of native soil or imported clay. Some mines now use synthetic liners composed of high-density polyethylene (HDPE) or very low-density polyethylene (VLDPE) in combination with compacted native materials. These liner systems are referred to as composite liners; depending largely on regulatory requirements, there may be a leachate collection system between the liners to detect and collect any leakage through the primary liner. On-off pads are generally constructed of asphaltic concrete to protect the liner from potential damage by heavy machinery used during unloading.

Agglomeration. Ores with a high proportion of small particle size (minus 200 mesh) require additional preparation before leaching can be done effectively. Because percolation of the lixiviant through the heap may be retarded as a result of blocked passages by fine-grained particles (thus preventing the solution from contacting and recovering the gold from sections of the heap), these types of ores are often agglomerated to increase particle size. Agglomeration aggregates individual particles into a larger mass, thus enhancing percolation of the lixiviant and extraction efficiency. This technique may increase the flow of cyanide solution through the heap by a factor of 6,000, decreasing the overall leaching time needed. Agglomeration is currently used in about half of all heap leaching operations. The agglomeration technique typically involves the following (Bureau of Mines, 1986):

- Adding Portland cement (a binding agent) and/or lime (for alkalinity) to the crushed ore as or before it is placed on the heap
- Wetting the ore with cyanide solution to start leaching as or before the ore is placed on the heap (e.g., spraying cyanide solution over ore on the conveyor that transports ore from the crusher to the heap)
- Mechanically tumbling the ore mixture so fine particles adhere to the larger particles. This can occur, for example, when ore is dumped from the end of a conveyor or truck and then mechanically spread on the heap.

As noted above, a variation of heap leaching is valley fill leaching. This method is used at facilities with little or no flat land and utilizes liner systems similar to those used in heap leaches for solution containment. In valley fill leaching, the ore material is placed on top of a liner system located behind a dam on the valley floor. As in heap leaching, the ore is treated with lixiviant but is contained and collected internally at the lowest point in the ore on the liner system for further beneficiation, rather than in an external solution collection pond. Montana, Utah, and other States have approved valley fill operations.

In either of these two configurations, cyanide complexes with gold and other metals as the barren solution percolates through the ore. Leaching typically takes from weeks to several months, depending on the permeability and size of the pile. An "average/normal" leach cycle takes approximately three months (Lopes and Johnston, 1988).

The reaction of the solution with the free gold is oxygen-dependent. Therefore, the solution is oxygenated prior to application or during spraying. Barren solution may be kept in a barren pond prior to application, or may be routed directly to the heap from tanks. Barren solution is made up by adding fresh water, cyanide, and lime to recycled water from the carbon columns (see below).

After being applied to the surface of the ore by sprays or drip irrigation, the cyanide solution percolates through the ore and is collected by pipes placed on the liner beneath the pile, drains directly to ditches or ponds around the pile, or is recovered from sumps constructed at the liner surface (Bureau of Mines, 1986; Lopes and Johnston, 1988). The solution is then collected in a pond or tank. The pregnant solution pond may be used as a holding pond, a surge pond, or a settling basin to remove solids contained in the cyanide solution. Some operations use a series of ponds, which may include one for the barren solution, an intermediate solution pond (from which semi-pregnant solution is directed back to the heap for further leaching before gold is recovered), a pregnant solution pond, and one or more emergency overflow ponds.

These ponds may be single-lined but are now more often double-lined with plastic (HDPE), butylrubber, and/or bentonite clay to prevent seepage. Composite liners, often with leachate collection systems to detect leaks are becoming increasingly common in response to more stringent States requirements. Particularly in the arid west, but also in the east (e.g., South Carolina) wildlife and waterfowl may be attracted to the ponds, and the cyanide solutions present an acute hazard. To control wildlife access to cyanide solution, at least one operation (Castle Mountain in California) has elected to construct tanks to collect and store leachate solutions as an alternative to open ponds. Many active operations now fence or cover solution ponds with screening or netting to prevent wildlife or waterfowl access, respectively.

Leaching occurs according to the following reactions, with most of the gold dissolving in the second reaction (van Zyl et al., 1988):

- $4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4NaAu(CN)_2 + 4NaOH$ (Elsener's Equation and Adamson's 1st Equation)
- $2Au + 4NaCN + O_2 + 2H_2O \rightarrow 2NaAu(CN)_2 + H_2O_2 + 2NaOH$ (Adamson's 2nd Equation).

Leaching is generally effective at a pH of 9.5 to 11, with the optimum being approximately 10.5. More acidic conditions may result in the loss of cyanide through hydrolysis, reaction with carbon dioxide, or reaction with hydrogen to form hydrogen cyanide (HCN). Alternatively, more basic conditions tend to slow the reaction process (Bureau of Mines, 1984). Typically, the recovered cyanide solution contains between 1 and 3 ppm of gold material (Bureau of Mines, 1986). Leaching continues until the gold concentration in pregnant solution falls below about 0.005 ounces per ton of solution (Lopes and Johnston, 1988); when that occurs at permanent heaps, another lift is added and leached or the heap is prepared for closure.

Barren solution must be treated to reduce cyanide levels to regulatory levels—cyanide species regulated can be weak-acid-dissociable, free, or total cyanide—when recycling is no longer necessary. Treatment occurs when contaminants build up in the recycling cyanide solution, at the end of leaching seasons, and/or at facility closure. Depending on regulatory requirements, the solution may then be land applied, stored in ponds, or evaporated.

When leaching ends, the spent ore that makes up the heap usually remains in place. Where on-off pads are used, however, spent ore will have been successively removed from the pad for disposal in onsite piles or dumps. Prior to final reclamation (or prior to ore removal from on-off pads), the spent ore generally must be de-toxified. This is typically accomplished by repeated rinsing with water, usually mine water or mill wastewater. Hydrogen peroxide or other oxidants may be added to rinse waters. Cyanide in rinse water may be treated using one or more of the methods described below. Most States require reductions in residual cyanide concentrations in rinse water/leachate to below 0.2 mg/l and a pH from 6 to 9 s.u. before the heap can be reclaimed and/or abandoned. The time necessary for rinsing heaps is enormously variable, ranging from a few days for some on-off heaps to months or years for some permanent heaps.

Depending on the method and completeness of detoxification, spent ore may continue to have a high pH. Heaps with agglomerated ores may prove particularly difficult to detoxify, since this tends to keep pH high. Reclaimed piles may have passive controls to control run-on and runoff; the design capacity of these controls may be based on the 10-, 25-, or 100-year 24-hour maximum storm event

or the probable maximum precipitation event, depending on the component and State regulatory requirements.

If sulfide ores are present, they may generate acidic leachate over time, which in turn may mobilize heavy metals that are present in the ore. Although heap leach piles are generally lined, liners may be damaged or may deteriorate, or may be intentionally punctured as part of reclamation.

Current technology and environmental concerns have led to the development of several methods for complexing or decomposing cyanide. These include:

- Lagooning or natural degradation through photodecomposition, acidification by CO_2 and subsequent volatilization, oxidation by oxygen, dilution, adsorption on solids, biological action, precipitation with metals, and leakage into underlying porous sediments.

- Oxidation by various oxidants:

  - Chlorine gas
  - Sodium and calcium hypochlorites
  - Electro-oxidation and electrochlorination
  - Ozone
  - Hydrogen peroxide
  - Sulfur dioxide and air.

  In all cases, cyanide is oxidized initially to the cyanate, CNO^-. In some cases the cyanate ion is oxidized further to NH_4+ and HCO_3-, and finally the ammonium ion may be oxidized to nitrogen gas.

- Acidification, with volatilization and possibly subsequent adsorption of HCN for reuse.

- Adsorption of cyanide complexes on ion exchange resins or activated carbon.

- Ion and precipitation flotation through cyanide complexation with base metals and recovery with special collectors.

- Conversion of cyanide to less toxic thiocyanate (CNS^-) or ferrocyanide $(Fe(CN)_6)^{4-}$.

- Removal of ferrocyanide by oxidation or precipitation with heavy metals.

- Biological oxidation.

Hydrogen peroxide, for example, can be used to detoxify cyanide in spent heaps, tailings, and solution ponds and tanks. The cyanide-bearing solution is sent to a series of hydrogen peroxide reaction tanks (Ahsan et al., 1989). Hydrogen peroxide and lime are added to the solution forming precipitate of metal hydroxides and oxidizing free and weakly complexed cyanide into cyanate (OCN-). Additional steps precipitate copper ferrocyanide, a reddish-brown solid that is stable at a pH

of less than 9. Precipitates are separated from the solution and discharged to the tailings impoundment. The solution is then recycled until the desired cyanide concentration is attained in the effluent.

INCO has also developed a technique for detoxification of mine waste streams containing cyanide—such as CIP and CIL pulps, barren solution, tailings pond waters, and heap leach rinse solutions—by removing cyanide and base metal complexes. The INCO process uses SO_2 and air, which is dispersed in the effluent using a well-agitated vessel. Acid produced in the oxidation reaction is neutralized with lime at a controlled pH of between 8 and 10. The reaction requires soluble copper, which can be provided in the form of copper sulfate (Devuyst et al., 1990).

Each treatment method may generate a different waste, with the chemical compounds used in cyanide removal as constituents. Some of these (e.g., chlorine, ozone, hydrogen peroxide) are toxic to bacteria and other life forms but are unlikely to persist or can be cleaned up easily. Others (e.g., chloramine or chlorinated organic compounds) may persist for long periods in the natural environment. In general, the long-term persistence of cyanide residues in mining waste are not completely understood (University of California at Berkeley, 1988).

Following detoxification, heaps may be regraded to more stable long-term configurations. Liners may be punctured and the heap covered with topsoil and reclaimed/revegetated. In some cases, heaps may require capping to reduce leaching of heavy metals. Reclamation requirements vary among the States, and the types of reclamation that are suitable for a given heap generally depend on the nature of the site and of the spent ore. Any ponds are usually backfilled. Pond liners may be removed, folded over and sealed to encapsulate sludges or other wastes, punctured, or otherwise handled, depending on State requirements. Because of the enormous amounts of spent ore in heaps/valleys and in spent ore dumps, any long-term environmental problems must be anticipated during design, since it is not practical to move the materials after operations end.

Carbon Loading. Recovery of gold from the pregnant solution generated by heap leaching is accomplished using carbon adsorption or direct precipitation with zinc dust (known as the Merrill-Crowe process). These techniques may be used separately or in a series with carbon adsorption followed by zinc precipitation. Both carbon adsorption and zinc precipitation separate the gold-cyanide complex from the noncomplexed cyanide and other remaining wastes, including water and spent ore. Unconventional techniques used to recover gold values include solvent extraction, direct electrowinning, and, more recently, ion exchange resin. Activated carbon recovery and zinc precipitation are described below.

Activated carbon techniques are better able to process solutions with low metal concentrations and are thus most often used on solutions with a gold concentration below 0.05 oz/t of solution (Bureau of Mines, 1978 and 1984). Carbon adsorption is used both for heap leach solution and for tank leaching.

In heap leaching, carbon adsorption uses the Carbon-in-Column (CIC) technique. In the CIC technique, the pregnant solution collected from the leach pile is pumped from a collection pond or tank into a series of cascading columns containing activated carbon. The solution mixes with the carbon column in one of two methods: fixed-bed or fluid-bed.

The fluid-bed method involves pumping pregnant solution upward through the column at a rate sufficient to maintain the carbon bed in a fluid state moving gradually down through the column without allowing the carbon to be carried out of the system. Thus, loaded carbon can be removed from the bottom of the tank and fresh carbon added at the top. The fluid-bed method is the more common of the two methods used in operations adsorbing gold-cyanide values from unclarified leach solutions containing minor amounts of slimes. Because the fluid-bed method uses a countercurrent operating principal, it is often more efficient and economical than the fixed-bed method in adsorbing the gold-cyanide complex from solution (Bureau of Mines, 1978 and 1984).

In the fixed-bed method, the gold-laden cyanide solution is pumped downward through a series of columns. The columns generally have either flat or dished heads and contain a charcoal retention screen as well as a support grid on the bottom. Normally, the height-to-diameter ratio of the tanks is 2:1, although, in some instances, a larger ratio will increase the adsorption capacity of the system (Weiss, 1985). In each vessel, the gold-cyanide complex is adsorbed onto activated carbon granules that preferentially adsorb the gold-cyanide complex from the remaining solution as the material flows from one column to the next. The advantage of the fixed-bed method over the fluid-bed method is that it requires less carbon to process the same amount of solution (Bureau of Mines, 1978 and 1984).

Elution. Typically, the activated carbon collects gold from the cyanide leachate until it contains between 100 and 400 ounces of gold per ton of carbon depending on the individual operation. Loading efficiency decreases with solutions containing less gold (Bureau of Mines, 1978). The precious metals are then stripped from the carbon by elution. The values can be desorbed from the carbon using a boiling caustic cyanide stripping solution (1.0 percent NaOH and 0.1 percent NaCN). Modifications of this method include the addition of alcohol to the stripping solution and/or stripping under elevated pressure or temperature (40°C to 150°C) (Bureau of Mines, 1986). At least one mine, Barneys Canyon, uses a stripping solution of hot sodium hydroxide that has proven to be as effective as caustic cyanide (LeHoux and Holden, 1990).

Carbon used in adsorption/desorption can be reactivated numerous times. The regeneration technique varies with mining operations, but generally involves an acid wash before or after elution of the gold-cyanide complex, followed by reactivation in a kiln and re-introduction into the adsorption circuit (Bureau of Mines, 1985). Generally, activated carbon is washed with a dilute acid solution (pH of 1 or 2) to dissolve carbonate impurities and metal-cyanide complexes that adhere to the carbon along with the gold. This technique may be employed either immediately before or after the gold-cyanide complex is removed. Acid washing before the gold is removed enhances gold recovery. Based on impurities to be removed from the carbon and metallurgical considerations, different acids and concentrations of those acids may be used. Usually, a hydrochloric acid solution is circulated through 3.6 metric tons (4 short tons) of carbon for approximately 16 to 20 hours. Nitric acid is also used in these types of operations, but is thought to be less efficient than hydrochloric acid (HCL) in removing impurities. The resulting spent acid wash solutions may be neutralized with a high-pH tailings slurry, dilute sodium hydroxide (NaOH) solution, or water rinse. When the wash solution reaches a stable pH of 10, it is typically sent to a tailings impoundment. Metallic elements may also be precipitated with sodium sulfide (Smolik et al., 1984; Zaburunov, 1989).

The carbon is then screened to remove fines and thermally reactivated in a rotary kiln at about 730°C for 20 minutes (Smolik et al., 1984). The reactivated carbon is subsequently rescreened and reintroduced into the recovery system. Recirculating the carbon material gradually decreases performance in subsequent adsorption and reactivation series. Carbon adsorption efficiency is closely monitored and fresh carbon is added to maintain efficiency at design levels (Bureau of Mines, 1984 and 1986).

Carbon particles not of optimum size are either lost to the tailings slurry or, to the greatest extent practicable, captured after reactivation. Carbon lost to the circuit is replaced with virgin, optimum-size carbon. Wastes from the reactivation circuits may include carbon fines and the acid wash solution. The carbon may contain small amounts of residual base metals and cyanide. The acid wash residues may contain metals, cyanide, and the acid (typically hydrochloric or nitric); according to Newmont Gold Company, the acid is usually neutralized in a totally enclosed system prior to release. Up to 10 percent of the carbon may be lost in any given carbon recovery/reactivation circuit from abrasion, ashing, or incidental losses. Most operations capture less-than-optimum-size carbon particles and extract additional gold values (or send fines offsite for gold recovery). Onsite or offsite, this may involve either incinerating the carbon/gold that could not be desorbed chemically during the normal course of operations or subjecting the material to an extended period of concentrated cyanide leach. Any liquids used to wash or transport carbon material are recirculated.

Gold Recovery. Gold in the pregnant eluate solution may be electrowon or zinc precipitated. Electrowinning (or electrodeposition) uses stainless or mild steel wool, or copper, as a cathode to collect the gold product. After two or more cycles of electrodeposition, the steel wool must be

removed and replaced. The depleted stripping solution may then be reheated and recycled to the carbon stripping system. The steel wool or electrowinning sludge, laden with gold value, is fluxed with sodium nitrate, fluorspar, silica, and/or sodium carbonate and melted in a crucible furnace for casting into bullion. For gold ores containing mercury, a retort step is required before gold smelting to recover metallic mercury (Bureau of Mines, 1986; Smolik et al., 1984).

Although carbon adsorption is the most common method of gold recovery in the United States, zinc precipitation is the most widely used method for gold ore containing large amounts of silver. Because of its simple and efficient operation, the Merrill-Crowe process is used at the 10 largest gold producing mines in the world, all of which are in South Africa. This technique is well suited to new mines where the ore has a high silver to gold ratio (from 5:1 to 20:1) (van Zyl et al., 1988).

In zinc precipitation operations (the Merrill-Crowe process), pregnant solution (or the pregnant eluate stripped from the activated carbon) is filtered using clarifying filters coated with diatomaceous earth to aid in the removal of suspended particles (see Figure 8) (Weiss, 1985). Dissolved oxygen is then removed from the solution using vacuum tanks and pumps. This is necessary because the presence of oxygen in the solution inhibits recovery (Bureau of Mines, 1984).

Metallic zinc dust then is combined with the deoxygenated pregnant solution. At some operations, a small amount of cyanide solution and lead nitrate or lead acetate is added. Lead increases galvanic activity and makes the reaction proceed at a faster rate. Zinc precipitation proceeds according to the reaction described below; the result is a gold precipitate (Bureau of Mines, 1984).

$$NaAu(CN)_2 + 2NaCN + Zn + H_2O \rightarrow Na_2Zn(CN)_4 + Au + H + NaOH.$$

The solution is forced through a filter that removes the gold metal product along with any other precipitates. Several types of filters may be used, including submerged bag, radial vacuum leaf, or plate-and-frame. The gold precipitate recovered by filtration is often of sufficiently high quality (45 to 85 percent gold) that it can be dried and smelted in a furnace to make doré (unrefined metals). In cases where further treatment is necessary, the precipitate may be muffle roasted or acid treated and calcined with borax and silica before smelting (Weiss, 1985). Following filtration, the barren solution can be chemically treated (neutralized) or regenerated and returned to the leach circuit (Weiss, 1985).

The wastes from zinc precipitation include a filter cake generated from initial filtering of the pregnant solution prior to the addition of zinc, and spent leaching solution, which is often returned to the leaching process. The filter cake consists primarily of fine gangue material and may contain gold-cyanide complex, zinc, free cyanide, and lime. The filter may be washed with water, which is disposed of as part of the waste. The waste is typically sent to tailings impoundments or piles.

Tank Leaching

As noted previously, tank leaching techniques for gold recovery are preferred over heap leaching for higher-grade ores, typically those with gold values averaging over 0.04 troy ounces per ton of ore. In tank leaching operations, primary leaching takes place in a series of tanks, often in the mill building, rather than in heaps. Finely ground gold ore is slurried with the leaching solution in tanks. The resulting gold-cyanide complex is then adsorbed on activated carbon. In the Carbon-in-Pulp method, leaching and adsorption occur in two separate series of tanks; in the Carbon-in-Leaching method, they occur in a single series. Both are described below. In either, the pregnant carbon then undergoes elution, followed either by electrowinning or zinc precipitation, as described previously. The recovery efficiencies attained by tank leaching are significantly higher than for heap leaching. Tank methods typically recover from 92 to 98 percent of the gold contained in the ore.

Continuous countercurrent decantation (CCD) is a method of washing the solution containing metal values from the leached ore slurry to produce a clear pregnant solution. This procedure is used for ores with high silver values that preclude the use of activated carbon and that are very difficult to filter, thus precluding the use of filters. The resulting pregnant solution is generally treated by the zinc precipitation technique described above.

A new technology employed in South Africa uses ion exchange resin in place of carbon in the CIP technique. This technology—Resin-in-Pulp (RIP)—is expected to have lower capital costs and energy consumption than CIP operations if it is operated effectively (Australia's Mining Monthly, 1991). If the use of ion exchange resins is found to be compatible with a wide range of ores, the industry may shift to these resins wherever activated carbon is now used.

Carbon-in-Pulp (CIP). In the CIP technique, a slurry of ore, process water, cyanide, and lime is pumped through a series of tanks for agitation and leaching. Then, the slurry containing leached ore and pregnant solution is pumped through a second series of tanks for adsorption (or subjected to continuous countercurrent decantation).

In the second series of CIP tanks, the slurry is introduced into a countercurrent flow with activated carbon. The slurry enters the first tank in the series, which contains carbon that is partially loaded with the gold-cyanide complex. In the suspended slurry, the activated carbon adsorbs gold material on the available exchange sites. As the carbon material becomes laden with precious metals, the carbon is pumped forward in the circuit toward the incoming solids and pregnant solution. Thus, in the last tank, the low-gold percentage solution is exposed to newly activated and relatively gold-free carbon that is capable of removing almost all of the remaining precious metals in the solution. Fully loaded carbon is removed at the feed end of the tank train for elution, followed by electrowinning or zinc precipitation as described previously. (Bureau of Mines, 1978 and 1986; Stanford, 1987).

Carbon-in-Leach (CIL). The CIL technique differs from CIP in that activated carbon is mixed with the ore pulp in a single series of agitated leach tanks. Leaching and adsorption of values occur in the same series of tanks. A countercurrent flow is maintained between the ore and the leaching solution and activated carbon. In the first tanks of the series, leaching of the fresh pulp is the primary activity. In later tanks, adsorption is dominant as fresh carbon is added to the system countercurrent to the pulp. Adsorption takes place as the gold-cyanide complex mixes with the carbon. As with Carbon-in-Pulp and heap leach operations, the pregnant carbon undergoes elution to remove values. The pregnant eluate then undergoes electrowinning or zinc precipitation to recover the gold.

The number and size of tanks used in domestic CIP and CIL facilities vary. For example, the Ridgeway facility in South Carolina uses 10 tanks measuring 52 feet in diameter and 56 feet in height; the Mercury Mine uses 14 tanks, each of which are 30 feet in diameter and 32 feet in height; the Golden Sunlight Mine uses 10 tanks, each of which are 40 feet in diameter and 45 feet in height. Retention times vary as well, ranging from 18 to 48 hours, depending on the facility, equipment used, and ore characteristics (Smolik et al., 1984; Fast, 1988; Zaburunov, 1989).

For either CIP or CIL, ore preparation (including grinding, lixiviant strength, and pulp density adjustment) and the time required to leach precious metal values vary depending on the type of ore. Oxide ores are typically beneficiated by grinding to 65 mesh and leaching with 0.05 percent sodium cyanide (for a pulp density of 50 percent solids) over a 4- to 24-hour period. Sulfide ores are typically beneficiated by grinding to 325 mesh and leaching with 0.1 percent sodium cyanide for a 10- to 72-hour period (for a pulp density of 40 percent solids) (Weiss, 1985).

Both of these tank beneficiation methods produce a waste slurry of spent ore pulp, or tailings, which is pumped as a slurry to a tailings impoundment (Bureau of Mines, 1986; Calgon Carbon Corporation, undated; Stanford, 1987). The tailings slurry is composed primarily of spent ore and water, along with small (but sometimes significant) amounts of residual cyanide, lost gold-cyanide complex, gold in solution, and any constituents in the water, including those added to control scale. The solid component of tailings consists of very fine materials, ranging from sand-sized to talc-sized. The characteristics of tailings vary greatly, depending on the ore, cyanide concentration, and the source of the water (fresh or recycled). In some cases, the tailings slurry may be treated to neutralize cyanide prior to disposal.

Tailings are disposed of in large tailings impoundment (up to hundreds of acres). Disposal requires a permanent site with adequate capacity for the life of the mine. The method of tailings disposal is largely controlled by the water content of the tailings. Generally, three types of tailings may be identified based on their water content: wet (greater than 40 percent of the total weight is water), thickened (approximately 40 percent water), and dry (less than 30 percent water). Where topography allows, tailings impoundments are located near the mill, but pipelines can be used transport tailings to

suitable locations a mile or more away (always downhill). The design of tailings dams depends primarily on the topography and the configuration of the impoundment (see Section 3.2.6); the preferred method is for the dam to span a valley, with tailings impounded in the valley. Dam construction materials include native soils and clays, waste rock, and components of the tailings (e.g., coarser sands in certain areas of the dam and finer "slimes" on the upper face.. Dams must be engineered to withstand seismic events, and to control the flow of liquids through or under the dam to prevent catastrophic failure. Dam design must also consider water flow in the drainage following the active life of the mine, since free water is typically kept to a minimum during operation by recycling it back to the mill.

In part because of the Clean Water Act requirement that there be no discharge from gold beneficiation operations that use cyanidation methods, most of the liquid component of tailings is recycled back to the mill. Newer tailings impoundments are on prepared surfaces of compacted soils and clays, with a few impoundments using clay or synthetic liners. In addition to water in the tailings slurry, there can be infiltration of groundwater into the impoundment (this volume of water may be discharged under the Clean Water Act). In many or most cases, it has been necessary to construct one or more seepage and overflow ponds immediately downgradient of the tailings dam. This has proven necessary for several interrelated reasons: the zero discharge effluent limitation guidelines, which require impoundment of all liquids, but that allow seepage to groundwater; State groundwater protection requirements that require liners or other means to reduce the loss of fluids to the subsurface; the presence of liquids in the tailings from the mill and from groundwater infiltration; and the need to control the movement of fluids through or under the dam. During the active life of the mine, solutions captured in such ponds are generally pumped back to the impoundment itself or directly to the mill.

States usually require reseeding/revegetation of impoundments when the mine closes. Because impoundments are often in drainages, reclamation may include permanent diversions around the tailings or preparing channels over or through the tailings. Reactive tailings (e.g., acid-forming) may have to be capped before reclamation, and root penetration or erosion of any such caps may have to be considered in reclamation planning.

3.3.2 Gold Placer Mining

Placer mines have historically produced approximately 35 percent of the total U.S. gold production. However, while net gold production has increased annually in recent years, placer production has decreased as the readily accessible placer deposits have been mined out and with the development of more cost-effective technologies for mining and beneficiating lode deposits. Placer mines produced only two to three percent of the total U.S. gold production during the period from 1984 through 1989; since that time, placer production has accounted for approximately one percent of U.S. annual production.

The size and nature of placer mines range from open cut operations disturbing tens of acres annually to small sluices operated solely as a recreational activity. In 1987, the average number of employees at placer mines in the contiguous 48 states was between three and four, and few mines employed more than 10 people (EPA, 1988b).

Regardless of size, most placer mines operate on a seasonal basis (ADEC, 1986; EPA, 1988a). The small size of most placer operations and the relative ease in establishing an operation make it difficult to establish the number of mines operating at any one time (EPA, 1988a). A 1986 EPA survey showed a total of 454 placer mines in operation in the U.S. Also in 1986, the Bureau of Mines estimated there were just more than 207 operational placer mines. While the final totals are quite different, both surveys revealed the overwhelming majority of the mines were in Alaska (190 according to EPA and 195 according to the Bureau). All the mines identified in both surveys were west of the Mississippi, with most large operations in Alaska.

Placers exist in different types of sedimentary deposits (fluvial, marine, eolian, etc.), although they all originate from lode deposits. Most of the gold placers mined in the U.S. are of fluvial origin. Placer deposits are typically found in unconsolidated sedimentary deposits, although depending on the nature of the associated materials, placers may be cemented to varying degrees. The terms pay streak, pay dirt, and pay gravel refer to the zone where the economic concentration of gold is located. This layer is often found adjacent to the bedrock. Finer gold particles are carried farther from their source and have a greater tendency to be distributed throughout the sediments in which they are found. The value of the pay streak is usually assessed as troy ounces per cubic yard, and varies throughout the deposit (Boyle, 1979).

The density of gold, and its resistance to weathering, are the two principal factors for the development of placer deposits. Gold is considerably more dense that the minerals typically associated with it (19.13 grams per cubic centimeter (g/cc) versus 2.65 g/cc for quartz). Heavy minerals typically settle to the bottom of a stream or beach, displacing lighter material in the process. Gold continues a downward migration in response to additional agitation in the streambed. Settling action also occurs on land in colluvium although the downward migration is not as pronounced in the absence of a fluid matrix. Placer deposits are formed as particles accumulate in this manner (Park and MacDiamid, 1970).

At a typical placer mine, overburden is removed and ore is blasted to fluff-up the material and make it easier to excavate. The ore is then hauled by trucks to a wash plant, which consists of a combination of equipment used to size and concentrate the ore. A typical wash plant consists of a grizzly and/or a trommel, where sizing takes place. The ore is then washed into a sluice, where the gold (and other heavy minerals) settle below the riffles and onto matting. The gold remains in the sluice, while the tailings and wash water flow out of the sluice and into a tailings or settling pond.

Periodically (every 1-2 days), the wash plant is shut down and the gold is removed. The concentrate may then be subjected to further, more refined concentration, with gravity separation techniques such as jigs, shaking tables and pinched sluices, and possibly magnetic separation, if magnetite is present, to produce a high grade concentrate suitable for processing.

3.3.2.1 Mining

Extraction methods employed at gold placer operations differ substantially from hardrock extraction methods. Large amounts of overburden, waste rock, and ore must be excavated and concentrated to remove the trace constituent gold. The stripping ratio (i.e., the ratio of overburden/waste rock to ore) at gold placer mines is high, sometimes as high as 10:1. In the coldest regions where gold placer mining occurs, frozen overburden (consisting of vegetation, muck, and waste rock) and ore deposits must be loosened by blasting and/or mechanical means prior to extracting the ore. They may also be thawed by a system or grid of water pipes circulating over the deposit.

Gold ore extraction at placer operations may be conducted using either surface or underground techniques, but surface methods are most commonly used because they generally are the least expensive (Whiteway, 1990). The principal surface extraction method is open cut mining. Other extraction methods employed at gold placer mines include dredging, hydraulicking, and other recreational and small-scale extraction techniques, such as panning and small suction dredging. Currently, use of dredging and hydraulicking methods is limited in the United States. Underground mining methods include bore-hole and drift mining. (Alaska Miner's Assn., 1986; Argall, 1987)

Open cut mining involves stripping away vegetation, soil, overburden, and waste rock to reach the ore buried below. The pay ore is blasted if necessary and can be excavated by bulldozers, loaders, scrapers, and draglines; conveyors or trucks then transport the ore to a wash plant for beneficiation. Usually the excavation site is located upstream or upslope of the wash plant, and the direction of the mining activity is away from the plant. Once a cut has been mined, it is generally either backfilled with excavated overburden and waste rock or converted to a water recycle or sediment pond (ADEC, 1987).

Dredges are used in both surface mining and underwater mining of placer deposits, but are generally associated with the mining and beneficiation of metal-bearing minerals (values) below water level. Dredges are limited by the availability of a saturated placer gold deposit or the existence of a water table near the surface to create the appropriate excavating environment (i.e., a pond). Four commonly used dredging systems include bucketline (also referred to as bucket-ladder), backhoe, dragline, and suction dredging.

In hydraulic mining, water under pressure is forced through an adjustable nozzle called a monitor or giant and directed at a bank to excavate gold placer ore and to transport it to the recovery unit, which

is generally a sluice box. The pressurized water jet can also be used to thaw frozen muck and to break up and wash away overburden. This is generally not used today, having been outlawed in most jurisdictions. However, hydraulic removal of overburden may still be practiced at a few mines

Small-scale extraction methods include panning and suction dredging. Panning is a low budget, labor intensive method involving fairly rudimentary gravity separation equipment. Panning is also a sampling method used by prospectors to evaluate a placer gold deposit to determine whether it can be mined profitably. Small-scale gold placer miners also use a variety of other portable concentrators, including long toms, rocker boxes, and dip boxes (EPA, 1988a). Small suction dredges are used by recreational or small (part-time) gold placer ventures. A pump varying from one to four inches usually floats immediately above the mined area. The mechanism that recovers the gold sits in a box next to the suction pipe and is carried under water. Alternatively, the nozzle has two hoses, one that transports water to the head and the other that transports material to the surface of a beneficiation device (i.e., usually a small sluice box that deposits tails back into the stream).

Drift mining and bore-hole mining are terms applied to working alluvial placer deposits by underground methods of mining. Drift mining is more expensive than open cut sluicing and hydraulicking, so it is used only in rich ground. In drift mining, the paystreak is reached through a shaft or an adit. Ore that has been separated from the vein either by blasting or with hand tools is carried in wheelbarrows or trammed to small cars that transport the gravel to the surface for beneficiation. If a deposit is large, then regular cuts or slices are taken across the paystreak, and work is generally performed on the deposit in a retreating fashion from the inner limit of the gravel (DOI, 1968; Argall, 1987).

3.3.2.2 Beneficiation

Beneficiation of placer ores involves the separation of fine gold particles from large quantities of alluvial sediments. Gravity separation is the most commonly used beneficiation method. Magnetic separation is used in some operations to supplement the gravity separation methods. Water is used in most, if not all steps to wash gold particles from oversized material and then to move ore concentrate through the wash plant. For land-based operations, the plant may be stationary but is often mounted on skids so that it can be moved along with the mining operation as it progresses. Dredge operations frequently employ floating wash plants, where the beneficiation equipment is carried within the dredge.

Beneficiation typically involves three general steps: the first is to remove grossly oversized material from the smaller fraction that contains the recoverable gold; the second is to concentrate the gold; and the third is to separate the fine gold from other fine, heavy minerals. The same type of equipment is often used in more than one step. For example, an array of jigs may be employed to handle successively finer material (Flatt, 1990).

Classification (sizing) is the initial step in the beneficiation operation when the large, oversize material (usually over 3/4 inch) is removed during beneficiation. A rough (large diameter) screen is usually used. This step may be fed by a bulldozer, front-end loader, backhoe, dragline or conveyor belt. Within the industry, this step is also referred to as roughing (EPA, 1988a). The ore is then subjected to a coarse concentration stage. This step, referred to as cleaning, may employ trommels or screens. Other equipment used in the coarse concentration stage includes sluices, jigs, shaking tables, spiral concentrators and cones. Depending on the size of the gold particles, cleaning may be the final step in beneficiation (Flatt, 1990; Silva, 1986).

Fine concentration is the final operation used to remove very small gold values from the concentrate generated in the previous stages. Many of the previously identified pieces of equipment can be calibrated for finer separation sensitivity. Final separation uses jigs, shaking tables, centrifugal concentrators, spiral concentrators or pinched sluices.

3.3.2.3 Wastes and Management Practices

Mining and beneficiation wastes associated with gold placer mining include tailings and water used for beneficiation. Most of these materials are either disposed of at the mine site (overburden and/or tailings), recycled during the active life of the mine (water), or used for onsite construction material or reclamation concurrently with mining or after operations end (overburden and/or tailings). Large amounts of overburden or waste rock are associated with placer mining. Because the desired material is such a small fraction of the material mined (< 0.1 troy oz/ton) there is a tremendous amount of waste rock generated. Then, large amounts of water are used to process the material. The type, volume, and characteristics of the wastes resulting from gold placer mining, as well as the waste management units associated with these wastes are discussed below. (Again, the use of the term "wastes" is not intended to identify materials that are "solid wastes" under RCRA.)

Waste rock is generally disposed of in waste rock dumps near the point of excavation. Eventually, the stockpiled waste rock may be used to backfill the mine cut during reclamation. Surface mining operations generate more waste per unit of crude ore extracted than underground operations, although stripping ratios vary from one site to the next. Overburden removed from the mine cut is stored nearby, sometimes piled along the edge of the pit until mining ceases, at which time it is used to backfill the cut.

Wastes from gravity concentration operations consist of a slurry of gangue (non-gold material) and process water that passes through the concentration operation. Tailings are classified by their size into three classes: coarse or oversize tailings, intermediate tailings (middlings), and fine tailings (slimes). Of the three grades delineated, fine tailings can be further broken down into two categories. Components of the slurried tailings can be classified as settleable solids, which are made up of sand

and coarse silt, or as suspended solids, composed mostly of fine silt and some clay size particles. (EPA, 1988a)

Large volumes of flowing water are used to carry the ore through the classification operation. The velocity of the flowing water generates a large volume of intermediate and fine tailings in the form of suspended sediment and lesser quantities of dissolved solids. Historically, the water and sediments were released to streams and created problems downstream from the mining sites. Currently, release of sediment is controlled by using impoundment structures where the water is held and the velocity is consequently reduced. As flow is restricted, sediments are deposited. Exposure of waste rock and ore during mining and beneficiation greatly increases the likelihood that soluble constituents will be dissolved. Once in solution, dissolved solids are much more likely to pass through sedimentation structures and reach surface waters.

Recycling or recirculating water at gold placer mines reduces the volume of effluent to be discharged after treatment. Production statistics from 1984 show that 21.3 percent of the Alaska gold placer mining industry achieved 90-100 percent recycle of the process wastewater (Harty and Terlecky, 1984a). Operations that separate oversize tailings prior to sluicing typically use less water than mines that do not classify the excavated material (Harty and Terlecky, 1984b). Where classification methods are used, approximately 1,467 gallons of water per cubic yard of ore are needed, whereas at mines that do not classify material, average water usage is 2,365 gallons per cubic yard of ore (EPA, 1988a; ADEC, 1987). The Clean Water Act effluent limitations guidelines for placer mines (40 CFR Part 440, Subpart M), promulgated in 1989, generally require recycling of process wastewater and have reduced the total discharge of wastewater from placer mining operations.

Chemicals are not typically used during beneficiation at placer gold mines, so tailings contain the same constituents found in the extracted ore. Potential natural constituents of gold placer wastes include mercury, arsenic, bismuth, antimony, thallium, pyrite, and pyrrhotite. These are often found in discharges from placer mines.

Waste and non-waste materials generated as a result of extraction and beneficiation of gold placer ore are managed (treated, stored, or disposed) in discrete units. These units are divided into two groups: (1) waste rock piles and (2) tailings impoundments.

In general, the goal of treating or managing waste streams of gold placer mines is to separate the silt and fine-grained solids from the water, reusing the water or ensuring it meets NPDES discharge requirements prior to discharging to a stream. Most waste management occurs after sluicing; the stacking of overburden and waste rock in areas proximate to the mining operation, however, constitutes an interim method of managing the materials prior to their ultimate return to the mine cut (Alaska Miner's Assn., 1986).

There are two ways to maximize the quality of the effluent discharged from a gold placer operation. They are used separately or, increasingly frequently, together. The effluent can be treated using a variety of impoundments (tailraces, pre-settling ponds, and settling/recycle ponds), filtration, and, in rare instances, flocculants. The mining operation also can be modified to reduce water use during beneficiation, thereby reducing the volume of effluent discharged. Waste management methods used to achieve this reduction include classification, recycling, use of a bypass, and control of water gain (i.e., surface and subsurface seepage) (Alaska Miner's Assn., 1986).

Tailings are typically disposed of in impoundments or used for construction. The method of tailings disposal is largely determined by the water content of the tailings. Tailings impoundments associated with gold placer mines are generally unlined containment areas for wet tailings. At most gold placer operations, the disposal of tailings requires a permanent site with adequate capacity for the life of the mine. The size of tailings impoundments varies between operations, however, if the impoundment is going to function effectively, the dimensions and characteristics are tailored to meet the specifications for a particular operation.

Tailraces and pre-settling ponds are characteristic of open cut surface mining operations. Even at open cut mines, however, there are variations of the typical tailrace and pre-settling pond. Two pre-settling ponds are sometimes used simultaneously and in series to provide extra storage in case the first pond fills prematurely or in the event that a scheduled cleaning is missed. Alternatively, two parallel pre-settling ponds might be used at alternating times. (Alaska Miner's Assn., 1986; ADEC, 1987) Settling ponds are similar in form and function to tailings impoundments and are used primarily by large-scale placer operations. Settling ponds are usually created by constructing a dam composed of tailings across the downstream end of the mined cut. When the next cut is mined, most of the extracted sediment is captured in this new pond. Thus, as mining progresses, a series of ponds emerge.

3.3.2.4 Environmental Effects

Most environmental effects associated with placer mining activities concern water quality. Historically, the most severe impacts have been physical disturbances to stream channels and the addition of large quantities of sediment downstream.

Prior to the initiation of any regulatory controls, little or no effort was made to recontour waste rock piles to resemble premining topography. Natural revegetation of historical placer grounds from Alaska to California ranges from none to complete. Depending on the remaining substrate, natural stream patterns in some areas may take a century to return to premining condition. These operations were also responsible for generating large quantities of sediment and increasing concentrations of heavy metals, including arsenic, copper, lead, and mercury, downstream from mining activities (ADEC, 1986; Clark, 1970; Holmes, 1981).

A 1985 Alaskan field study indicated that total suspended solids were elevated in a number of actively mined streams. During this study, sediment ponds were employed at some operations and provided a wide range of effectiveness. Downstream uses such as water supply, aquatic life, and recreation were precluded as a result of the increased sediment loads in two of the three streams studied. Fine sediments were readily carried downstream in response to increased stream flows (spring runoff), therefore the severity of localized impacts could change with time as sediments were picked up and redeposited in different locations downstream (ADEC, 1986).

The same study found that total dissolved solids were not categorically increased as a result of mining activities although levels of iron, manganese, cadmium, mercury, copper and arsenic were elevated below mining operations in some streams. (It is not clear from the study whether these concentrations are expressed as total or dissolved). A study of water quality within the Circle District, Alaska, conducted in 1983, showed elevated levels of total arsenic, copper, lead, and zinc, and elevated levels of dissolved arsenic and zinc downstream from placer mining activity. Mercury and cadmium levels were not elevated downstream from mining. Concentrations of dissolved constituents are typically of more concern in terms of water quality as the dissolved fraction is available for uptake by living organisms (ADEC, 1986; LaPierriere, et al., 1985).

The physical locations of placer mining activities and wetland ecosystems often overlap. Mining activities, particularly those mining recent alluvial deposits potentially impact wetlands directly during the removal of vegetation and soils or indirectly by removing or rerouting the hydrologic regimes that support wetland hydrology. Operators impacting wetlands are required to obtain a Clean Water Act Section 404 permit, and comply with Section 404(b)(1) guidelines.

Wildlife may also be impacted by placer mining through the physical disturbance of stream channels, the addition of sediments to streams, and the presence of human activities and heavy equipment in what are typically remote areas. Mining presents a physical barrier to fish migration through the disruption or diversion of active stream channels. Sediment concentrations in streams can result in gill damage, reduced fertility, and changes in blood chemistry, and reproduction may be inhibited or precluded when spawning grounds are lost to siltation and eggs are suffocated when covered by excess sediment (ADEC, 1986; Reynolds, 1989).

3.3.3 LEAD-ZINC

In 1990, there were a total of 29 lead/zinc mines operating within the United States. Of these 29 mines, 16 produce both lead and zinc; two produce lead but not zinc; and 11 produce zinc but not lead. In 1990 alone, these mines produced 495,000 metric tons of lead concentrate (making the U.S. the world's largest primary producer) and 515,000 metric tons of recoverable zinc. For the same year, employment figures were estimated to be 4,500 workers at mines and mills and 3,300 at secondary smelters and refineries. Twenty-one of the mines are located west of the Mississippi, in

the States of Missouri (9 mines), Idaho (3), Alaska (2), Colorado (2), Washington (2), Montana (1), New Mexico (1), and Oregon (1). The remaining eight mines are located in Tennessee (5 mines) and New York (3).

Lead is used primarily by transportation industries (70 percent) in batteries, fuel tanks, solder, seals, and bearings. Another 25 percent is used in electrical/electronic/communication (including batteries), ammunition, and other industries. U.S. and world demand has declined in recent years, in large part in response to environmental concerns. Zinc is used in galvanizing (53 percent), zinc-based alloys (20 percent), brass and bronze (14 percent), and for other purposes.

3.3.3.1 Mining

Lead and zinc are mined almost exclusively in underground operations, although a few surface operations do exist. The decision to use underground or surface mining techniques is dependent on the proximity of the ore body to the surface. Room-and-pillar techniques are commonly used to extract lead-zinc ore from large, flat-lying, tabular-shaped, strata-bound deposits. In contrast, extraction of lead-zinc ore from vein-type deposits is best suited to more selective stope mining methods. The exact mining method used is determined by the individual characteristics of each ore body.

Profitable recovery of lead-zinc ores ranges from as low as three percent metal in ore for large, easily accessed mines, to six percent for small, difficult-to-access underground mines, to more than 10 percent for extremely high-cost, remote areas. Low grade lead and zinc ores can also be mined profitably when produced as a byproduct of copper mining, or when appreciable quantities of precious metals (such as silver) are present (Weiss, 1985). Few lead-zinc deposits contain more than 50 million tons of ore.

3.3.3.2 Beneficiation

Beneficiation of lead and zinc ores is a three-step process consisting of milling, flotation, and sintering. Before the advent of flotation in the early 1900s, gravity concentration was the chief method by which lead-zinc ores were concentrated. However, with more selective reagents and advancements in grinding techniques, flotation has virtually replaced gravity concentration. Gravity concentration techniques, however, may still be used for preconcentrating before fine grinding and flotation (Bureau of Mines, 1984c and 1985).

Milling

Milling begins with a multistaged operation of crushing and grinding. Crushing is usually a dry operation, using water sprays only to control dust. Frequently, a primary crusher (jaw crusher) is located at the mine site to reduce the ore material into particles less than 150 millimeters (mm) (6

inches) in diameter. The crushed ore is then transported to a mill site for additional crushing, grinding, classification, and concentration.

Additional milling uses a cone crusher, usually followed by grinding in rod and ball mills. Grinding is a wet operation in which water and initial flotation reagents are added to form a slurry. Alternatively, the ore may be fed into an autogenous mill (where ore itself acts as a grinding medium) or a semi-autogenous mill (where the ore is supplemented with large steel balls).

Between each grinding unit operation, hydrocyclones are used to classify coarse and fine particles. Coarse particles are returned to the mill for further size reduction. The resulting size of the classified ore is usually about 65-mesh (6.3 mm). Chemical reagents that will be used during flotation separation activities may be added to the ore during milling activities (Bureau of Mines, 1985 and 1990a). Mill production capacities can be as high as 7,000 to 9,000 tons per day.

Flotation

Flotation is the most commonly used technique to concentrate lead-zinc minerals. Several separate flotation steps may be necessary to beneficiate these polymetallic ores. Most sulfide ores contain varying amounts of minerals such as lead, zinc, copper, and silver; thus, multiple floats are needed to concentrate individual metal values (Bureau of Mines, 1985a; Weiss, 1985). The tailings (residual material) from one mineral float are then used as feed for a subsequent float to concentrate another mineral. A typical example includes the following steps (Fuerstenau, 1976):

- Bulk flotation of lead-copper minerals
- Depression of zinc and iron minerals using such chemicals as sodium sulfite and zinc sulfate
- Flotation of a copper concentrate
- Rejection of a lead (sink) concentrate using sulfur dioxide and starch
- Activation and flotation of the sphalerite (using copper solution) from iron and gangue minerals
- Flotation of pyrite, if recovery is desired
- Flotation of barite concentrate.

The froth recovered in each of the cleaning cells is transferred to thickeners, where the concentrate is then thickened by settling. The thickener underflow (the concentrate) is pumped, dewatered by passage through a filter press, and then dried. The liquid overflow from the thickener contains wastewater, flotation reagents, and dissolved and suspended mineral products. This solution may be recycled or sent to a tailings pond (Fuerstenau, 1976).

Wastes from the various cells (typically rougher, scavenger, and cleaning cells) are collected and directed to a tailings thickener. Overflow from this unit (wastewater containing high solids and some wasted reagent) is often recycled back to the flotation cells. Thickener underflow (tailings) contains remaining gangue, unrecovered lead-zinc material, chemical reagents, and wastewater. This underflow is pumped as a slurry to a tailings pond. The solid content of the slurry varies with each operation, ranging from 30 to 60 percent.

Sintering

Concentrates of lead and zinc minerals that are to be processed by pyrometallurgical methods, such as smelting and refining, may require sintering, depending on the processing methods used. Sintering operations consist of several steps, including blending, sintering, cooling, and sizing. Raw materials, such as ore concentrates, ore screening, fluxes, plant recycle dusts, filter cake, and coke breeze are blended with small amounts of moisture in pug mills, balling drums, or balling pans. The concentrate feed is then fired (sintered) and cooled. The sinter is crushed during cooling and is typically less than six inches in diameter. This product will be graded and further crushed in some operations to produce a smaller sinter product (Weiss, 1985). Four of the five primary lead processing facilities in the United States sinter the concentrate prior to processing.

3.3.3.3 Wastes

Wastes generated by lead-zinc operations include mine water, waste rock, tailings, and refuse. Many of these wastes may be disposed of onsite or offsite, while others may be used or recycled during the active life of the operation. Waste constituents may include base metals, sulfides, or other elements found in the ore, and any additives or reagents used in beneficiation operations. The primary waste generated by underground mines is mine development rock, which is typically used in onsite construction for road or other purposes. Surface mines usually generate large volumes of overburden and waste rock that are usually disposed of in waste rock dumps. (As before, "wastes" discussed here are not confined to RCRA solid wastes.)

Overburden and Mine Development Rock

Waste generated as a result of lead-zinc mining include overburden and mine development rock collectively referred to as waste rock. As noted previously, the materials can be used onsite or placed in waste rock dumps. The quantity and composition of waste rock generated at lead-zinc mines varies greatly between sites. These wastes will contain minerals associated with the ore body and host rock. Typical minerals associated with sulfide ores are chalcopyrite, pyrite, calcite, and dolomite (Weiss, 1985).

Mine Water

Mine water consists of all water that collects in mine workings, both surface and underground, as a result of inflow from rain or surface water, and groundwater seepage. As necessary, water may be pumped from the mine to keep it dry and allow continued access to the ore. The pumped water may then be used in beneficiation, pumped to tailings ponds, or discharged to surface water. The quantity and chemical composition of mine water varies from site to site, depending on the geochemistry of the ore body and the surrounding area. Mine water may also contain small quantities of oil and grease from extraction machinery and nitrates (NO_3) from blasting activities. Based on studies of lead mines in the United States, the range of concentrations in mine water (mg/l) for lead was 0.1-1.9, zinc 0.12-0.46, chromium 0.02-0.36, sulfate 295-1,825, and pH 7.9-8.8. After the mine is closed and pumping stops, the potential exists for water exposed to sulfur-bearing minerals in an oxidizing environment, such as open pits or underground workings, to acidify. This may lead to the mobilization of metals and other constituents in the remaining ore body exposed by mining and to the contamination of surface and/or groundwater. Alternatively, flooding of underground workings can reduce exposure of sulfide minerals to oxygen and effectively eliminate acid generation.

Flotation Wastes

After the removal of values in the flotation process, the flotation system discharges tailings composed of liquids and solids. Between 1/4 and 1/2 of the tailings generated are made up of solids, mostly gangue material and small quantities of unrecovered lead-zinc minerals. The liquid component of the flotation waste is usually water and dissolved solids, along with any remaining reagents not consumed in the flotation process. These reagents may include cyanide, which is used as a sphalerite depressant during galena flotation. Most operations send tailings to impoundments where solids settle out of the suspension. The characteristics of tailings from the flotation process vary greatly, depending on the ore, reagents, and processes used.

Chemical Wastes

In addition to wastes generated as part of extraction and beneficiation, facilities also store and use a variety of chemicals needed for mine and mill operations. A list of chemicals used at lead-zinc mines is provided in Exhibit 3-8.

3.3.3.4 Waste Management

Wastes generated as a result of mining and beneficiating lead and zinc minerals are managed (treated, stored, and/or disposed) in discrete units—waste rock piles or dumps, mine pits and underground structures, and tailings impoundments.

Exhibit 3-8. Chemicals Used at Lead-Zinc Mines

Acetylene	Sodium Cyanide	Kerosene
Calcium Oxide	Sulfur Dioxide	Methane, Chlorodifuoro-
Hexone	Sulfuric Acid	Sodium Aerofloat
Hydrogen Chloride	Diesel Fuel No. 1	Sulfuric Acid Copper (2+)
Methyl Chloroform	Diesel Fuel No. 2	Salt (1:1)
Methyl Isobutyl Carbinol	Chromic Acid, Disodium Salt	Zinc Solution
Nitric Acid	Copper Solution	Zinc Sulfate
Propane		

Source: National Institute for Occupational Safety and Health, 1990.

Waste Rock Piles

Waste rock (overburden and mine development rock) removed from the mine is stored and/or disposed in unlined piles onsite. Constituents of concern in runoff and leachate from waste rock piles includes heavy metals. These piles also can generate acid drainage if sulfide minerals and moisture are present in sufficient concentrations without adequate neutralization potential or other controls.

Mine Pits and Underground Workings

In addition to wastes generated during active operations, when the mines close or stop operation, pits and underground workings may be allowed to fill with water. This accumulating water, which may become mine drainage, can acidify through aeration and contact with sulfide minerals and become contaminated with heavy metals. At pits where quartz minerals are associated with lead-zinc deposits, silica dust exposure may be a problem both during mine operations and following closure. Asbestos minerals, which may be present in pits where limestone and dolomite ores are mined, may also be a concern (U.S. Department of Health and Human Services, 1982).

Tailings Impoundments

The disposal of tailings requires a permanent site with adequate capacity for the life of the mine. Impoundments can range up to several hundred acres in size. The method of tailings disposal is largely controlled by the water content of the tailings. Two general classes of impounding structures may be used to construct a tailings pond: water-retention dams and raised embankments. Water retention dams involve the construction of a dam, usually in a natural drainage area, and tailings are impounded behind the dam. The water retention method relies on natural topography to assist in the impoundment of tailings and tailings water. A raised embankment is a phased approach to impoundment construction in which the earthen dam structure, composed of native soils, waste rock, and tailings, is built up in successive lifts over the life of the project as need arises and materials are

available. Water retention dams are more costly but typically allow greater storage of process water and effluent in the impoundment.

3.3.4 COPPER

The physical properties of copper, including malleability and workability, corrosion resistance and durability, high electrical and thermal conductivity, and ability to alloy with other metals, have made it an important metal to a number of diverse industries. Copper was an historically important resource for the production of tools, utensils, vessels, weapons, and objects of art. According to the Bureau of Mines, in 1992, copper production was used for building construction (41 percent), electrical and electronic products (24 percent), industrial machinery and equipment (13 percent), transportation (12 percent), and consumer products (10 percent) (Bureau of Mines, 1993a).

The United States is the second largest copper producer in the world. Next to Chile, the United States had the second largest reserves (45 million metric tons) and reserve base (90 million metric tons) of contained copper in 1992. United States' copper operations produced about 1.7 million metric tons in 1992. In 1991, 1.63 million metric tons were produced. The total value of copper produced in 1992 was $4.1 billion. Arizona led production in 1992, followed by New Mexico, Utah, Michigan, and Montana. In the same year, copper was also recovered from mines in seven other States (Bureau of Mines, 1993a and 1993b).

The number of operating copper mines decreased from 68 mines in 1989 to 65 mines in 1992. Of the 65 mines actively producing copper in 1992, 33 listed copper as the primary product. The remaining 32 mines produced copper either as a byproduct or co-product of gold, lead, zinc, or silver (Bureau of Mines, 1993b). Thirteen of the 33 active mines that primarily produce copper are located in Arizona; the remaining mines are located in New Mexico, Utah, Michigan, and Montana (Bureau of Mines, undated).

In 1991, the top 25 copper producers in the United States accounted for more than 95 percent of the United States' domestic copper production. These producers are listed in Exhibit 3-9 (Bureau of Mines, 1993b).

3.3.4.1 Geology of Copper Ores

Copper deposits are found in a variety of geologic environments, depending on the rock-forming processes that occurred. In general, copper deposits are formed by hydrothermal processes (i.e., the minerals are precipitated as sulfides from heated waters associated with igneous intrusions or areas of otherwise abnormal lithospheric heating). These deposits can be grouped in the following broad classes: porphyry and related copper deposits, sediment-hosted copper deposits, volcanic-hosted

Exhibit 3-9. Leading Copper Producing Facilities in the United States

Rank	Mine	County and State	Operator
1	Morenci/Metcalf	Greenlee, AZ	Phelps Dodge Corporation
2	Bingham Canyon	Salt Lake, UT	Kennecott, Utah Copper Corporation
3	San Manuel	Pinal, AZ	Magma Copper Company
4	Chino	Grant, NM	Phelps Dodge Corporation
5	Tyrone	Grant, NM	Phelps Dodge Corporation, Burro Chief Copper Company
6	Sierrita	Pima, AZ	Cyprus Sierrita Corporation
7	Ray Complex	Pinal, AZ	ASARCO Incorporated
8	Bagdad	Yavapai, AZ	Cyprus Bagdad Copper Company
9	Pinto Valley	Gila, AZ	Pinto Valley Copper Corporation
10	Mission Complex	Pima, AZ	ASARCO Incorporated
11	Inspiration	Gila, AZ	Cyprus Miami Mining Corporation
12	White Pine	Ontonagon, MI	Copper Range Company
13	Continental	Silver Bow, MT	Montana Resources, Inc.
14	Twin Buttes	Pima, AZ	Cyprus Sierrita Corporation
15	Troy	Lincoln, MT	ASARCO Incorporated
16	San Xavier	Pima, AZ	ASARCO Incorporated
17	Superior (Magma)	Pinal, AZ	Magma Copper Company
18	Miami	Gila, AZ	Pinto Valley Copper Corporation
19	Casteel	Iron, MO	The Doe Run Company
20	Silver Bell	Pima, AZ	ASARCO Incorporated
21	Lakeshore	Pinal, AZ	Cyprus Casa Grande Corporation
22	Johnson	Cochise, AZ	Arimetco Incorporated
23	Oracle Ridge	Pinal, AZ	South Atlantic Ventures Ltd.
24	Yerington	Lyon, NV	Arimetco Incorporated
25	Mineral Park	Mohave, AZ	Cyprus Mineral Park

massive sulfide deposits, veins and replacement bodies associated with metamorphic rocks, and deposits associated with ultramafic, mafic, ultrabasic, and carbonatite rocks.

Copper occurs in about 250 minerals; however, only a few of these are commercially important. The most common sulfide minerals are chalcopyrite ($CuFeS_2$), covellite (CuS), chalcocite (Cu_2S), bornite (Cu_5FeS_4), enargite (Cu_3AsS_4), and tetrahedrite ($(CuFe)_{12}Sb_4S_{13}$). Predominant oxide minerals are chrysocolla ($CuSiO_3$), malachite (Cu_2CO_3), azurite ($Cu_3(CO_3)_2(OH)_2$), and cuprite (Cu_2O). Chalcopyrite is the most common mineral found in porphyry-type deposits. Chalcocite occurs predominantly in hydrothermal veins (U.S. Geological Survey, 1973).

3.3.4.2 Mining

Conventional open-pit mining techniques are the predominant methods used today by the copper mining industry, representing 83 percent of domestic mining capacity. In open-pit mining, overburden is initially stripped off to expose the ore. The waste rock and ore are excavated by drilling rows of 6- to 12-inch (diameter) blast holes. Subsequently, large electric or diesel shovels or front-end loaders transport the ore onto trucks, trains, or conveyor belts for removal to milling or leaching facilities, depending on the type of ore (sulfide or oxide) and grade.

The remaining 17 percent of the active copper mines use various types of high-tonnage underground operations. The three main underground mining methods used to mine copper ore are stoping, room-and-pillar, and block caving. Waste rock and mine water are generated by underground mining operations (as well as by surface mines). See Section 3.1 for a broad discussion of conventional open-pit and underground mining techniques.

3.3.4.3 Beneficiation

Beneficiation of copper ores and minerals can occur either through conventional milling and flotation of high-grade sulfide ore or by leaching and solvent extraction/electrowinning (SX/EW) lower grade sulfide and oxide ore. The beneficiation method(s) selected varies with mining operations and depends on ore characteristics and economic considerations.

Conventional Milling/Flotation

The first step in the beneficiation of high-grade sulfide ore is comminution. Typically, this is accomplished by sequential size reduction operations—commonly referred to as crushing and grinding. Crushing and grinding operations at copper mines are typical of those found throughout the mining industry, including primary crushing in jaw or gyratory crusher (often in the mine workings), secondary and tertiary crushing in cone crushers (typically in the mill), and grinding in rod and ball or autogenous/semiautogenous mills. After grinding, ore is pumped to a classifier designed to separate fine-grained material (less than 5 mm) from coarse-grained material requiring further

grinding. The hydrocyclone is the standard technology for classification (Office of Technology Assessment, 1988; Taggart, 1945; Wills, 1981).

The second step in the beneficiation of sulfide ore is concentration. Froth flotation is the standard method of concentration used in the copper industry for higher-grade ores. About 70 percent of all copper is produced by this method. The ore is conditioned with chemicals to make the copper minerals water-repellent (i.e., hydrophobic) without affecting the other minerals. Air is then pumped through the agitated slurry to produce a bubbly froth. The hydrophobic copper minerals are aerophillic; that is, they are attracted to air bubbles, to which they attach themselves, and then float to the top of the cell. As they reach the surface, the bubbles form a froth that overflows into a trough for collection. The other noncopper minerals sink to the bottom of the cell. Following copper recovery, molybdenum (as molybdenite [MoS_2]) and other metals may then be recovered by selective flotation before the slurry is disposed of as tailings.

Conventional flotation is carried out in stages. The purpose of each stage depends on the types of minerals in the ore. Selective flotation of chalcocite-bearing sulfide ores and the rejection of pyrite utilizes three types of flotation cells: roughers, cleaners, and scavengers. Many copper mills now also include column flotation to further enhance product recovery after scavenger flotation. Reagents used in flotation concentrators at copper mines include collectors, depressants, activators, frothers, flocculants, filtering aides, and pH regulators. A list of the reagents typically used in a copper flotation circuit is presented in Exhibit 3-10 (Biswas and Davenport, 1976; Bureau of Mines, 1987).

Exhibit 3-10. Copper Flotation Reagents

Collectors	Activators
Ethylxanthate	Sodium sulfide or hydrosulfide
Amylxanthate	pH Regulators
Isopropylxanthate	Lime
Isobutylxanthate	Sulfuric acid
Unspecified xanthates	Caustic soda (NaOH)
Alkyl dithiophosphate	Frothers
Unspecified dithiophosphate	Aliphatic alcohol
Xanthogen formate	Pine oil
Thionocarbamate	Phenol
Unspecified sulfide collector	Polyglycol ether
Fuel oil	Unspecified polyol
Kerosene	Flocculants
Depressants	Anionic polyacrylamide
Phosphorous pentasulfide	Nonionic polyacrylamide
Cyanide salt	Polyacrylate
Sulfide salt	Unspecified polymer
Sodium silicate	Dispersants
	Sodium silicate
	Polyphosphate

Copper concentrates exiting the flotation circuit contain 60 to 80 percent water. The concentrate is dewatered in a thickener, then sent to disc or drum filters for final dewatering. The dewatered copper mineral concentrate is then sent to a smelter for processing. The collected water is usually recycled to the milling circuit. A second product, waste material or tailings, is sent to a tailings pond for disposal (possibly after additional flotation steps to recover other metal values). The settling of solids in the thickeners is enhanced by chemical reagents known as flocculants and filter cake moisture is regulated by reagents known as filtering agents. Typical flocculants and filtering agents used are polymers, nonionic surfactants, polyacrylate, and anionic and nonionic polyacrylamides (ASARCO, 1991).

Leach Operations

Copper is increasingly recovered by solution, or hydrometallurgical, methods. These include dump, heap, and vat leaching techniques, as well as underground (or *in situ*) leaching methods. Each of these methods results in a pregnant leach solution (PLS). Copper is recovered from the PLS through cementation or, more commonly, by solvent extraction/electrowinning (SX/EW) (U.S. Congress, Office of Technology Assessment, 1988). Currently, solution copper mining techniques account for approximately 30 percent of domestic copper production. Two-thirds of all United States copper mines employ various types of solution operations (Weiss, 1985).

Most ores occur as mineral compounds that are insoluble in water; leaching involves chemical reactions that convert copper into a water-soluble form followed by dissolution. Acid leaching of ores and concentrates is the most common method of hydrometallurgical extraction. Its use is confined to acid-soluble, oxide-type ores that are not associated with acid-consuming rock types containing high concentrations of calcite (such as limestone and dolomite). Typical acidic leaching agents include hydrochloric acid (HCL), sulfuric acid (H_2SO_4), and iron sulfate ($Fe_2(SO_4)$). Sulfuric and hydrochloric acid leaching at atmospheric pressure is the most common type of copper leaching. For certain minerals, alkaline (or basic) leaching and microbial (or bacterial) leaching are effective means of extracting copper. The principal reagents used in alkaline leaching are the hydroxides and carbonates of sodium and ammonia. The organism associated with bacterial leaching is *Thiobacillus ferrooxidans*.

Leaching Methods (In Situ, Dump, Heap, and Vat)

Exhibit 3-11 summarizes the major copper leaching methods. Each of these methods is discussed in the following sections.

Exhibit 3-11. Characteristics of Copper Leaching Methods

	Vat Leaching	Heap Leaching	Dump Leaching	Underground and *In situ* Leaching
Ore grade	Moderate to high	Moderate to high	Low	Low to high (dependent upon mine conditions and layout)
Types of ore	Oxides, silicates, and some sulfides	Oxides, silicates, and some sulfides	Sulfides, silicates, and oxides	Oxides, silicates, and some sulfides
Ore preparation	May be crushed to optimize copper recovery	May be crushed to optimize copper recovery	Blasting	None
Container or pad	Large impervious vat	Impervious barrier of clay, synthetic material, or both	None for existing dumps; new dumps intended to be leached would be graded, and covered with an impermeable polyethylene membrane, or bedrock, protected by a layer of select fill	None
Solution	Sulfuric acid for oxides; acid cure and acid-ferric cure provide oxidant needed for mixed oxide/sulfide ores	Sulfuric acid for oxides; acid cure and acid-ferric cure provide oxidant needed for mixed oxide/sulfide ores	Acid ferric-sulfate solutions with good air circulation and bacterial activity for sulfides	Sulfuric acid, acid cure, acid-ferric cure, or acid ferric-sulfate, depending on the ore type
Length of leach cycle	Days to months	Days to months	Months to years	Months
Solution application method	Spraying, flooding, and circulation	Spraying or sprinkling	Ponding/flooding, spraying, sprinkling, and trickle systems	Injection holes, recovery holes, or sumps
Metal recovery method	SX/EW for oxides and mixed oxide/sulfide ores; iron precipitation for mixed ores	SX/EW for oxides and mixed oxide/sulfide ores; iron precipitation for mixed ores	SX/EW for oxides and mixed oxide/sulfide ores; iron precipitation for mixed ores	SX/EW for oxides and mixed oxide/sulfide ores; iron precipitation for mixed ores

Source: Office of Technology Assessment, 1988.

In Situ Leaching. The leaching of low-grade copper ore without its removal from the ground is known as *in situ* leaching. *In situ* leaching allows only limited control of the solution compared to other types of leaching (see below). There are 18 *in situ* copper operations in the United States that leach ore in existing underground mines.

In situ leaching extracts copper from subsurface ore deposits without excavation. Typically, the interstitial porosity and permeability of the rock are important factors in the circulation system. The solutions are injected in wells and recovered by a nearby pump/production-well system. In some cases (where the ore body's interstitial porosity is low), the ore may be prepared for leaching (i.e., broken up) by blasting or hydraulic fracturing. Production wells (and/or sumps in underground mines) capture and pump pregnant lixiviant solution from the formation to the leach plant where copper metal is recovered by an SX/EW operation (Biswas and Davenport, 1976; EPA, 1984a; EPA, 1989).

Dump Leach Operations. Dump leaching refers to leaching of low-grade sulfide or mixed-grade sulfide and oxide rock that takes place on (usually) an unlined surface. Copper dump leaches are typically massive, with rock piles ranging in size from 20 to hundreds of feet in height. These may cover hundreds of acres and contain millions of tons of waste rock and low-grade ore (Biswas and Davenport, 1976). These operations entail the addition of low pH solution to the piles to accelerate leaching, the collection of PLS, and the extraction of copper by SX/EW or cementation. Since widespread application of leaching process is a relatively new process, copper mines have frequently applied leaching techniques to recover values from historic waste rock dumps. Collection of PLS may not be maximized (i.e., some PLS may escape to the environment). The sites for these historic dump leaches were selected primarily to minimize haulage distances. New dump leach units are typically located and designed to prevent or minimize the loss of leach solution (EPA, 1989).

The materials placed in dump leaches vary considerably in particle size, from large angular blocks of hard rock to highly weathered fine-grained soils. The material is typically less than 0.6 meter in diameter. In most dump leach operations, the material is hauled to the top of the dump by trucks. The material is deposited by end-dumping in lifts on top of materials that have already been leached. Large dumps are usually raised in lifts of 15 to 30 meters. After the lift is completed, the top layer is scarified (by a bulldozer and a ripper) to facilitate infiltration of the leach solution (EPA, 1989e).

Natural precipitation, mine water, raffinate (from the SX/EW plant), makeup water, and/or dilute sulfuric acid may be used as leach solution (i.e., lixiviant). As the lixiviant infiltrates the pile, copper minerals are leached by oxidizing the pyrite to form sulfuric acid and ferrous iron solution (the sulfuric acid solution reacts with the ore minerals to ionize the copper into solution). Several methods are used to distribute leach solutions over the dumps, including natural precipitation, sprinkler systems that spray the leach solution over the piles, flooding of infiltration ditches or construction of

leach solution ponds on top of dumps, distribution of leach solutions through perforated pipes on top of dumps (known as trickle systems), and the injection of leach solutions through drill holes into dumps. The leach solution percolates through the dump and PLS is collected in ditches or sumps at the toe of the dump where the slope of the native terrain provides the means for collection of pregnant liquor. These ditches and sumps are lined at some sites, and are unlined at others. PLS is then treated by solvent extraction or cementation. Metals associated with the copper minerals that are also found in PLS include arsenic, cadmium, chromium, and selenium (EPA, 1985; EPA, 1984a).

Heap Leaching. In contrast to dump leaching (described above), heap leaching refers to the leaching of low-grade ore that has been deposited on a specially prepared, lined pad constructed using synthetic material, asphalt, or compacted clay. In heap leaching, the ore is frequently beneficiated by some type of size reduction (usually crushing) prior to placement on the pad (EPA, 1989).

Heap leach pads are constructed above one or more layers of impermeable liner material. Liners can be constructed using synthetic membranes [such as High-Density Polyethylene (HDPE)] and/or natural material (such as compacted native soils or clays or unfractured/unfaulted bedrock). Most leach sites are selected to take advantage of existing, less permeable surfaces and to utilize the natural slope of ridges and valleys for the collection of PLS. Land with this type of geology and terrain, however, is not always within a reasonable hauling distance of the mining operation.

The same basic principles and procedures discussed above with regard to dump leaching operations apply to heap leach operations. Heap leach operations, as opposed to dump leach operations, have the following characteristics: (1) higher lixiviant concentrations generally are used; (2) leach piles may be neutralized after leaching operations are completed; (3) the leach pad design is substantially different (i.e., the size is smaller, averaging between 100,000 and 500,000 metric tons of ore); (4) the ore is finer grained (i.e., usually less than 10 cm); (5) the leaching is considerably faster; and (6) the extraction of oxide copper is greater (EPA, 1989e).

Vat Leaching. The vat leaching process works on the same principles as the dump and heap leaching operations described above, except that it is a high-production-rate method conducted in a system of vats or tanks using concentrated lixiviant solutions. Vat leaching is typically used to extract copper from oxide ores by exposing crushed ore to concentrated sulfuric acid (lixiviant) in a series of large tanks or vats. The vats are usually designed in a series configuration, which acts to concentrate the copper content of the solutions as a function of ore-lixiviant contact time (EPA, 1989e). A typical 25-meter-long, 15-meter-wide, and 6-meter-deep vat unit is capable of leaching between 3,000 and 5,000 tons of ore per cycle.

Vat and agitation (tank) leaching are usually performed on relatively higher grade oxidized ores. Tank methods tend to recover copper more rapidly using shorter leach cycle times than heap or dump

leaching operations. Generally, copper recovery is higher, and solution losses are lower with tank methods (EPA, 1984). The advantages of this method are high copper extraction rates and recoveries, short leach cycles, and negligible solution losses (EPA, 1989e). The disadvantages are the low tonnages beneficiated, high suspended solids concentrations in PLS that a cause problems in a SX/EW plant, and high operating costs.

Copper Recovery from Leach Solutions—Cementation and SX/EW

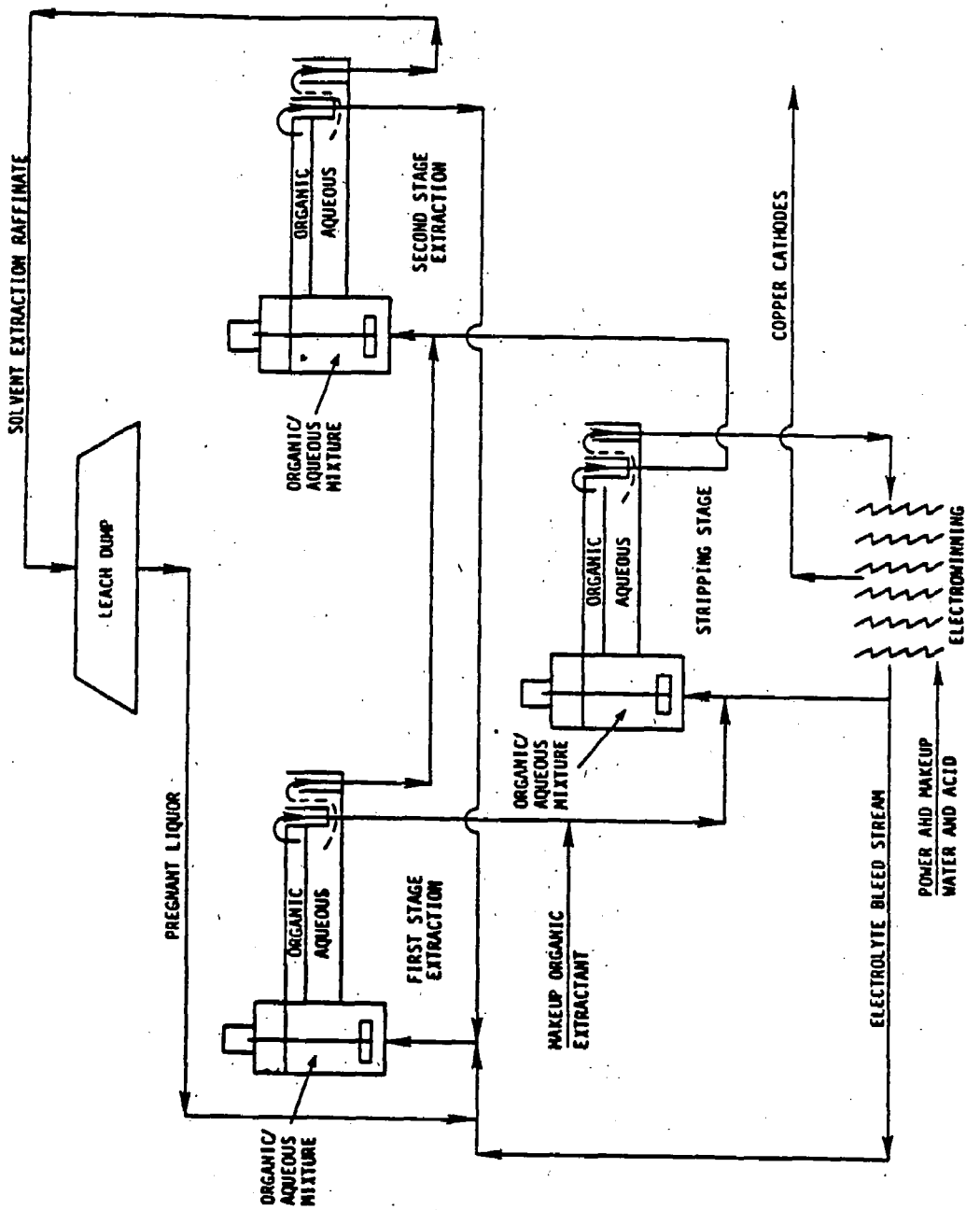
Cementation. In the past, copper produced from leach solutions was typically recovered by cementation techniques. In the cementation process, pregnant leach solution (PLS) flows to a precipitator pond filled with scrap iron or steel. The copper chemically reacts with, and precipitates onto the steel surfaces. The iron is dissolved into solution, and the copper precipitates out (i.e., replaces) the iron. The cemented copper later detaches from the steel surfaces as flakes or powder when it is washed with high-pressure streams of water. Although subsequent treatment by a normal smelting/refining method is required, copper recovery from the pregnant solution is very high.

While cementation has been a source of relatively inexpensive copper, the cement copper produced is relatively impure compared to electrowon copper and must be smelted and refined along with flotation concentrates (Beard, 1990). As a result, it has largely been replaced by SX/EW technology. However, several compact and dynamic cementation systems have been developed and are used industrially. The most successful is the Kennecott Cone System Precipitator, by which the PLS is forced upwards in a swirling motion through shredded steel scrap. In this system, fine, undissolved solid particles (called pulp) are concentrated with the copper cemented particles. Consequently, the cement concentrates containing the pulp must be further beneficiated by flotation. The cemented copper is easily floated with xanthate or dixanthogen collectors (Biswas and Davenport, 1976).

Solvent Extraction. The first SX/EW plant was developed during the 1960s at the Bluebird property near Miami, Arizona. Historically, solvent extraction was largely confined to copper oxides. However, recent refinements in leaching methods have made it economical for recovery from low grade sulfide ores. The major advantage of solvent extraction (over cementation) is that the electrolyte solution it produces is almost free of impurities.

Exhibit 3-12 provides a flow diagram for a typical SX/EW plant. The solvent extraction operation is a two-stage method. In the first stage, low-grade, impure leach solutions containing copper, iron, and other base-metal ions are fed to the extraction stage mixer-settler. In the mixer, the aqueous solution is contacted with an active organic extractant (chelating agent) in an organic diluent (usually kerosene), forming a copper-organic complex. The organic phase extractant is formulated to extract only the desired metal ion (i.e., copper), while impurities such as iron or molybdenum are left behind in the aqueous phase. The barren aqueous solution, called raffinate, is typically recirculated back to the leaching units. The loaded organic solution is transferred from the extraction section to the

Exhibit 3-12. Typical Solvent Extraction/Electrowinning (SX/EW) Plant



stripping section. The aqueous-organic dispersion is physically separated in a settler stage (Office of Technology Assessment, 1988; EPA, 1984; Engineering and Mining Journal, 1990).

In the second stage, the loaded organic solution is stripped with concentrated sulfuric acid solution (spent tankhouse electrolyte) to produce a clean, high-grade solution of copper for electrowinning. The stripping section can have one or more mixer-settler stages. The loaded-organic phase is mixed with the highly acidic electrolyte, which strips the copper ions from the organic phase. Then, the mixture is allowed to separate in settling tanks, where the barren organic solution can be recycled to the extraction stage. The copper-enriched, strong electrolyte flows from the stripping stages to the strong-electrolyte tanks, where it is pumped to the electrolyte filters for removal of the entrained organics or solids. The clarified, strong electrolyte flows to electrolyte circulation tanks, where it becomes the influent to the electrowinning tankhouse (Office of Technology Assessment, 1988; EPA, 1984a; Engineering and Mining Journal, 1990).

Electrowinning. Electrowinning is the method used to recover copper from the electrolyte solution produced by solvent extraction. To stabilize the tankhouse operating temperature and preheat the incoming electrolyte solution, strong electrolyte (after filtration) is passed through heat exchangers where heat is extracted from outgoing, warmer, spent electrolyte. After passing through starting-sheet cells, the strong electrolyte is received in a circulation tank. In the circulation tank, the strong electrolyte is mixed with spent electrolyte returning from the electrowinning cells. The feed electrolyte is then pumped to the electrolytic cells continuously. The electrochemical reaction at the lead-based anodes produces oxygen gas and sulfuric acid by electrolysis. Copper is plated on cathodes of stainless steel or on thin-copper starting sheets. The cathode copper is then shipped to a rod mill for fabrication. The spent acid is recycled and pumped back to the leaching operation, while some of the electrolyte is pumped to the solvent extraction strip-mixer-settlers via the electrolyte heat exchangers (Office of Technology Assessment, 1988; Engineering and Mining Journal, 1990).

Over time, electrolyte in the electrowinning cells becomes laden with soluble impurities and copper. When this occurs, the solution is removed and replaced with pure electrolyte (to maintain the efficiency of the solution and prevent coprecipitation of the impurities at the cathode). Purification is done by electrowinning in liberator cells. Liberator cells are similar to normal electrolytic cells, but they have lead anodes in place of copper anodes. The electrolyte is cascaded through the liberator cells, and an electric current is applied. Copper in the solution is deposited on copper starting sheets. As the copper in the solution is depleted, the quality of the copper deposit is degraded. Liberator cathodes containing impurities (such as antimony) are often sent to the smelter to be melted and cast into anodes. Purified electrolyte is recycled to the electrolytic cells.

3.3.4.4 Wastes and Waste Management

Wastes generated by copper mining and beneficiation operations include materials such as waste rock, mine water, spent ore, tailings, SX/EW sludges, and spent leaching solution. Many of these materials may be disposed of onsite or offsite, and others may be re-used or recycled during the active life of a mine. Waste constituents may include heavy metals, sulfides, or other elements found in the ore, acid mine drainage (AMD), and any additives used in beneficiation operations. (It should be noted that the use of the terms "mining waste" and "waste management unit" in this document does not imply that the materials in questions are "solid wastes" within the meaning of the Resource Conservation and Recovery Act. As indicated previously, the term "wastes" includes both RCRA wastes as well as other materials.)

Mine Water

Mine water consists of all water that collects in surface and underground mine workings as a result of inflow from surface water, precipitation, and groundwater. During the life of the mine, water is pumped out to keep the mine relatively dry and to allow access to the ore body. At surface copper mines, mine water may be pumped or allowed to drain to centralized sumps. At underground mines, the quantity of water entering the mine depends on local hydrogeologic conditions. At some facilities, little or no water is encountered. At others, groundwater may continually drain into the mine workings. Underground water inflows are often allowed to drain to low areas of the mine where sumps and pumps collect and pump the water from the mine. At some facilities, however, the inflow of water is so great that the capacities of the underground holding and pump mechanisms are exceeded, which can lead to mine flooding (Cumming, 1973). In these cases, wells near the mine may be used to pump groundwater, leading to a cone of depression around the mine and reducing inflow.

The quantity of mine water generated at mines varies from site to site. The chemistry of mine water is dependent on the geochemistry of the ore body and the surrounding area. Water exposed to sulfur-bearing minerals in an oxidizing environment, such as an open pit or underground workings, may become acidified. This potential is greatly dependent on site-specific factors (see Section 4.1).

Pumped water from copper mines may be used in extraction and beneficiation activities (including dust control), pumped to tailings ponds, or discharged. Because mine water at copper mines is often rich in dissolved copper and other metal ions, some operations pump it to an SX/EW plant to recover the copper values (Cumming, 1973).

Waste Rock

Waste rock is typically hauled from the mine to onsite waste dumps for disposal. At some surface mines, these dumps are located within the pits. Waste rock piles may be highly permeable to both air

and water. Sulfur-bearing minerals in waste rock, such as pyrite and pyrrhotite, can oxidize to form sulfuric acid. Factors that influence acid generation by sulfide wastes include: (1) the amount and frequency of precipitation, (2) the design of the disposal unit, and (3) the neutralization potential of the rock. Even where acid-generating conditions are not present, metals found in the waste rock may dissolve in infiltration runoff or runon. This low pH solution can dissolve and mobilize metals in the rock matrix and be transported to ground or surface water. Waste rock disposal units are generally constructed without liners. Because even waste rock would contain low concentrations of copper, some operations refer to waste rock as "low-grade ore" or "subore."

Spent Ore

Spent ore from heap and dump leaching contains residual amounts of lixiviant and associated copper and other metal complexes. The spent ore itself typically contains unleached metals and other minerals characteristic of the ore body. Dump leach piles are reported to range in size from 20 feet to hundreds of feet in height and may cover hundreds of acres and contain millions of tons of waste rock and low-grade ore. Most copper leaching operations are not constructed with synthetic liners (i.e., they are dump leach units, rather than heap leach units). However, newer units are frequently sited where natural low permeability features allow for drainage to a centralized collection point (to facilitate recovery of pregnant leach solution). After collection of leaching solution no longer becomes economically viable, operators must address reclamation/closure of the leach units and management of drainage.

Tailings

In 1985, 195 million tons of copper and copper-molybdenum ores were treated by flotation concentration, resulting in the production of 5.8 million tons of concentrate using 97 million gallons of water and 0.32 million tons of reagents. More than 97 percent (189 million tons) of ore tonnage processed in 1985 was typically disposed of as tailings (Bureau of Mines, 1987).

Tailings impoundments are surface disposal units for tailings generated during flotation. Slurried tailings are transported from the mill to the tailings pond by gravity flow and/or pumping through open conduits or pipes. In the arid southwest, where the majority of copper mines are located and evaporation rates exceed precipitation, the mine-mill water balance usually requires recycling tailings pond water for reuse in the mill. At copper mines in the central United States (such as the White Pine in Michigan) the reverse situation exists; precipitation exceeds evaporation rates and tailings pond water is typically discharged to surface water. Tailings impoundments may also be used to disposed of other smaller-volume wastes generated at copper mines including, spent electrolyte solution, SX/EW tank sludge, etc.

Upstream tailings impoundments are most commonly used in the copper mining industry. In this method (as described in Section 3.2), the embankment is erected by depositing successive layers of course material on top of the previous dike along the inside of its embankments. Thus, the centerline of the berm progresses upstream toward the center of the dam, while the outer slope remains stable (Bureau of Mines, 1984).

Solution Ponds (PLS and Raffinate Ponds)

Leaching operation ponds can be a source of acid/metal releases by ground and surface water. These include: pregnant solution ponds or tanks (where the copper-laden solution is collected), barren solution ponds (where lixiviant solution is held before being applied), surge ponds (to manage leachate during high precipitation events), make-up water holding ponds, and associated pipes or trenches. These units may be lined, depending on the quality of the solution to be contained, applicable regulatory requirements, the age of the unit, and permeability of the underlying formation.

PLS and raffinate ponds generally measure several hectares in size and, where the topography permits, are built into natural drainage basins. At most older copper leaching operations, the collection ponds and trenches through which the solutions flow are unlined. In addition, these areas received little or no surface preparation before leaching operations were initiated (EPA, 1989). At newer leaching operations, liners have been installed in the collection ponds to increase solution recovery and minimize environmental releases. Generally, the trenches have been lined with concrete, gunite, clay, or synthetics such as polyethylene (EPA, 1989).

3.3.5 IRON

The total quantity of usable iron ore product shipped from mines in 1991 was estimated to be 52.8 million long tons (lt),[1] valued at $1.7 billion. Of the total 1991 domestic production, 1.97 million lt of iron product (4 percent) were exported. The United States also imported 12.9 million lt of usable iron ore in 1991 for beneficiation and processing. According to the Bureau of Mines, "usable" iron ore implies that less than 5 percent of the material is made up of manganese (Bureau of Mines, 1991a).

In 1991, there were 20 companies operating 22 iron ore mines (21 open pit; 1 underground operation), 16 concentration plants, and 10 pelletizing plants. The primary iron ore producers are located in Minnesota and Michigan, which account for about 99 percent of all domestic crude iron ore. In 1991, 7 mines operated by 4 companies produced approximately 87 percent of the industry's total output (Bureau of Mines, 1992). The trend in the industry is toward larger mines and larger

[1]Industry tends to measure iron ore production in long tons (lt), while the Bureau of Mines used short tons (st) before 1989 and now uses metric tons (mt). Production data are presented here in long tons (1 long ton is equivalent to 2,240 lbs).

capacity mills. Operation capacities tend to be in the range of 1 to 10 million long tons of product per year (ltpy). A few mines, however, produce less than 100,000 ltpy (Weiss, 1985).

Nearly 98 percent of the demand for iron ore comes from the steel manufacturing industry. Iron is also a component in the manufacture of cement and heavy-media materials. Among the 22 mines producing iron ore, most larger operations produce material for the steel manufacturers. Mines producing for cement plants tend to be smaller operations located outside Michigan and Minnesota (Bureau of Mines, 1988b, 1991a, and 1992).

3.3.5.1 Geology of Iron Ores

Iron is an abundant element in the earth's crust averaging from 2 to 3 percent in sedimentary rocks to 8.5 percent in basalt and gabbro. Because iron is present in many areas, it is of relatively low value and thus a deposit must have a high percentage of metal to be considered ore grade. Typically, a deposit must contain at least 25 percent iron to be considered economically recoverable. This percentage can be lower, however, if the ore exists in a large deposit and can be concentrated and transported inexpensively (Weiss, 1985). Over 300 minerals contain iron but five are the primary sources of iron-ore minerals: magnetite (Fe_3O_4), hematite (Fe_2O_3), goethite ($Fe_2O_3H_2O$), siderite ($FeCO_3$), and pyrite (FeS_2). The first three are of major importance because of their occurrence in large economically minable deposits (U.S. Geological Survey, 1973).

Iron ore mineral deposits are widely dispersed in the continental United States and form in a wide variety of geologic environments, including sedimentary, metamorphic, and igneous rock formations. Iron ore deposits in the United States are formed by three geologic processes:

- Direct sedimentation forming bedded sedimentary deposits
- Igneous activity forming segregation or replacement deposits
- Enrichment due to surface and near surface weathering (EPA, 1985).

Historically, most iron ore was simply crushed and shipped directly to a blast furnace. Currently, some ores are high enough in iron content (greater than 50 percent) to be sent directly to furnaces without beneficiation activities other than crushing and washing. Most ores extracted today, however, must undergo a number of beneficiation procedures to upgrade the iron content and prepare the concentrate for the blast furnace. Technological advancements at blast furnace operations require ore feed of a specific size, structure, and chemical make-up for optimum efficiency (Weiss, 1985).

3.3.5.2 Mining

Iron ore is mined almost exclusively in surface operations. The most predominant surface mining methods used to extract iron ore are conventional open-pit and open-cut methods. However, there is

currently one operating underground iron mine, located in Missouri (five were in operation in Missouri in 1985). The mining of taconite, a tough and abrasive low-grade ore (ranging from 40 to 60 percent silica and 17 to 30 percent iron) common to Minnesota and Michigan, is especially difficult because of the extreme hardness of the ore but now dominates U.S. iron production.

In the iron industry, stripping ratios (overburden/ore) may be as high as 7:1 (for high-grade wash ores) or as low as 0.5:1 (for low-grade taconite ores) (United States Steel, 1973). Wastes generated as a result of open-pit and underground iron mining include overburden, waste rock, and mine water containing suspended solids and dissolved materials.

3.3.5.3 Beneficiation

Beneficiation at iron mines can include the following: milling (crushing and grinding); washing; filtration; sorting; sizing; gravity concentration; magnetic separation; flotation; and agglomeration (pelletizing, sintering, briquetting, or nodulizing). The American Iron Ore Association indicates that milling and magnetic separation are the most common methods used. Gravity concentration is seldom used at existing U.S. facilities. Flotation is primarily used to upgrade concentrates from magnetic separation by reducing the silica content of the concentrate (Ryan, 1991). Most beneficiation operations will result in the production of three materials: concentrate; middling or very low-grade concentrate, which is either reprocessed (in modern plants) or stockpiled; and tailings.

Milling

Milling operations are designed to produce uniform size particles by crushing, grinding, and wet or dry classification. Primary crushing is accomplished by using gyratory and cone crushers (Weiss, 1985). Primary crushing yields chunks of ore ranging in size from 6 to 10 inches. Secondary milling (comminution) further reduces particle size, to usually less than 1 inch (1/2 to 3/4 inches). Secondary crushing, if necessary and economical, is accomplished by using standard cone crushers followed by short head cone crushers. Gyratory crushers may also be used.

Subsequent fine grinding further reduces the ore particles to the consistency of fine powder (325 mesh, 0.0017 inches, 0.44 microns). Although most taconite operations employ rod and/or mill grinding, a few facilities use autogenous or semi-autogenous grinding systems. Autogenous grinding uses coarse pieces of the ore itself as the grinding media in the mill. Semi-autogenous operations use metallic balls and/or rods to supplement the grinding action of the ore pieces (Weiss, 1985). Between each grinding unit, hydrocyclones are used to classify coarse and fine particles. Coarse particles are returned to the mill for further size reduction.

Magnetic Separation

Magnetic separation is most commonly used to separate natural magnetic iron ore (magnetite) from a variety of less-magnetic or nonmagnetic material. Today, magnetic separation techniques are used to beneficiate over 90 percent of all domestic iron ore (Ryan, 1991). Magnetic separation may be conducted in either a dry or wet environment, although wet systems are more common. Magnetic separation operations can also be categorized as either low or high intensity. Low intensity wet processes typically involve conveyors and rotary drum separators using permanent magnets and are primarily used on ore particles 3/8 inch in diameter or less. Low intensity separators use magnetic fields between 1,000 and 3,000 gauss. High intensity wet separators produce high magnetic field gradients by using a matrix of shaped iron pieces that act as collection sites for paramagnetic particles. High intensity separators employ fields as strong as 20,000 gauss. (Weiss, 1985; United States Steel, 1973). Primary wastes from magnetic separation include: tailings made up of gangue in the form of coarse- and fine-grained particles, and wastewater slurry in the case of wet separation. Particulate wastes from dry separation may also be slurried.

Flotation

Conventional flotation is primarily used to upgrade concentrates resulting from magnetic separation. Over 50 percent of all domestic iron ore is upgraded using this technique. Flotation, when used alone as a beneficiation method, accounts for approximately 6 percent of all ore treated (Ryan, 1991).

Typically, 10 to 14 flotation cells are arranged in a series from roughers to scavengers. Roughers are used to make a coarse separation of iron-bearing metallic minerals (values) from the gangue. Scavengers recover smaller quantities of remaining values from the pulp. The pulp moves from the rougher cells to the scavengers as values are removed. Concentrates recovered from the froth in the roughing and scavenging cells are sent to cleaning cells to produce the final iron-bearing metallic mineral concentrate (Fuerstenau, 1970). Flotation reagents of three main groups may be used: collectors/amines, frothers, and antifoams.

Iron-bearing metallic mineral flotation operations are of two main types: anionic and cationic (although anionic flotation is not commonly used in North American operations). The difference between the two methods is related to which material (values or gangue) is floated and which sinks. In anionic flotation, fine-sized crystalline iron oxides, such as hematite or siderite, are floated away from siliceous gangue material such as quartz or chert. In cationic flotation, the silica material is floated and the value-bearing minerals are removed as underflow (Nummela and Iwasaki, 1986).

Wastes from the flotation cell are collected from the tailings overflow weir. Depending on the grade of the froth, it is recycled for further recovery of iron units or discharged as tails. Tailings contain remaining gangue, unrecovered iron minerals, chemical reagents, and process waste water.

Generally, tailings proceed to a thickener. Thickened tailings may be pumped to an impoundment or may be recycled for further beneficiation to collect remaining values. Clarified water is often reused in the milling process.

Gravity Concentration

Although gravity concentration was once widely used in the beneficiation of iron ores, today less than one percent of total domestic iron ore is beneficiated using this method. Gravity concentration is used to suspend and transport lighter gangue (nonmetallic or nonvaluable rock) away from the heavier valuable mineral. Three gravity separation methods have historically been used for iron ore: washers, jigs, and heavy-media separators (Weiss, 1985). Wastes from gravity concentration are tailings made up of gangue in the form of coarse- and fine-grained particles and process water. This material is pumped as a slurry to a tailings pond.

Agglomeration

After concentration activities, agglomeration is used to combine the resulting fine concentrates into durable clusters. The iron concentrate is balled in drums and heated to create a hardened agglomerate. Agglomerates may be in the form of pellets, sinter, briquettes, or nodules. The purpose of agglomerating iron ore is to improve the permeability of blast furnace feed leading to faster gas-solid contact in the furnace (Weiss, 1985). Pellets currently account for more than 97 percent of all agglomeration products (therefore, only the pelletizing technique is discussed below, although the other agglomerates are produced by similar high-temperature operations).

Pelletizing operations produce a "green" (moist and unfired) pellet or ball, which is then hardened through heat treatment (Weiss, 1985). The first step in pelletizing iron concentrates is forming the pellets. This is usually accomplished in a series of balling drums or discs. Additives such as limestone or dolomite may also be added to the concentrate in a process known as "fluxing," prior to balling to improve blast furnace recovery. One of three different systems can then be used to produce hardened pellets:

- **Travelling-Grate.** Used to produce pellets from magnetite concentrates obtained from taconite ores. Green pellets are fed to a travelling grate, dried, and preheated. The pellets then proceed to the ignition section of the grate where nearly all the magnetite is oxidized to hematite. An updraft of air is then used to cool the pellets.

- **Shaft-Furnace.** Green pellets are distributed across the top of a furnace by a moving conveyor belt and pass vertically down the length of the furnace. In the furnace, the pellets are dried and heated to 2400°F. The bottom 2/3 of the furnace is used to cool the pellets using an upward-rising air stream. The pellets are discharged from the bottom of the system through a chunkbreaker.

- **Grate-Kiln.** Combines the grate technique with a rotary kiln. No fuel material is incorporated into or applied to the pellets in this process. The pellets are dried and preheated on a travelling grate before being hardened by high-temperature heating in the kiln. The heated gas discharge from the kiln is recycled for drying and preheating (United States Steel, 1973).

Agglomeration generates byproducts in the form of particulates and gases, including compounds such as carbon dioxide, sulfur compounds, chlorides, and fluorides that are driven off during the production process. These wastes are usually treated using cyclones, electrostatic precipitators (wet and dry), and/or scrubbing equipment. These treatment technologies generate either a wet or a dry effluent, which contains valuable iron units and is commonly recycled back into the operation.

3.3.5.4 Wastes and Waste Management

Overburden, Mine Development Rock, and Ore Piles

Overburden and mine development rock removed from iron mines are stored or disposed of in unlined piles onsite. These piles may also be referred to as "mine rock dumps" or "mine dumps." As appropriate, topsoil may be segregated from overburden and mine development rock, and stored for later use in reclamation and revegetation. These dumps are generally unsaturated and provide a prime environment for acid generation if sulfide minerals are present. However, in Minnesota and Michigan, where most crude iron ore is produced, sulfide-bearing minerals are present in only one unique geologic environment (Guilbert, 1986). As a result, acid generation has only been observed at one site, LTV's Dunka site at the eastern edge of the Mesabi Range (see below).

Mine Pits and Underground Workings

In addition to wastes generated during active operations, pits and underground workings may be allowed to fill with water when the mine closes or stops operation, since the need for dewatering is over. At one site in Minnesota, the Dunka Mine, accumulated water, or mine drainage, has acidified through contact with sulfide minerals in an oxidizing environment and become contaminated with heavy metals, as well as suspended solids. However, the conditions at the Dunka site (as well as two other abandoned iron mines with similar acid rock drainage) are generally considered unique in the iron industry (because of localized sources of sulfide ore). Overall, mine water associated with iron operations is characterized by low pollutant levels. In fact, the mine water from at least one mine in Michigan is used to supplement the local drinking water supply.

At abandoned underground mines, deficiencies in mine shaft protection and mine subsidence may be a problem. Although there is only one underground iron mine currently operating in the United States, abandoned underground iron mines have contributed to the creation of subsidence features. In West Iron County, Michigan, subsidence features caused by abandoned iron mines have grown into large

pits and caused interruptions in utility service, damage to roadways, and loss of life (Michigan State, Geological Survey Division, 1983).

Tailings Impoundments

Impoundments, rather than piles, are used exclusively for tailings management in the iron ore industry. As a typical example, the tailings impoundment at LTV Steel Mining Company's facility at Hoyt Lakes is approximately 3,000 acres and contains about 500 million tons of tailings (LTV Steel Mining Company, 1991). Two general classes of impounding structures may be used to construct tailings pond at iron mines: water-retention dams and raised embankments. As solids settle out in either of these type of impoundments, water is either recycled to the mill or discharged.

Trace amounts of several toxic metals are found in raw mill tailings effluents. These metals include antimony, arsenic, beryllium, cadmium, chromium, copper, lead, nickel, selenium, silver, and zinc. In some instances (Silver Bay, Minnesota and Groveland Mine, Michigan), amphibole minerals with fibrous characteristics may be a constituent in the tailings. While amphibole minerals (cummington-grunerite) are present in some Eastern Mesabi Range taconite formations, asbestos has not been identified as such (EPA, 1976). Most of these contaminants are effectively removed or reduced by settling in tailings impoundments.

3.3.6 URANIUM

Uranium is extracted using surface, underground and solution mining (*in situ*) techniques. Although the industry is relatively young, developing in the 1940s, the volume of ore recovered by U.S. mines has dropped significantly since peaking in the early 1980s. Low commodity prices, a reduced demand from the military and commercial power generators, and abundant foreign supplies are responsible for the depressed market.

3.3.6.1 Geology of Uranium Ores

Elemental uranium is generally found in naturally occurring minerals in one of two ionic states: U^{6+} (the uranyl "oxidized" ion) and U^{4+} (the uranous "reduced" ion). Common uranyl minerals include tyuyamunite ($Ca(UO_2)_2V_2O_8 \cdot 8H_2O$), autunite ($Ca(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$), torbernite ($Cu(UO_2)_2(PO_4)_2 \cdot 8\text{-}12H_2O$) and uranophane ($(H_3O)_2Ca(UO_2)_2(SiO_4)_2 \cdot 3H_2O$) (Smith, 1984; Hutchinson and Blackwell, 1984). Common uranous minerals include uraninite (UO_2), pitchblende (a crystalline variant of uraninite) and coffinite ($USiO_4$) (Smith, 1984; Hutchinson and Blackwell, 1984). Uranium occurs in the minerals as one of three isotopes: U-234, U-235 and the most abundant of the isotopes, U-238 (Tatsch, 1976). In the uranium market, references to ore, intermediate, and some final products, are in terms of percent of uranium oxide or uranium oxide equivalent. Uranium oxide is a generic term for a number of common chemical forms of uranium, the most common being U_3O_8. Yellowcake is another generic term, used to describe the yellow powder generated as the end product

of uranium beneficiation. The purity of yellowcake typically ranges from 60 to 75 percent U_3O_8 (Merritt, 1971).

3.3.6.2 Mining

Economically recoverable uranium deposits in the United States historically fit into one of four types of deposits: stratabound, solution breccia pipes, vein, and phosphatic. The most economically important deposits occur within stratabound deposits within the Wyoming Basin, south Texas, and the Colorado Plateau. Stratabound deposits have been mined using surface and underground techniques and are currently the target of solution mining operations. Grades of ore mined from these deposits range from 0.15 to 0.30 percent U_3O_8. Solution breccia pipe uranium deposits are located in the Northern Arizona Strip and average approximately 0.64 percent U-238; these deposits have been mined using surface and underground methods (Pillmore, 1992). Vein deposits have been mined on an infrequent basis using underground methods in Colorado and Utah. Phosphatic deposits are associated with phosphate ores in Florida; uranium has been recovered to a limited extent as a byproduct of phosphoric acid production from these ores.

Proprietary information surrounding the small number of mines currently producing uranium limits the level of detail available about the nature and size of recent operations. The primary extraction (and beneficiation) method used to recover uranium from ore deposits is *in situ* leaching. According to the U.S. Energy Information Administration, *in situ* mining operations generated two-thirds of the uranium produced in the United States in 1991. The remaining 33 percent of the uranium produced in 1991 was by conventional milling operations (DOE/EIA, 1992). Prior to the drop in uranium prices, ore was more commonly beneficiated using conventional milling techniques.

3.3.6.3 Beneficiation

In conventional uranium milling, the initial step involves crushing, grinding, and wet and/or dry classification of the ore to produce uniformly sized particles. Ore initially feeds into a series of crushers where it is reduced to fragments less than 19mm (3/4 inch). Ore from the crushers feeds into the grinding circuit where ball and/or rod mills, and/or autogenous or semiautogenous grinding, continue to reduce the size of the ore. Water or leach liquor is added to the system in the grinding circuit to facilitate the movement of the solids, for dust control, and (if leach liquor is added) to initiate leaching (DOI, 1980).

Classifiers, thickeners, cyclones, or screens are used to size the finely ground ore, returning coarse materials for additional grinding. The slurry generated in the grinding circuit contains 50 to 65 percent solids. Fugitive dust generated during crushing and grinding is usually controlled by water sprays or, if collected by air pollution control devices, recirculated into the beneficiation circuit. Water is typically recirculated through the milling circuit to reduce consumption (EPA, 1983a).

After grinding, the slurry is pumped to a series of tanks for leaching. Two types of leaching have been employed by uranium mills, acid and alkaline. Acid leaching has been the predominant leaching process employed by conventional mills, although some mills have used an alkaline system and some have included both (Merritt, 1971). In the discussions that follow, an overview of leaching is provided followed by a more detailed description of both acid and alkaline leaches.

The first step in any uranium leaching operation is oxidation of the uranium constituents. Uranium is found as uranium dioxide (UO_2, U^{+4} oxidation state) in many deposits (pitchblende and uraninite). Uranium dioxide is insoluble; to create a soluble form, UO_2 is oxidized from the U^{+4} to the U^{+6} oxidation state. Iron present within the ore, and oxygen, are used to perform oxidation via the following reactions (Twidwell et al., 1983):

(1) alkaline $UO_2 + \frac{1}{2}O_2 \rightleftarrows UO_3$
(2) acid $UO_2 + 2Fe^{+3} \rightleftarrows UO_2^{+2} + 2Fe^{+2}$

Iron can be readily reoxidized by the addition of O_2, sodium chlorate ($NaClO_3$), or manganese oxide (MnO_2) to the lixiviant.

The second step in leaching is the stabilization of the uraniferous ions in solution. The uraniferous ions form stable, soluble complexes with sulfate (SO_4^{-2}) or carbonate (CO_3^{-2}). Sulfuric acid is added as the source for sulfate ions; sodium bicarbonate, sodium carbonate, or carbon dioxide are added to alkaline leach circuits to provide a carbonate source. Uraniferous complexes are formed through the following reactions (Twidwell et al., 1983):

(1) alkaline $UO_3 + CO_3^{-2} + 2HCO_3^- \rightleftarrows UO_2(CO_3)_3^{-4} + H_2O$
(2) acid $UO_2^{+2} + 6SO_4^{-2} \rightleftarrows UO_2(SO_4)_6^{-4}$.

In a typical acid leaching operation, sulfuric acid is added to the crushed ore slurry to maintain the pH between 0.5 and 2.0. Twenty to 60 kilograms of sulfuric acid per metric ton of ore are normally required to reach the target pH. $NaClO_3$ or MnO_2 is added to maintain the oxidation by iron. Because iron is normally found in uranium deposits, the ore body itself supplies the iron in the leach step (Twidwell et al., 1983; EPA, 1983a).

Alkaline leaching is not as effective as acid leaching for uranium recovery and is not used except in cases of high lime-content ores. Typically, ore bodies containing greater than 12 percent carbonates will be alkaline leached. Alkaline leaching is primarily employed in *in situ* mining operations, although a few conventional mills have maintained alkaline leach circuits (Merritt, 1971). Alkaline leaching requires the use of a strong oxidant and long retention times to oxidize the uraniferous minerals (Twidwell et al., 1983). As stated previously, oxygen and a carbonate source are added to

water to make up the lixiviant. The carbonate (CO_3^{-2}) and bicarbonate (HCO_3^-) concentrations are typically 40-50 g/L and 10-20 g/L respectively (Merritt, 1971). For its leaching process, the Highland *in situ* project injects O_2(g) and CO_2(g) into the lixiviant prior to underground injection. The dissolution of CO_2 in the lixiviant produces both CO_3^{-2} and HCO_3^- ions (Hunter, 1991).

Leaching may be performed in tanks, heaps or *in situ*. *In situ* leaching is practiced on low-grade ores; after crushing and grinding, higher grade ores are typically leached in tanks at conventional mills. Low-grade ores may also be amenable to heap leaching; however, the available literature indicates that the application of this technique to uranium ores has been and is limited and consequently it is not be discussed in detail. Leach times vary depending on the grade of the ore, grain size (amount of grinding), and the method used. Leaching in tanks may take from four to 24 hours while heap leaching may be measured in days or weeks (Twidwell et al., 1983).

Once the uraniferous compounds have been leached from the ore, the pregnant leach solution is separated from the solids using classifiers, hydrocyclones, and thickeners. Sand-sized particles are removed first and washed with clean water or barren lixiviant/raffinate . Continued treatment removes the slimes, which are also washed. Depending on the settling time allowed by beneficiation operations, flocculants may be added to the process to encourage settling of suspended solids. After final washing, the solids (sands and slimes) are pumped as a slurry to a tailings pond for further settling. The pregnant leach solution then enters a solvent extraction or ion exchange circuit. Wash solution is recycled to reduce consumption of leach chemicals, solute, and water (DOI, 1980; EPA, 1983a).

Solvent extraction is an operation that concentrates specific ions. Generally, solvent extraction uses the immiscible properties of two solvents (the pregnant leach solution and a solvent extraction solution) and the solubility properties of a solute (uraniferous ions) in the two solvents. Solvent extraction is typically employed by conventional milling operations since solvent extraction can be used in the presence of fine solids. The pregnant leach solution is mixed in tanks with the solvent exchange solution. Selection of a solvent in which the target solute (uraniferous ions) is preferentially soluble allows the solute to migrate to the solvent exchange solution from the pregnant leach solution while other dissolved compounds remain in the leach solution. Normally, the solvents are organic compounds that can combine with either solute cations or solute anions. As uranyl-carbonates or sulfates are commonly generated in the leaching step, anionic solvent extraction solutions are typically employed; cationic solvent extraction solutions may be employed depending on unique characteristics of the ores or leaching solutions.

Among the anionic SX solutions are secondary amines with aliphatic side chains, high molecular weight tri-alkyl tertiary amines, and quaternary ammonium compounds. Cationic SX solutions

include monododecyl phosphoric acid (DDPA), di-2-ethylhexyl phosphoric acid (EHPA), heptadecyl phosphoric acid (HDPA), and dialkyl pyrophosphoric acid (OPPA). (Twidwell et al., 1983)

Typically, the solvent extraction solution is diluted in a low cost carrier such as kerosene with a tributyl phosphate modifier or a long chain alcohol (Twidwell et al., 1983). The uraniferous ions preferentially move from the aqueous pregnant leach solution into the organic solvent as the two are mixed and agitated (DOI, 1980). After the uraniferous compounds are thus extracted from the pregnant leach solution, the barren lixiviant (raffinate) is typically recycled to the leaching circuit.

After the solute exchange has taken place, the pregnant solvent extraction liquor must be stripped. The uraniferous solute is typically in an anionic state, and accordingly many solvent extraction solutions are anionic-based. Amine solvent extraction solutions can be stripped by many different agents such as nitrates, chlorides, sulfates, carbonates, hydroxides, and acids. Chlorides are used most frequently due to their cost-effectiveness (Twidwell et al., 1983).

The pregnant stripping liquor is then pumped to the precipitation step while the stripped organic solvent is recycled to the beginning of the solvent extraction circuit. Solvent exchange can be done as a batch or continuous process (Twidwell et al., 1983).

Like solvent exchange, ion exchange operations make use of organic compounds to perform solute concentration. Generally, fixed organic resins contained within a column are used to remove uraniferous compounds from the pregnant leach solution by adsorption. After adsorption, the uraniferous compounds attached to the resins are released (eluded) by a stripping solution and sent to precipitation. Ion exchange is used by most if not all *in situ* operations and was employed by some conventional mills. It was not determined if the currently operational mills employ ion exchange circuits within their operations.

Resins are constructed with anionic or cationic functional groups (typically anionic for uranium compounds) that have an affinity for the target compound and specifically bind the compound to the resin. Resins are synthetic polymers in which hydrocarbon groups make up a three-dimensional network that hold stable, reactive functional groups (e.g., strong acid-SO_3H; weak acid-COOH; strong base-NR_3Cl; weak base-NH_2RCl). Resins containing acid groups are called cation exchangers while resins containing basic groups are termed anion exchangers (Twidwell et al., 1983). Chloride ions can exchange with the anionic component of all the functional groups, thus providing an inexpensive stripping solution (i.e., any chloride salt solution) for any of the resins.

As the pregnant leach solution passes through the ion exchange resins, the uraniferous compounds bind to the resins. The barren leach solution is recycled back to the leaching circuit. As the resins' binding ports are filled by the uranyl ions, the uranyl ion concentration at the outlet of the ion

exchange column increases. Once the uranyl ions at the outlet reach a predetermined concentration, the column is considered to be loaded and ready for elution. Typically, the pregnant leach stream is then directed to a fresh vessel of solvent exchange resins. A concentrated chloride salt solution is then directed through the loaded resins, eluting off the uraniferous complexes. The pregnant elute liquor can then be directed to the precipitation circuit. The pregnant elute solution may be acidified slightly to prevent the premature precipitation of uraniferous compounds (Twidwell et al., 1983).

Once the uraniferous ions have been concentrated by solvent extraction or ion exchange, they are precipitated out of solution to produce yellowcake. The precipitate is then washed, filtered, dried and drummed. The chloride stripping solution is recycled back to the stripping circuit. The type of ion concentration solution (e.g., acid or alkaline solution) governs the precipitation method employed. With acid pregnant stripping liquors or pregnant elute liquors, neutralization to a pH of 6.5 to 8 using ammonia hydroxide, sodium hydroxide or lime results in the precipitation of ammonium or sodium diuranate (Merritt, 1971). Hydrogen peroxide may also be added to an acid pregnant stripping liquor or pregnant elute liquor to precipitate uranium peroxide (Yan, 1990). All forms of the uraniferous precipitate are known as yellowcake.

Alkaline pregnant stripping liquors or pregnant elute liquors typically contain uranyl carbonates. Prior to precipitation of the uranyl ions, the carbonate ions must be destroyed. An acid (usually hydrochloric acid) is added to the carbonate concentrate solution to break down the carbonates to carbon dioxide; the carbon dioxide is vented off. Once the carbonates have been destroyed, the acidified solution is neutralized with an alkali or treated with hydrogen peroxide to precipitate the uraniferous compounds. Precipitation operations based on neutralization of acid solutions are favored because of the higher purity of the yellowcake product; sodium, carbonate, and, in some cases, vanadium, are impurities that may be present in yellowcake produced from alkaline neutralization (Merritt, 1971).

The yellowcake is separated from the precipitation solution by filtration. Thickeners may be used in conjunction with filtration units. The filtered yellowcake can then be dried and packaged for shipping (Bureau of Mines, 1978). The supernatant generated from precipitation and dewatering circuits can be recycled to the respective solvent extraction or ion exchange stripping solution.

Typically, yellowcake is shipped to a Federal facility for processing. In the processing step, uranium fluoride (UF_6) is produced from yellowcake. The uranium fluoride is then enriched, an operation that concentrates the U-235 from 0.7 percent to approximately two to three percent. The enriched uranium fluoride is further refined to ultimately produce the fuel rods used in nuclear reactors.

In situ leaching is the most commonly employed solution technique and continues to be employed by at least two mines in Wyoming. Nebraska's Department of Environmental Control permitted an *in*

situ operation in 1990 although its operational status was not determined (NDEC, 1990). Deposits amenable to *in situ* leaching are usually (if not always) within an aquifer. Water quality within a mineral deposit may vary depending on the presence of and boundary between oxidizing and reducing groundwaters. Ore body characteristics, including chemical constituents, grade, and permeability, are key considerations in the development of production methods (selection of lixiviants, arrangement of well patterns, etc.). Ideally, the deposit should be confined by impermeable strata above and below the deposit to prevent contamination of adjacent aquifers by excursions (solution leaks from the ore zone). *In situ* production operations consist of three phases: removal of minerals from the deposit, concentration of uraniferous minerals, and generation of yellowcake. In addition to the production operations, water treatment and, in some cases, deep well injection facilities, are employed.

In the case of *in situ* operations, beneficiation serves as the first phase of the mining operation. In *in situ* mining, barren solvent (lixiviant) is introduced to the deposit through injection wells to initiate the operation. The lixiviant contains both an oxidizing agent to solublize the target minerals and a complexing agent that binds to the target minerals and keeps them in solution. Wyoming *in situ* operations recover uraniferous compounds using oxygen gas as the oxidizer and carbon dioxide, as the complexing agent (WDEQ, 1991). The barren lixiviant is charged with carbon dioxide as the solution leaves the ion exchange facility. Oxygen is injected into the solution in the wellfields, immediately before the lixiviant flows into the injection wells. As the solution moves through the deposit, uraniferous minerals are oxidized and uraniferous ions move into solution. Carbon dioxide in the lixiviant reacts with water, forming carbonic acid, which in turn complexes with the solubilized uraniferous ions, forming uranyl carbonates. The uranyl carbonates and gangue minerals solubilized in the operation remain in solution as the pregnant solution is pumped to the surface through production (recovery) wells.

Pregnant lixiviant is pumped from the production wellheads through sand filters to remove any large particulates; the lixiviant is then transferred to ion exchange units. Depending on the facility, the ion exchange units may be placed in trailer-mounted tanks or moved via tanker truck from satellite plants to a central processing facility. When the resins in the ion exchange units are loaded, the uraniferous compounds are stripped from the resins and precipitated to form yellowcake. The lixiviant, after passing through the ion exchange units is recharged with carbon dioxide and oxygen following the ion exchange circuit and injected back into the ore body.

Numerous well patterns have been investigated since the early 1960s when *in situ* mining techniques were first employed. Five spot well patterns, which consist of four injection wells forming the corners of a square, and a production well in the center, are common in the industry. Alternating injection and production wells are used in narrow deposits. The spacing between injection and production wells can range from 20 to 200 feet and the number of well patterns in a well field may also vary.

Mining units are portions of the deposit to be mined during one operation, often following "pods" of ore deposited along a roll front. Mining units may be mined in sequence or simultaneously. Pumping rates at one *in situ* operation in Wyoming ranged from two gallons per minute (gpm) to 30 gpm for injection wells and five gpm to 40 gpm for production wells. Approximately one percent of the fluid drawn from the well field is removed as a bleed to generate a cone of depression within the "production zone." Pumping rates can be varied at each well individually in order to compensate for differences in permeability of the deposit and the gradient being generated by the production operation.

Uranium recovery rates at *in situ* operations are highest within the first year of operation; economically viable recovery within a wellfield usually lasts one to three years under recent (1990s) market conditions.

Restoration of the aquifer can be conducted using one (or more) of the following techniques: groundwater sweep, forward recirculation, reverse recirculation, and directional groundwater sweeping. In some cases, a reducing agent may be injected prior to any restoration to reverse the oxidizing environment created by the mining process. A reducing agent may also be injected during later stages of restoration if difficulties arise in stabilizing the aquifer (Lucht, 1990).

A groundwater sweep involves the selective operation of production wells to induce the flow of uncontaminated groundwater into the mined zone while the withdrawn water continues to be treated through the ion exchange circuit. Contaminated water withdrawn from the aquifer can be disposed of in lined evaporation ponds or treated and discharged. Groundwater sweeps are most effective in aquifers with "leaky" confining layers, since uncontaminated groundwater can be induced to flow into the mined areas. Typically, two or more pore volumes are required to improve water quality parameters. The disadvantage to groundwater sweeping is its consumptive use of groundwater (Osiensky and Williams, 1990).

Forward recirculation involves the withdrawal and reinjection of groundwater through the same injection and production wells that were used during the mining operation. Groundwater withdrawn from the mined aquifer is treated using ion exchange or reverse osmosis with the clean water being reinjected and recirculated through the system. The water being reinjected is treated to the extent that it meets or exceeds the water quality required at the endpoint of restoration. The method does not allow the removal of any lixiviant or mobilized ions that may have escaped from the mined aquifer. For this reason, forward recirculation is most effective in restoring the portions of the aquifer associated with the interior of the well field (Osiensky and Williams, 1990).

Reverse circulation techniques can also be employed in which the function of production and recovery wells is reversed. Again, "clean" water is injected, this time through the recovery wells, while the

injection wells are employed to withdraw groundwater from the aquifer. This method is also more effective in restoring the aquifer in the interior of the well field than along the perimeter (Osiensky and Williams, 1990).

Directional groundwater sweeping techniques involve the pumping of contaminated groundwater from specific wells while treated water (at or surpassing baseline quality) is injected into the aquifer beyond the mined sections of the aquifer. The clean water is then drawn into the contaminated portions of the aquifer, removing the residual mobilized ions. Clean water injection can progress across a wellfield as the contaminants are progressively withdrawn (Osiensky and Williams, 1990).

Uranium can be recovered during the early stages of the restoration process as the water from the production wells passes through the ion exchange system. Eventually, uranium recovery is abandoned while restoration continues. A rinse of multiple aquifer pore volumes is typically required to reach a satisfactory level of restoration. The number of pore volumes required depends on the ease with which the aquifer returns to baseline conditions and the permit requirements established in State permits (Osiensky and Williams, 1990; Bureau of Mines, 1979).

Demonstration of successful aquifer restoration is accomplished through extended monitoring. The State of Wyoming, for example, requires that selected wells be monitored for stability for a period of at least six months following the return of monitoring parameters to baseline levels (WDEQ, 1990).

3.3.6.4 Wastes and Waste Management

Wastes generated by uranium mines and mills would include those generated in other mining sectors (e.g., waste rock, spent extraction/leaching solutions, tailings, and refuse). Mining method (conventional versus solution) has a bearing on the types of wastes produced. Under the Uranium Mill Tailings Remediation Control Act (UMTRCA), source handling licenses issued by the Nuclear Regulatory Commission (NRC) place specific requirements on the disposal of radioactive wastes; the design and construction of tailings impoundments thus have to address requirements for permanent storage of these wastes. Radionuclide-containing wastes generated by *in situ* operations are typically shipped to tailings impoundments at mill sites.

The greatest volume of waste generated by open pit and underground mines is waste rock, which is typically disposed of in waste rock piles. Some waste rock may be used for onsite construction (roads, foundations, etc.). The generation of acid mine drainage is one of the principal concerns surrounding waste rock in other mineral sectors. The potential for generation of acid drainage from uranium waste rock has not been addressed in available reference materials. However, pyrite is typically a constituent of uranium-containing ores, and may present the potential to create acid mine drainage. Other materials generated by open pit and underground mining operations, including low-grade ore and mine water, are typically managed on-site during the active life of the facility. Low-

grade ores that are not beneficiated ultimately become waste rock. If a mill is co-located with a mine, mine water can be used as makeup water in the beneficiation operation. If a mill is not nearby, mine water may be treated and discharged as mine drainage or used for dust suppression.

The principal waste generated by conventional beneficiation operations is tailings. *In situ* operations, and to a lesser extent conventional mills, generate waste leaching solutions. Disposal of these wastes is dependent on the type of operation; beneficiation wastes generated by *in situ* operations are disposed of by one of four management methods: evaporation ponds, land application, deep well disposal, or shipment to NRC-licensed waste disposal facilities. Most beneficiation wastes generated at conventional mills are disposed of in tailings impoundments.

Waste constituents of concern include: radionuclides (radium, radon, thorium, and to a lesser extent lead), arsenic, copper, selenium, vanadium, molybdenum, other heavy metals, and dissolved solids. Brines, spent ion exchange resins, and chemicals used in beneficiation operations are also constituents of wastes generated during beneficiation. Airborne particulates from blasting, loading, and vehicular traffic can also be of concern.

3.3.7 Other Metals

3.3.7.1 Aluminum

Bauxite (a mixture of primarily three aluminum hydroxide minerals, diaspore, gibbsite and boehmite, and impurities) is the ore of aluminum (Hurlbut and Klein, 1977). Deposits of bauxite in the United States are located in Arkansas, Georgia and Alabama. In 1992, bauxite was being mined from surface excavations in Georgia and Alabama (Bureau of Mines, 1993). Virtually all of this domestic bauxite ore is consumed in the production of nonmetallurgical products (primarily refractory grogs) and not in producing aluminum (Bureau of Mines, 1993). Imported metallurgical-grade bauxite is used in the production of aluminum in the United States.

Alumina production is shifting to the large-scale bauxite producing countries in response to increasing energy costs in North America and Europe (Bureau of Mines, 1993). If this results in increased costs for alumina for U.S. plants, nonbauxitic aluminum resources in the United States may become economically more attractive. Current conditions indicate that the United States will continue to be a major importer of metallurgical-grade bauxite and alumina, precluding the need for extensive expansions of U.S. bauxite mines (Bureau of Mines, 1993).

The two active bauxite mines use the general surface mining operations discussed in Section 3.1. Draglines, shovels and haulers remove ore from open pits and transport it to a storage area. Ore may be loaded directly from storage to the processing plant, or it may undergo beneficiation at the mine.

Beneficiation commonly requires crushing, washing and drying. Crushing is common to all bauxite processing; however, the steps following crushing depend on the makeup of the ore. After crushing, the ore may be washed to remove sand and clay sized impurities. Impurities such as iron, and titanium may be removed using heavy media or magnetic separation, jigging, or spiral concentrators. The washed ore is generally shipped without further processing; however, it may be dried or calcined at the mine. Most bauxite ores are not dried at the mine site, because drying may create serious dust problems during transportation and handling (EPA, 1979).

The wastes produced from the beneficiation of bauxite ores is the wastewater used in the washing process. Generally this water is discharged to the pits and not to surface waters. Chromium, copper, mercury, nickel and zinc have all been found in low concentrations in drainage from bauxite mines (EPA, 1982). In addition, the drainage can be of low pH (EPA, 1982).

3.3.7.2 Tungsten

The principal ore minerals for tungsten are wulframite ((Fe, Mn) WO_4) and scheelite ($CaWO_4$). Tungsten's physical properties, a high melting point (3,410°C), high density, good corrosion resistance and good thermal and electrical conductivity, make it an important material for use in domestic and military industries. As of 1992, the only two U.S. mines producing tungsten concentrate were in California. Tungsten ores have generally been mined using conventional underground mining methods.

Tungsten ores are often beneficiated using gravity concentration or flotation methods. The specific gravity of tungsten minerals is high and therefore gravity concentration methods primarily are used. However, scheelite (the principal U.S. ore) is very friable and in the process of wet-grinding a considerable amount of slimes are produced and this reduces recovery by gravity techniques. To increase overall recovery, finely divided scheelite particles in the slimes are concentrated by flotation techniques using fatty acids as collectors. Several hydrometallurgical procedures are used for upgrading tungsten concentrates. Scheelite concentrates from flotation tend to be lower grade than gravity concentrates. Calcite and apatite are the principal contaminants in these low-grade concentrates (scheelite concentrates seldom contain sulfides in large amounts). These impurities may be leached out with acid, and the concentrates upgraded in the process. A first-stage leach with hydrochloric acid (HCl) removes the calcite as calcium chloride ($CaCl_2$) solution, which is discarded, while a second-stage leach is used to dissolve the apatite, which is not dissolved in the presence of calcium chloride.

One of the many variations of tungsten ore beneficiation procedures is the hydrometallurgical treatment of low-grade scheelite group concentrates to produce calcium tungstate. A water slurry of scheelite concentrates from flotation machines is digested in a pressurized digester vessel with sodium carbonate and steam to produce tungstate and molybdate in solution. To remove the molybdenum,

the solution is filtered and heated to 91 °C (195 °F), and sodium sulfide is added to precipitate molybdenum. The solution is adjusted to pH 3.0 with H_2SO_4 to complete this separation. The hot purified solution is neutralized with sodium hydroxide to a pH 9.2, then treated with calcium chloride to precipitate calcium tungstate. Alternatively, the filtered solution after molybdenum separation may be solvent-extracted by a proprietary process to produce ammonium paratungstate, which is crystallized out of solution and dried (EPA, 1976).

The discharge from tungsten milling operations has been found to contain high concentrations of copper, lead, and zinc (EPA, 1982).

3.3.7.3 Molybdenum

Molybdenum is an important metal for use as an alloying agent in steel, iron and superalloys (Bureau of Mines, 1993). Molybdenite is the major ore mineral mined for molybdenum. In the United States, the economically important deposits of molybdenite are generally low-grade porphyry or disseminated deposits, but contact-metamorphic zones, quartz veins, pegmatites and aplite dikes, and bedded deposits in sedimentary rocks have also been exploited for molybdenite. Most porphyry copper deposits contain low concentrations of molybdenite (0.02 percent to 0.08 percent). Primary molybdenite deposits typically grade 0.2 percent to 0.5 percent molybdenite. In 1992, 45,500 metric tons of molybdenum was mined in the United States, two-thirds for export. Three mines (in Colorado and Idaho) mined molybdenum ore and 11 (in Arizona, California, Montana, New Mexico, and Utah) recovered molybdenum as a byproduct. The United States was the major producer of molybdenum in 1992, and will continue as a top five world producer throughout the rest of the century (Bureau of Mines, 1993).

Molybdenum ore is mined by both open pit and underground operations in the United States. In 1992, approximately 40 percent of U.S. production was from underground mines and 60 percent from open pits. Underground mines typically use caving methods, since these methods allow for the economic removal of large tonnages of low grade ores at a low cost. Conventional open pit mining methods are used. In underground mines, very little waste rock is removed. Significant tonnages of waste rock can be removed in the development and mining of an open pit.

After the molybdenum ore is mined, it is transported to a mill for beneficiation. The ore is generally crushed and ground at the mill before traditional flotation methods are used to concentrate the ore minerals. A final concentrate of 90 percent to 95 percent molybdenite is produced by the beneficiation operation. The major impurities in the concentrate are copper, iron and lead minerals. Molybdenite recovery from copper ore is more complex due to the low percentage present in the ore.

As in the flotation of other ores, the major wastes produced are tailings, and these are generally disposed of in tailings impoundments.

3.3.7.4 Vanadium

Vanadium is generally not mined as the primary metal of an ore, but as a co-product, as in carnotite ores (recovered for uranium and vanadium) mined in the western United States. Currently, one mine in the United States recovers vanadium as the primary constituent of the ore. The primary use of vanadium is as an iron and steel alloying agent. Mining of the uranium and vanadium ores in the western United States has employed open pit and underground mining methods. The vanadium mine in Arkansas uses open pit methods to extract the vanadium ore.

Mined vanadium ore is crushed, dried, ground, and screened to sizes less than 1.17 mm (-14 mesh). It is then mixed with about 7 percent weight of salt, pelletized, and roasted at 850 °C (1,560 °F) to convert the vanadium to soluble sodium vanadate, $NaVO_3$. It is then quenched in water and acidified with sulfuric acid to pH 2.5-3.5. The resulting sodium decavanadate ($Na_6V_{10}O_{28}$) removes impurities such as sodium, calcium, iron, phosphorous, and silica. Slightly soluble ammonium vanadate, NH_4VO_3, is precipitated from the stripping solution with ammonia. The ammonium vanadate is then calcined to yield vanadium pentoxide, V_2O_5 (EPA, 1976).

3.3.7.5 Titanium

Aircraft and space applications account for 75 percent of titanium metal consumption, with the remainder used in chemical processing, power generation, and other applications. The principal ore minerals for titanium are ilmenite ($FeTiO_3$), and rutile (TiO_2). These minerals are found concentrated in hard-rock and sand deposits. In 1993, only sand deposits of ilmenite were being mined in the U.S (Bureau of Mines, 1993).

The method of mining titanium minerals depends upon whether the ore to be mined is a sand or rock deposit. Sand deposits occurring in Florida, Georgia, and New Jersey contain 1 to 5 percent TiO_2 in the form of grains of ilmenite, ilmenite/magnetite, rutile, and leucoxene, and are mined with floating suction or bucket-line dredges handling up to 1,100 metric tons (1,200 short tons) of material per hour. No hard rock deposits are currently active.

The sand ore is treated by wet gravity methods using spirals, cones, sluices, or jigs to produce a bulk, mixed, heavy-mineral concentrate. As many as five individual marketable minerals are then separated from the bulk concentrate by a combination of dry separation techniques using high-tension electrostatic and magnetic separators, occasionally in conjunction with dry and wet gravity concentrating equipment. The high-tension electrostatic separators are employed to separate the titanium minerals from the silicate minerals. The minerals are fed onto a high-speed spinning rotor, and a heavy corona (glow given off by high voltage charge) discharge is aimed toward the minerals at the point where they would normally leave the rotor. The minerals of relatively poor electrical conductance are pinned to the rotor by the high surface charge they receive on passing through the

high-voltage corona. The minerals of relatively high conductivity do not hold this surface charge as readily and so leave the rotor in their normal trajectory. Titanium minerals are the only ones present of relatively high electrical conductivity and are, therefore, thrown off the rotor. The silicates are pinned to the rotor and are removed by a fixed brush.

Titanium minerals undergo final separation in induced-roll magnetic separators to produce three products: ilmenite, leucoxine, and rutile. Separation of these minerals is based on their relative magnetic properties which, in turn, are based on their relative iron content: ilmenite has 37 percent to 65 percent iron, leucoxine has 30 percent to 40 percent iron, and rutile has 4 percent to 10 percent iron.

3.3.7.6 Platinum

Platinum is one of the six closely related platinum-group metals (platinum, palladium, rhodium, ruthenium, iridium, and osmium). Platinum and palladium are the most commercially important metals of the group; in 1992, an estimated 1,730 kilograms of platinum and 6,050 kilograms of palladium were mined. The United States automobile industry is a major consumer of platinum for use in catalytic converters. Platinum group metals also are used in electrical and electronic (29 percent), medical (9 percent), and other applications (24 percent). Demand for platinum is expected to remain high as the use of catalytic converters increases around the world to control automobile emissions (Bureau of Mines, 1993).

In the past, platinum mining in the United States was mostly from placer deposits. The only currently active platinum mine in the United States is the Stillwater Mine in Montana; platinum-group metals also were recovered as byproducts of copper refining in Texas and Utah. Platinum and palladium (at a ratio of 1:3) occur in an igneous, strataform ultramafic rock at the Stillwater mine (Stillwater Mining Company, undated). The deposit is exploited through underground cut and fill mining methods. The ore is transported to the mill for crushing and grinding prior to entering the concentrate circuit. After grinding, the ore is added to the froth flotation units along with reagents. The recovered concentrate is dried before transport to a refining facility for the recovery of the palladium and platinum. The mine received an amended permit in 1992 to double the mine's daily production from 1,000 tons to 2,000 tons.

The tailings slurry at the Stillwater Mine is separated into coarse and fine fractions prior to disposal (Stillwater Mining Company, undated). The coarse fraction is pumped underground to be used as sand-fill in the underground mine. The fine fraction is pumped to a lined tailings impoundment. The facility recycles water from the tailings impoundment back into the mill. Very little waste rock is removed during mining. Most of the waste rock is used to raise the dam of the tailings impoundment when additional capacity for the tailings impoundment is required (Stillwater Mining Company, undated).

3.4 COAL MINING

This section focuses on surface and underground coal mining operations and environmental impacts unique to the coal mining industry. Specifically, the subsections below addresses types of coal, geographic location of coal, and mining and reclamation methods as the primary determinants of environmental impact. This approach was taken to isolate those areas of concern that are unique to coal mining activities and to establish a workable methodology to assess the magnitude and significance of potential impacts.

There are both similarities and differences between coal and other types of mining operations. Any type of surface mining requires the removal3 of overlying soil and rock (collectively known as overburden) prior to the removal of the resource. Coal and non-coal operations use many of the same techniques in the development and often in the production phase of mining. All mining activities must control surface water runoff, minimize fugitive dust, and avoid impacts to the surrounding environment.

In addition to other environmental regulations, coal mining operations must also comply with the Surface Mining Control and Reclamation Act of 1976 (SMCRA). SMCRA greatly expanded the regulatory requirements placed on the operation and reclamation of coal mines (see Chapter 6). One of the most significant aspects of this program is that of reclamation; areas disturbed by coal mining activities must be returned to approximate original contour and reclamation must be conducted concurrently with mining.

3.4.1 COAL FORMATION AND GEOGRAPHICAL DISTRIBUTION

3.4.1.1 Types and Composition of Coal

Coal was formed through the accumulation and compaction of marine and freshwater plants and animals living in ancient marshes. The accumulated organic material was buried by sediments and altered from complex organic compounds to carbon.

Coal is classified based on the percentages of fixed carbon, natural moisture, and volatile matter present. Lignite, subbituminous coal, bituminous coal, and anthracite comprise the major classes of coal. The percentage of fixed carbon increases, the percentage of volatile matter decreases, and the heating value increases from lignite to anthracite (see Exhibit 3-13). Based solely on heating value, the market value of coal can be expected to increase from lignite to anthracite. Because sulfur content and other end-use specifications and requirements can significantly influence the demand for coal, the heating value is only one of several criteria that determine the actual market value of coal deposits.

Exhibit 3-13. Types of Coal and Relative Percentages of Constituents

Type	Fixed Carbon (Percent)	BTUs/Pound	Volatiles (Percent)	Moisture (Percent)
Anthracite	> 86	12,000 - 15,000	< 14	3
Bituminous	47 - 86	11,000 - 15,000	14	3 - 12
Subbituminous	42	9,700	34	23
Lignite	30	6,600	25	45

Sulfur is the most abundant trace element in coal, and reduces the value of those coals in which it is found. Sulfur occurs both as an inorganic constituent mineral (mostly in the form of pyrite) in coal itself and as part of organic complexes associated with the deposit. When the coal is burned, sulfur contributes to air pollution and reduces coking quality. When exposed to oxygen and water, the inorganic forms produce acid mine drainage.

The sulfur content of coals found in the United States ranges from 0.2 percent to about 7.0 percent by weight. The percentage of sulfur in coal generally is greatest in the bituminous coals of the Interior and Eastern coal fields. The sulfur content of coal generally is less than 1 percent in the Northern Great Plains and Rocky Mountain Provinces for subbituminous coal and lignite. More than 90,000 million tons (64 percent) of the total surface-minable reserves in the United States are low-sulfur and occur in the west.

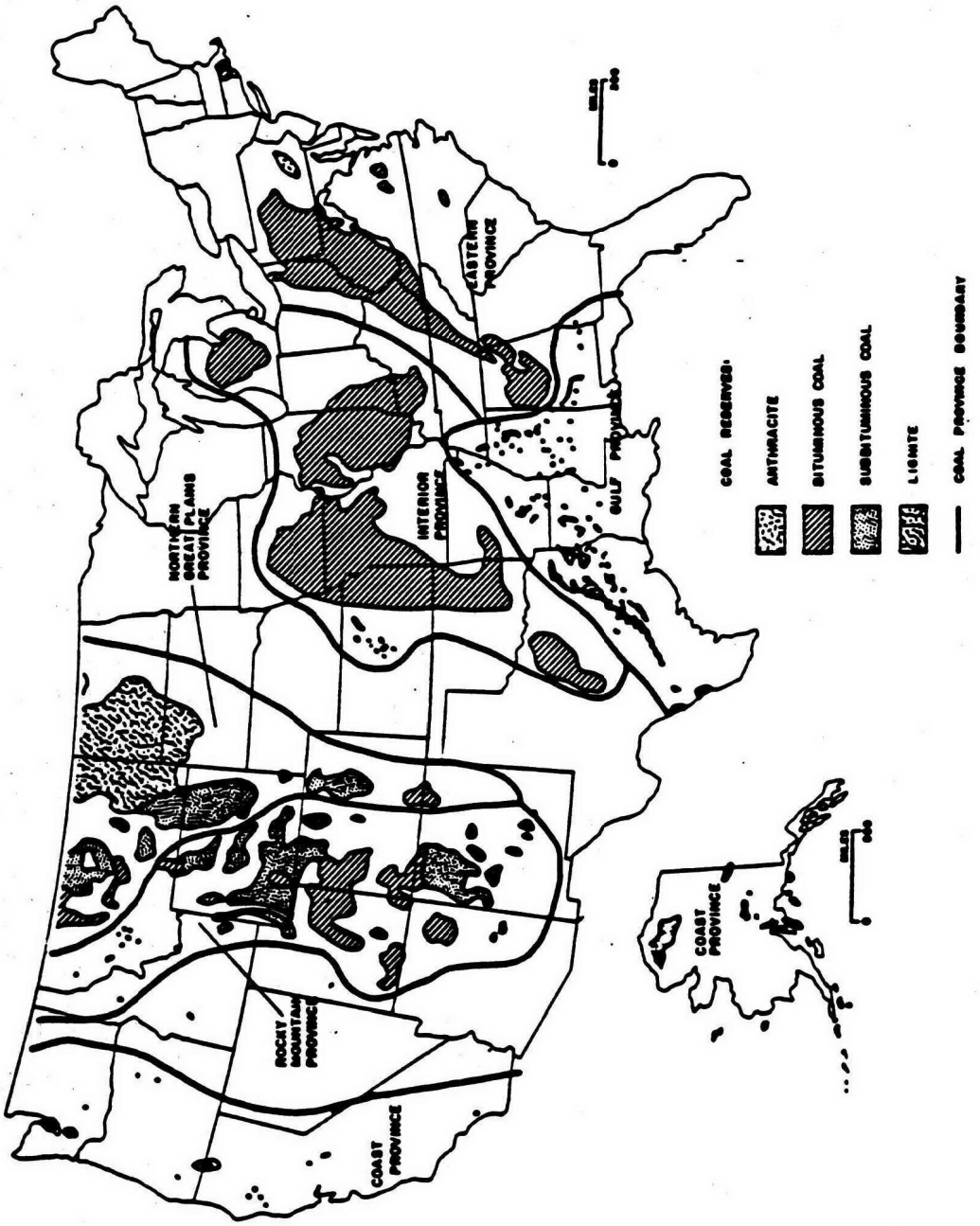
Coal contains traces of virtually all elements. Burning coal results in the concentration of most of these elements in the ash, although a few may be volatilized and emitted to the atmosphere. Arsenic, barium, beryllium, bismuth, boron, cobalt, copper, fluorine, gallium, germanium, lanthanum, lead, lithium, mercury, molybdenum, nickel, scandium, selenium, silver, strontium, tin, vanadium, uranium, yttrium, zinc, and zirconium occur in some coals in concentrations that are greater than their average abundance in the crust of the earth.

3.4.1.2 Coal Provinces

Six coal provinces (Exhibits 3-14 and 3-15) are defined in the United States: the Pacific Coast, Rocky Mountain, Northern Great Plains, Interior, Gulf Coast, and Eastern.

Coal deposits in the Pacific Coast province are found in scattered fields in California and Oregon, and in one large field and scattered small fields in Washington. California coals are mostly of Eocene to Miocene age, and range in rank from lignite to high volatile bituminous. Oregon coals range from subbituminous to bituminous. Washington coals range from subbituminous to anthracite, but most are

Exhibit 3-14. Coal Provinces of the United States



Source: University of Oklahoma. 1975. Energy alternatives; a comparative analysis. Science and Public Policy Program, Norman OK, OY1-011-00025-Y, variously paged.

Exhibit 3-15. Summary of Environmental Considerations by Province

Coal Province	Mining Method	Regional Characteristics	Environmental Considerations
Eastern	Mountaintop removal; contour; room and pillar; longwall	Climate humid.	High sulfur concentrations in coal and surrounding material; abundant surface and groundwater resources; numerous small mines; subsidence
Interior	Strip; longwall (limited)	Climate humid to subhumid	Prime farmland; potential large-scale disturbances; surface and groundwater; subsidence (limited)
Gulf	Strip	Climate humid. Precipitation recharges aquifers directly through soils. Water quality good to excellent.	Groundwater; land use
Northern Great Plains	Strip (limited underground)	Water quality ranges from poor (saline) to good.	Groundwater; large tracts of surface disturbance from adjacent mining; land use (alluvial valley floors, prime farmland, wildlife habitat)
Rocky Mountain	Strip; longwall (limited); room and pillar (limited)	Climate arid (low elevations) to subhumid (high elevations). Groundwater occurs in alluvium and in fractured sandstone, shale, and coal. Discharges to springs, baseflow of streams, and through deep-rooted plants. Quality variable throughout the region from poor (saline) to good.	Groundwater; land use (wildlife habitat)
Pacific Coast	Surface	Climate humid. Groundwater in alluvium, recharged by precipitation and snowmelt; discharges to springs and streams. Water quality is aquifers surrounding coal typically adequate for domestic purposes.	Steep slopes; abundant surface and groundwater resources

subbituminous to bituminous; some also are of coking quality. Coals in Alaska range from lignite to high volatile bituminous grades. Coals are found in large fields along the Arctic Coastal Plain, and in smaller fields located both inland and along or near southern shorelines.

The Rocky Mountain Coal Province is bordered on the east by the Great Plains, and on the west by a series of high plateaus, including most of New Mexico, Colorado, Utah, Arizona, and parts of Montana and Idaho. Scattered small fields are found in central and southern New Mexico.

High volatility bituminous coal is found in rocks of Upper Cretaceous age in the western Montana area. Coal beds are thin, impure, and usually greatly disturbed by folding and faulting. The Big Horn Basin coals of Wyoming and coal found in extreme southwest Wyoming range in age from late Cretaceous and Paleocene and is classified from lignite through high volatile subbituminous. These deposits occur in lenticular beds which rarely persist at a minable thickness for more than 5 miles at outcrop. Dips of locally folded strata can reach 50°, resulting in an irregular distribution of coal outcrops. The Paleocene age coals of the Hams Fork region range in rank from subbituminous to high volatile bituminous. Beds of higher grade coals may be as thick as 20 feet; thicknesses of lower grade coal range to 100 feet. These coal beds are situated in a highly complex zone of thrust faults and folded rocks, resulting in steeply dipping strata and thereby making mining difficult in most parts of the region.

In central Wyoming (the Wind River Basin) coal beds are Late Cretaceous to Paleocene in age, and are mostly subbituminous. Although coal beds may approach thicknesses to 17 feet, surface mining is made difficult by the steep dips of the strata. In southwestern Wyoming, coals range in rank from subbituminous to high volatile bituminous, and higher rank coals locally may occur in areas of igneous intrusion and intense structural deformation.

Coals of the North Park area of the Colorado Mountains are subbituminous and occur in several major beds up to 77 feet thick. Coals found in the Green River Region within the Colorado Plateau of Arizona, New Mexico, Colorado, and Utah, are generally found in horizontal strata of sedimentary origin. Erosion of these strata has resulted in formation of canyons, mesas, and buttes. The landscape comprises wide plateaus, uplifts, and broad basin areas. The Late Cretaceous age coal beds of the Uinta Coal Region range in rank from subbituminous to coking quality high volatile bituminous; some semianthracite and anthracite deposits occur in the Crested Butte Field of the Uinta Region. Coal bed thicknesses generally range from 5 feet to 15 feet, but locally may approach 40 feet. The Late Cretaceous age coals of the Southwestern Utah Coal Region range in rank from subbituminous to high volatile bituminous, with local occurrences of anthracite. These coals are found in flat-lying to gently dipping beds from 2 feet to 30 feet thick. The Late Cretaceous and Eocene age coals of the San Juan River Coal Region occur as lenticular, discontinuous deposits up to 5 feet thick in areas of complex geologic structure. Thicker, more continuous coal beds up to 38 feet

thick with numerous shaly partings are found in structurally less complex parts of this region. San Juan River region coals are generally subbituminous, but high volatile bituminous coals also are found.

The Northern Great Plains coal province the includes coal regions that occur in the Great Plains east of and adjacent to the Rocky Mountains. The area is characterized by little surface relief, gently rolling plains, some areas of badlands and dissected plateaus, and isolated mountains. Rocks of this province occur in nearly horizontal sedimentary strata which curl up sharply along the flanks of the Rocky Mountains. Coal found in central Montana is of Late Jurassic age and is high volatile bituminous containing 1.7 to 4.0 percent sulfur. Coals from north-central Montana are of Late Cretaceous age and range from subbituminous to high volatile bituminous. These coal beds generally are discontinuous and too thin to be of commercial importance, other than as sources of local fuel. Coal deposits found in extreme northeastern Montana and western North Dakota contains an estimated 438 billion tons of lignite, the largest single coal resource in the United States. Coals are Late Cretaceous to Paleocene in age, and increase westward from lignite in North Dakota to subbituminous in Montana. Coals found in southern Montana and northeastern Wyoming are Upper Cretaceous to Eocene in age, and range from subbituminous to high volatile bituminous. An 8,000 square mile area of gently rolling plains in northeast central Colorado are underlain by Late Cretaceous and Paleocene age coal bearing rocks. Coals generally are subbituminous and occur in lenticular, discontinuous beds up to 17 feet thick. Extensive deposits of lignite also are found in this region. The coal found in southern Colorado is of Late Cretaceous and Paleocene age and range from coking high volatile bituminous to non-coking high volatile bituminous.

The Interior coal province is an extensive area of low relief underlain by flat-lying Paleozoic age sandstones, limestones, conglomerates, and shales which lie between the Appalachian Plateaus and the Rocky Mountains. Coal beds of this province are of Pennsylvanian age, and generally comprise high volatile bituminous grades which improve in quality in the western part of the coal region. In Oklahoma and Arkansas, some coal deposits have been devolatilized to coking low volatile bituminous and semianthracite ranks.

The Gulf Coast coal province comprises extensive lowlands and coastal areas. The subsurface generally is composed of unconsolidated beds in detrital sediments and limestones which dip gently seaward. Outcrops of rock become successively older inland. The province has a good supply of surface water and groundwater, and droughts are uncommon except in southwest Texas. Coal deposits consist of Upper Cretaceous age bituminous beds near the Mexican border, and extensive deposits of lignite which extend from southern Texas to Alabama.

The Eastern coal province extends 800 miles from northern Pennsylvania to northern Alabama and essentially is mountainous for its entire length. Coals of this province were deposited in the

Pennsylvanian age Appalachian Basin, which consists of a series of sandstones, shales, limestones, conglomerates, and coals. Structural features such as faults and fold axes trend northeast-southwest, parallel to the basin margins. The eastern part of the basin is extensively folded and faulted, and contains the higher grade coals of the region. These coals range in rank from medium volatile bituminous coals of the major eastern Appalachian coal fields to the high quality anthracite of northeastern Pennsylvania. The western part of the Appalachian basin is marked by strata in broad, open folds which dip gently westward. Coals of the western part of the basin generally are of the high volatile bituminous grade. The ranks of coals in the Eastern Coal Province generally decrease from east to west in bands which trend northeast-southwest, parallel to major structural features.

3.4.1.3 Trends

Trends in the coal industry are primarily driven by a change in the accessibility of eastern and western deposits and trends in the use of coal as a fuel, particularly in light of the Clean Air Act. These trends are manifest in the continued development of large, western surface mines as major suppliers of coal, while underground techniques are being more widely applied in the east and midwest. The demand for the low sulfur coals that are common throughout the west and the desulfurization of high sulfur coals for use as boiler fuels is produced by increasingly stringent limitations on stack emissions on sulfur dioxide and particulates.

The coal industry will likely continue to grow at moderate levels within the foreseeable future. Whether the trend in increasing production from western operators continues may be based on the demand for clean burning coals. Western coals typically have lower sulfur concentrations and hence burn cleaner than eastern coals. However, the lignite and subbituminous coals of the west contain fewer BTUs and carry increased transportation costs (either for the coal or for electrical power).

Production trends in the surface coal mining industry include (1) shifts of mining activity to coal regions which contain large reserves of economically recoverable and usable coal and (2) shifts of mining activity within regions to situations which previously were avoided because adverse topography, overburden thickness, or other factors precluded an economic return on investment in mining operations.

Several factors in addition to the low sulfur content have contributed to the dramatic expansion of the western surface coal mining industry since 1977. Large tracts of relatively flat land underlain by thick, horizontal seams are amenable to high production surface mining operations. The pit, spoil piles, haul roads, and ancillary facilities can be designed to minimize the cycle times of unit mining operations, thus maximizing productivity per shift.

Operators of eastern surface mines use such methods as mountaintop removal combined with head-of-hollow fill to offset the disadvantages of surface mining in steeply sloping terrain. Although the

extent and magnitude of their environmental impacts have been controversial, mountaintop removal and head-of-hollow fill will continue. The east has also demonstrated an increase in the number of underground mining operations to address the limitations established by topography and economics.

3.4.2 SURFACE MINING SYSTEMS

Surface mining systems are sequences of unit operations which have been designed to accommodate the limitations on mining imposed by geology, topography, and regulatory requirements. Three kinds of surface mining systems are employed in the removal of overburden and coal extraction. Area mining and contour mining are by far the most commonly used methods, the third surface mining technique, open pit mining, is used to a limited extent in southwestern Wyoming.

3.4.2.1 Area Mining

Two forms of area mining are conducted, conventional or strip mining, and mountaintop removal. Strip mining is employed throughout the United States, primarily in the large mid-western and western coal fields and to a more limited extent in the Eastern coal province. This type of mining is applied in regions with flat to rolling terrain where the coal seams lie horizontal or nearly horizontal to the surface. Overburden in these areas is relatively shallow and regrading to approximate original contour is possible. Mountaintop removal is used in rugged terrain of the Appalachian Mountains, where regrading to approximate original contour may not be feasible or desirable. Both methods essentially result in total recovery of the mined resource.

A typical strip mining operation proceeds in the following manner (see Exhibit 3-16). A trench (box-cut) is excavated through the overburden to the coal seam. This trench usually is extended linearly to the perimeter of the permitted area, to the edge of the coal deposit, or to a location that accommodates future development of the mine. The mined overburden (spoil) from the box cut is stockpiled parallel to the trench on unmined ground, and coal is recovered from the exposed seam. Successive cuts are made parallel to the initial trench, and spoil from each succeeding cut is placed in the trench of the previous cut. Spoil from the initial cut is typically placed in the trench of the final cut. The disturbed area is progressively regraded to the approximate original contour and reclaimed as mining progresses. As required by SMCRA, approximate original contour requires the elimination of all highwalls and other mining-related escarpments and depressions not needed to facilitate revegetation and reclamation of the disturbed area.

The mountaintop removal method (Exhibit 3-17) does not return the mined area to the approximate original contour as an entire mountaintop is typically mined through. This type of operation often makes use of a head of hollow fill to handle the box cut spoil and any excess overburden. To initiate a mountaintop removal operation, a box-cut is made through the overburden along a line more or less parallel to the coal outcrop. This cut is made in a manner such that at least a 15-foot-wide barrier of

Exhibit 3-16. Area Mining With Stripping Shovel

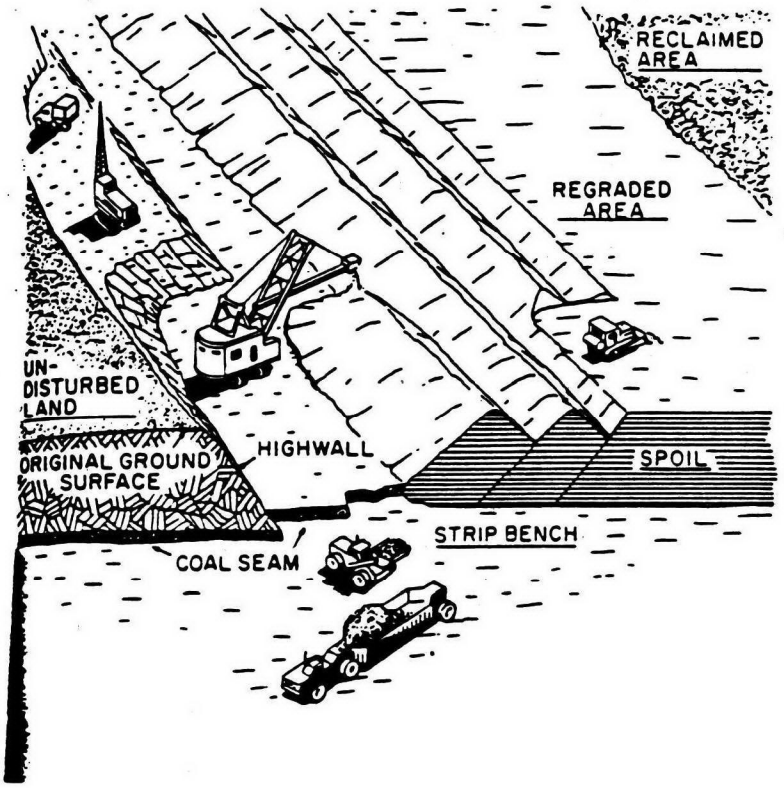
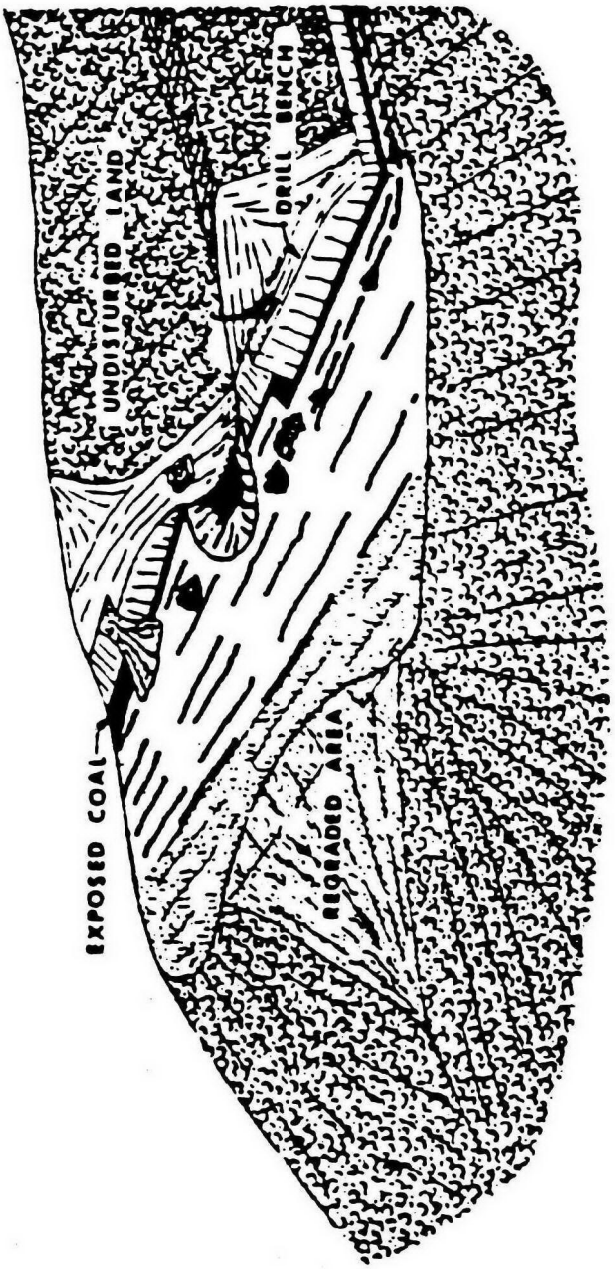


Exhibit 3-17. Mountaintop Removal With Head-of-Hollow Fill



coal seam at the outcrop remains undisturbed. This "bloom" or "blossom" of undisturbed coal acts as a buttress to help stabilize spoil slopes during mining operations and subsequent reclamation. Spoil from the initial cut is transported to the head of hollow fill or other approved stockpile area. Successive cuts are made parallel to the initial cut, and spoil from each successive cut is stockpiled in the trench of the previous cut. Final stabilization and revegetation of the mined area can result in flat to gently rolling terrain suitable for various uses.

3.4.2.2 Contour Mining

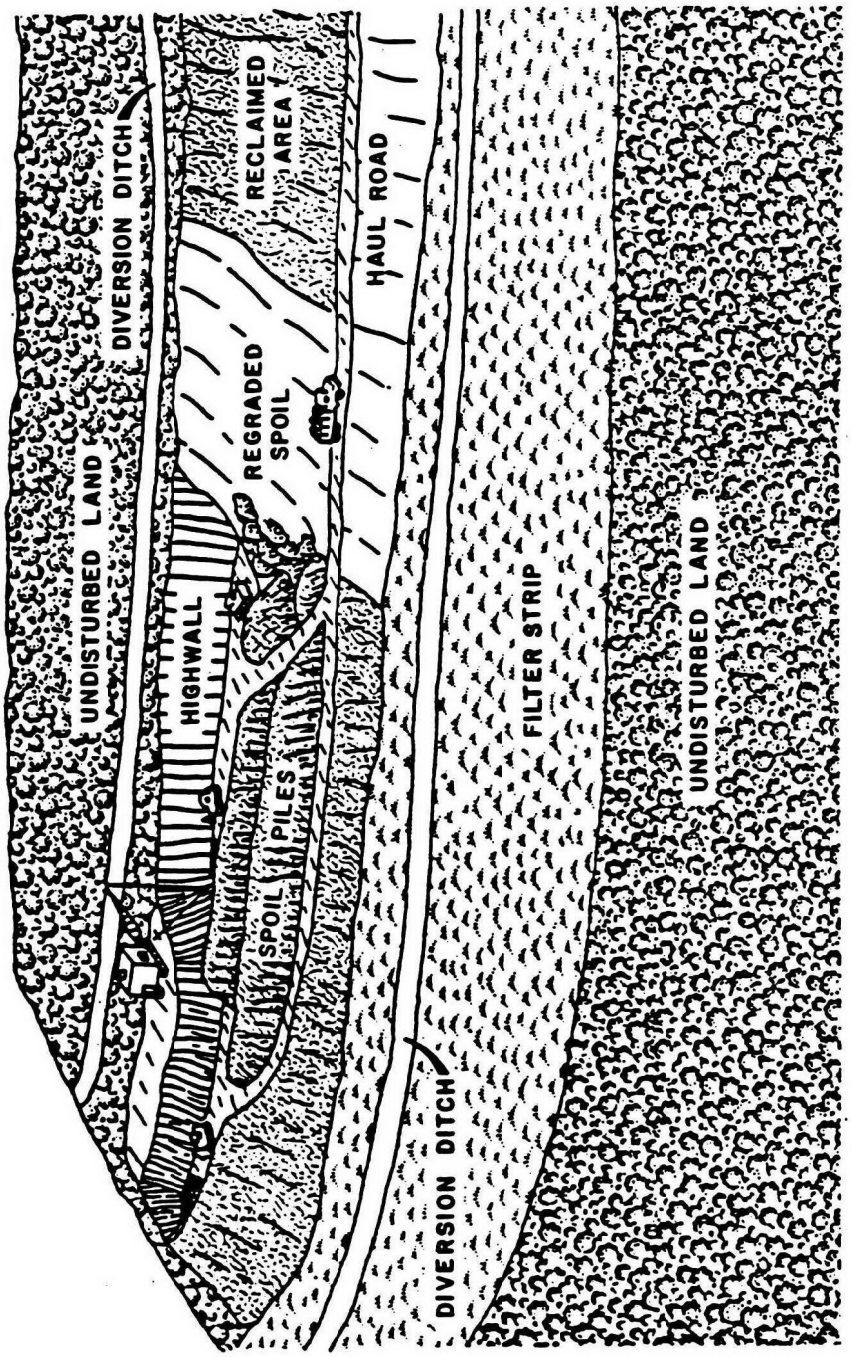
Contour mining methods generally are employed in the mountainous terrain of the Eastern coal province. Currently, contour mining makes use of one of three methods of operating: box-cut, block-cut, or haul-back.

Box-cut operations resemble area mines (Exhibit 3-18) but make use of a smaller number of cuts, usually two or three. The initial cut aligned parallel with the coal outcrop; mining progresses across the hill within each cut and uphill in successive cuts. Prior to the initial cut, a bulldozer clears vegetation from the box cut area and the area immediately downhill. As the initial cut is developed, overburden is pushed downhill forming an outslope. After coal is removed from the box cut, overburden from the next cut is placed in the mined out area. Operation of a dragline to place overburden into the mined out cut requires the development of a bench on the uphill (highwall) side of the operation. Operations making use of shovels and front end loaders can move overburden to the mined out cut without the development of a bench. A barrier of undisturbed overburden at least 15 feet wide is typically left at the downhill foot of the coal outcrop.

A haul road and parallel drainage ditch are constructed along the coal outcrop and the exposed coal is removed. Often the unrecovered coal seam at the base of the final highwall is mined with augers. Following maximum recovery by the augers, the auger holes generally are sealed with clay or some other nondeleterious, impervious material. The cut then is backfilled with previously stockpiled overburden so that (1) the backfilled slope is stable, (2) all highwalls are eliminated, and (3) toxic and acid-forming wastes and unmined coal seams will not contaminate ground and surface waters with deleterious siltation or leachate. Backfill is regraded to the approximate original contour, where possible. The regraded site is then revegetated with appropriate species of plants and monitored for a specified length of time to insure success of the revegetation effort. Haul roads are either abandoned in an acceptable manner or are stabilized for use during and after reclamation (Gentry and McCarter, 1992; Grim and Hill, 1974).

The development of a block-cut contour mine (Exhibit 3-19) is similar to box-cut mining, with major differences in spoil handling techniques and the sequence of mining sections. Whereas the box cut method generally proceeds up and around a mountain in one direction, block cut mining progresses in both directions along the coal outcrop. An initial block of overburden is excavated near the center of

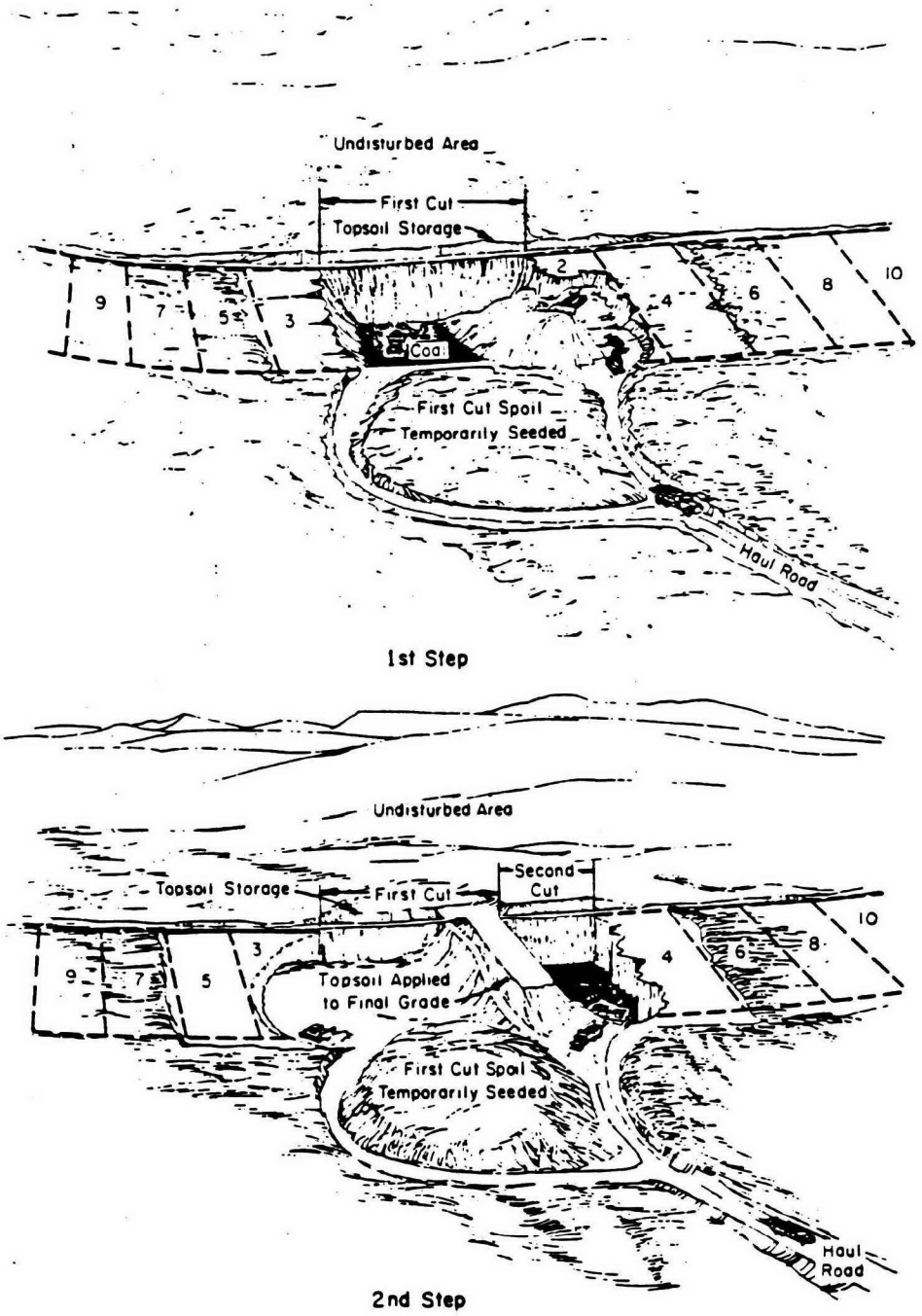
Exhibit 3-18. Box-Cut Mining Operations



Source: Adapted from Chironis, Nicholas P. (ed). 1978. Coal age operating handbook of coal surface mining and reclamation. McGraw-Hill, Inc., New York NY, 442 p.

Exhibit 3-19. Block-Cut Mining Operation

(Skelly and Loy, 1975)



the permit area, and spoil temporarily is placed downslope of the coal outcrop, or in a head of hollow fill. The initial cut is two to three times larger than successive cuts. After the coal has been loaded out, spoil from the second cut is placed in the trench of the first cut. Because the second cut is only one-third to one-half the width of the first cut, spoil from the third cut also can be placed in the first cut. The third cut is stripped as coal is loaded out of the second cut. In some cases, each successive cut is smaller than the previous cut, minimizing the amount of spoil to be hauled to final the cut. Block-cut mining can also be applied in area mining (Ramani and Grim, 1978; Gentry and McCarter, 1992).

Haulback mining can be used on smaller coal outcrops requiring greater flexibility than box-cut or block-cut methods. In this method, rectangular pits are developed along the contour of the seam. The width of the rectangle (pit) is established by topographic or economic recovery constraints. Overburden from the initial cut is stockpiled in a suitable location. As successive pits are developed, spoil is "hauled back" to the previous pit by truck, scraper or conveyor. The spoil from the initial box cut is deposited in the final pit. Reclamation occurs progressively with the backfilling and regrading of each successive pit (Gentry and McCarter, 1992).

3.4.2.3 Open Pit Mining

The only open pit coal operation currently in production includes a combination of area mining and contour mining techniques to recover coal from steeply dipping seams in the mountainous terrain of the western Wyoming. This operation is classified under the "Special Bituminous Coal Mines" category by OSM and is subject to special performance standards which closely parallel existing Wyoming law. Open pit techniques typically defer reclamation until the resource is mined out completely or to economic limits. This deferred reclamation for open pit methods contrasts with SMCRA's contemporaneous reclamation requirements.

Equipment selection, spoil placement, and the depth to which coal will be mined are dependent on the ratio of overburden thickness to coal seam thickness (overburden ratio) and the number of seams to be mined. Mining usually is initiated in the oldest (lowest) coal seam in the permit area. A dragline or stripping shovel can be used to cast overburden on both sides of the pit, forming spoil piles on the previously mined highwall and adjacent to the outcrop of the next coal seam to be mined. Coal is loaded out with shovels or bucket loaders, and bulldozers reclaim the mined area to a configuration approved by regulatory authorities. Combinations of scraper loaders and stripping shovels also can be used for overburden removal.

Coal seams thicker than 70 feet with overburden ratios of 1:1 or less are mined by multiple bench open pit methods. Emphasis in the development of this mining method is placed more on proper sequencing of coal loading, hauling, and storage techniques than on overburden handling. Overburden is removed from the initial cut by scraper loaders or a combination of shovels and

haulers, and is stockpiled adjacent to the pit. Subsequent overburden cuts are backfilled into the pit as stripping shovels load coal into haulers for transport to conveyors or unit trains. Both of these transport systems can feed preparation facilities or generating plants.

3.4.2.4 Special Handling

If segregation or selective placement of overburden horizons is necessary to achieve rehabilitation of the site to a particular post-mining land use, a combination of excavators, including scraper, loaders, draglines, bucket wheel excavators, and truck/shovel operations can be employed. Pit geometry may be engineered so that excavators can pass one another during bidirectional mining. It also may be necessary to place two or more excavators on separate benches to achieve proper location of spoil.

3.4.2.5 Equipment

The operational details of surface mines primarily depend upon the excavating, loading, and hauling equipment employed at the mine-site. Equipment selection generally is based on the depth and texture of overburden to be removed, the number of coal seams to be mined, the thickness of partings between multiple seams, the friability of the coal seams and the planned geometry of the pit.

Equipment used to remove overburden is based on the above criteria and includes the following, which may be used alone or in combination: draglines, shovels, bucket wheel excavators, front end loaders, scrapers, and bulldozers. Draglines and stripping shovels can be used if the overburden to be regraded in the mined-out trench or pit can be homogenized during stripping without adversely affecting the reclamation process. Shovels and front end loaders loading trucks can effectively handle wastes that need selective placement in the backfill. (Usually, a limited amount of special handling can be done using a dragline.) Scrapers are effective for removing shallow, unconsolidated overburden and bulldozers may be employed to prepare for benches or pads for draglines.

Coal is transported from the mine site to cleaning plants, transfer points, and consumption points via trucks and conveyors. Trucks used for coal hauling range in capacity from 25 to 150 short tons, and may off-load in a rear-dump, bottom-dump, or side-dump mode, depending on the design of the receiving station. Trucks in the lower load ranges can be operated on-road and off-road, subject to State and local restrictions. Mobile conveyor belts are used in some larger mines to decrease the truck haulage cycle time. Permanent conveyors can be employed to transport coal from truck dump points to cleaning plants, railheads, barge points, and consumption points.

3.4.3 Underground Mining Systems

Underground mining systems range in complexity from conventional drill-and-shoot operations to fully automated longwall systems. Summary discussions of mining systems (DOE, 1978; EPA, 1978, 1976d, and 1975) and comprehensive texts (Britton and Lineberry, 1992; Hittman Associates, Inc.,

1976) describe in detail the technical aspects of the development, operation, and abandonment of underground coal mines. This section presents an overview of underground coal production methods, including a brief discussion of each production method, and a general discussion of the environmental impacts typically associated with underground coal mining.

As stated previously, underground mines account for approximately 40 percent of domestic coal production. The majority of this production comes from operations using room and pillar methods. Longwall mining operations account for approximately 25 percent underground production. Shortwall mining techniques are employed but only to a limited extent (McElfish and Beier, 1990).

The following presents descriptions of underground mining systems using the minimum level of detail necessary to identify the sources of potential environmental impact associated with underground coal mining.

Like new operations in other mining sectors, opening a modern underground coal mine represents planning, development, and intensive capital investment for several years preceding the profitable production of coal from the mine. Underground mines are significantly more expensive to develop and operate than surface mines. Therefore they usually are planned for long-term operation in coal seams that are not recoverable economically by surface mining methods alone.

The considerations necessary to put an underground coal mine into production, including development, ventilation, roof stability, and moving the coal from the site of extraction to a loadout or cleaning plant, are similar to those of other underground operations as discussed above in Section 3.1. The buildup of methane gas within the mine workings is an additional concern unique to underground coal mining; additionally, in some circumstances, subsidence tends to be a greater problem than in other underground mining operations. This discussion will focus on those aspects where underground coal mining techniques differ from those employed at non-coal operations.

3.4.3.1 Development

The development or construction of an entire underground coal mine may take decades, and extraction may commence in some parts of the mine years before development begins in others. While mine development is underway, the some coal may bee produced, however, the extent of production may be minuscule compared to the annual tonnages produced during full scale operation. Plans for mine development and extraction may change radically after mining commences, based on the availability of capital, innovative technology, and markets. However, after a operating plan has been approved and a permit issued, these types of changes must be approved by OSM or the State regulatory authority as amendments or revisions to the current permit.

Mine development generally includes a standard set of operations beginning with the establishment of access to the coal seam.. Conventional drill-and-blast techniques may be used to drive entryways for initial access. Once the seam is accessed (or if the seam is accessible by an outcrop), coal cutting machinery is used further develop entryways and crosscuts, producing a honeycomb of unexcavated coal and voids. The configuration of entryways and crosscuts depends on the strength and thickness of the coal seam and overburden, the amount of subsidence permissible, and the method used for recovering the coal (Britton and Lineberry, 1992; Hittman Associates, Inc., 1976). Roof control systems are installed within the entryways and crosscuts. The specific method used for roof control is a function of the geometry of coal left in place during mine development. Bolts, props, trusses, shields, and other artificial roof support systems are used to prevent roof falls.

Ventilation, haulage, and electrical systems are installed as development progresses. One function of the layout of pillars and barriers is to minimize the cost of providing adequate ventilation to all working areas of the mine. A minimum number of entryways and crosscuts also is necessary for rapid and efficient transport of coal from work areas.

The pattern of crosscuts and entryways appropriate for an individual mine is determined on the basis of lithology of the overburden, safety requirements, conservation practices, and workspace needs underground. In the ideal situation, entryways and crosscuts are advanced through the coal seam to the limits of the property to be mined. Coal then is extracted from pillars and longwalls in retreat (that is, in the direction opposite to the development advance).

To support the roof properly, a generally symmetric system of pillars, barriers, abutments, and ribs remains unexcavated until the extraction phase commences. The dimensions and geometry of unexcavated features generally reflect their intended life spans and purposes, as well as the strengths and structural properties of the coal seam and overburden.

An underground mine may be reached through shaft, drift, or slope entryways. Shafts and slope entryways are driven through overburden to reach the coal seam where it is not exposed at an outcrop. The choice of vertical shaft versus slope entryway usually depends on the proposed size of the entryway and the proposed haulage system, as well as the ventilation system and other service considerations. A drift entryway is driven into a coal seam from its outcrop.

3.4.3.2 Extraction

Coal is extracted during production either with conventional drill and shoot techniques or by continuous mining systems. Extraction systems for mine development and coal production are chosen based on the operator's experience, available capital, and the following coal seam variables:

- Seam height, which determines one economic basis for choosing a mining system. Conventional mining systems become less efficient as seam height or thickness increases. Longwall mining systems are impeded by variations in seam height.

- Bottom quality, which ranges from excellent (dry, firm, and even) to poor (wet, soft, and pitted or rutted), and affects machine operations by limiting traction and restricting maneuverability.

- Roof quality, which limits the amount of coal that may be extracted from the without artificial protection against collapse of the mine roof.

- Methane liberation, which in some seams occurs at a rate proportional to the rate at which coal is cut or sheared from the working face. Methane accumulates and sometimes ignites in underground workings when it is not removed by the ventilation system. Methane accumulation is monitored at least once every 20 minutes at the seam face, causing disruption of otherwise continuous work cycles.

- Hardness of seam, which primarily affects the choice of coal cutting equipment.

- Depth of seam, which determines the response of the overburden to excavation of the coal seam.

- Water, which may infiltrate the underground workings through channels, fractures, fissures, or other water transmitting voids in mine walls, roof, and bottom.

Conventional (drill and shoot) mining systems utilize five categories of unit operations (Hittman Associates, Inc., 1976) which can proceed simultaneously at separate working faces. The categories include:

- Cutting a slit or kerf along the bottom of the working face across its full length

- Drilling a pattern of blast holes into the working face

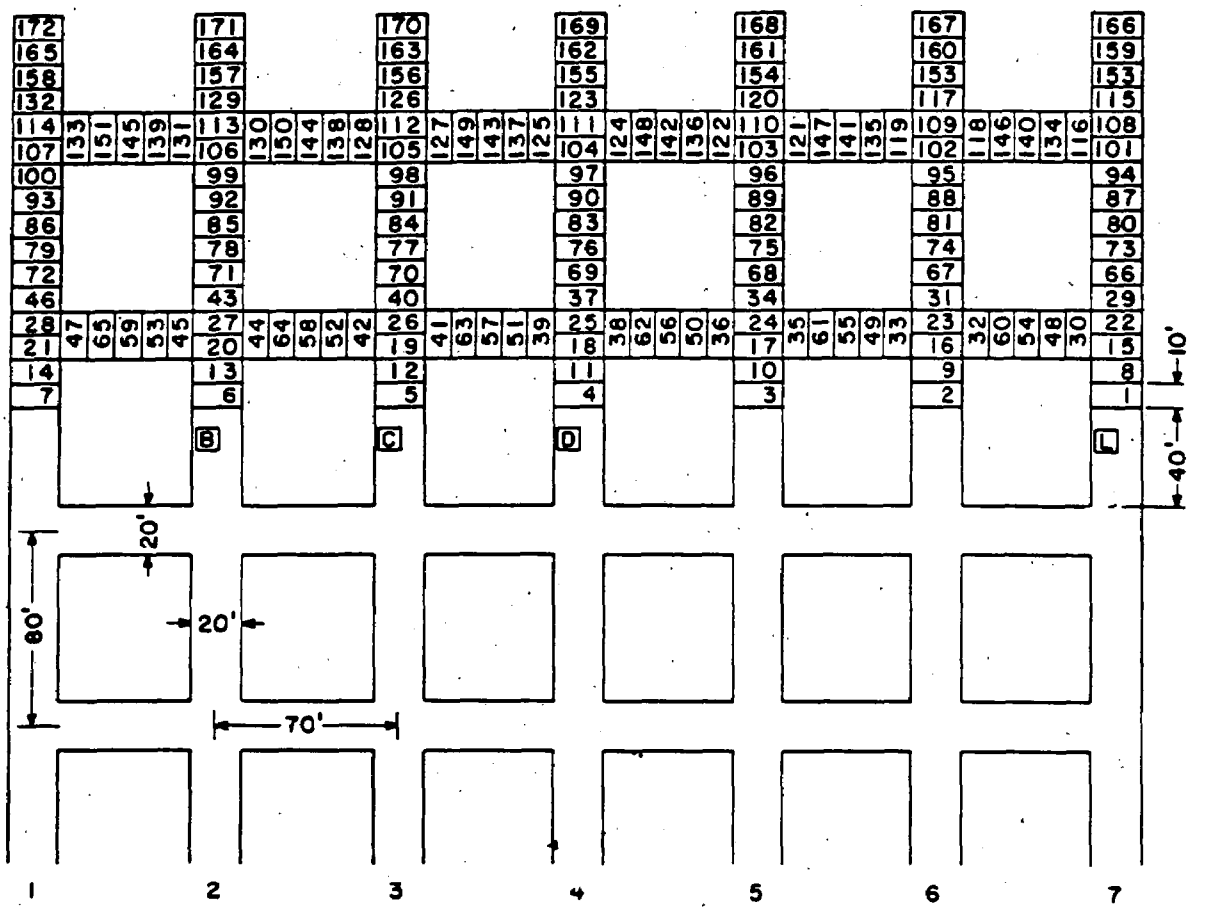
- Blasting the coal with chemical agents or charges of compressed gas

- Loading and hauling the fractured coal from the face to a centralized crushing and loadout facility for shipment to the cleaning plant

- Roof bolting with rods, trusses, props, and bolts to ensure the safety of underground personnel and to minimize the deterioration of roof conditions before a mining section is abandoned.

A typical sequence for mine development and extraction with conventional techniques is shown in Exhibit 3-20. The flow of work depicted in the figure is from right to left. Each numbered panel represents an approximate 3 m (10 ft) thickness of coal to be extracted.

Exhibit 3-20. Operations in Conventional Room and Pillar Mining



Equipment Deployment
L Loading machine
S Shuttle car
D Mobil coal drill
C Cutting machine
B Bolting machine

The cycle of unit operations in Exhibit 3-20 starts with coal loading and ends with roof bolting. After the coal is loaded from Panel 1, the bolting crew moves up to the face of Panel 8 to secure the roof over Panel 1. A coal cutting machine then is moved or trammed to Panel 8. A cut 3 m (10 ft) deep is made in the coal seam with the machine-mounted blade, which is extended into the seam from the stationary machine. The cutting blade is inserted into the base of the coal and is traversed across the width of the panel (usually 6 m or 20 ft); the blade produces a narrow kerf, or slot along the base of the recoverable coal.

After the cutting machine is trammed to the next panel (panel 9), the drilling crew cuts a specified pattern of blast holes into the face of Panel 8. The holes are loaded with a blasting agent and then shot, exposing the working face of Panel 15. The cycle at Panel 8 then returns to loading, and the coal is removed from the face area ahead of the bolting crew.

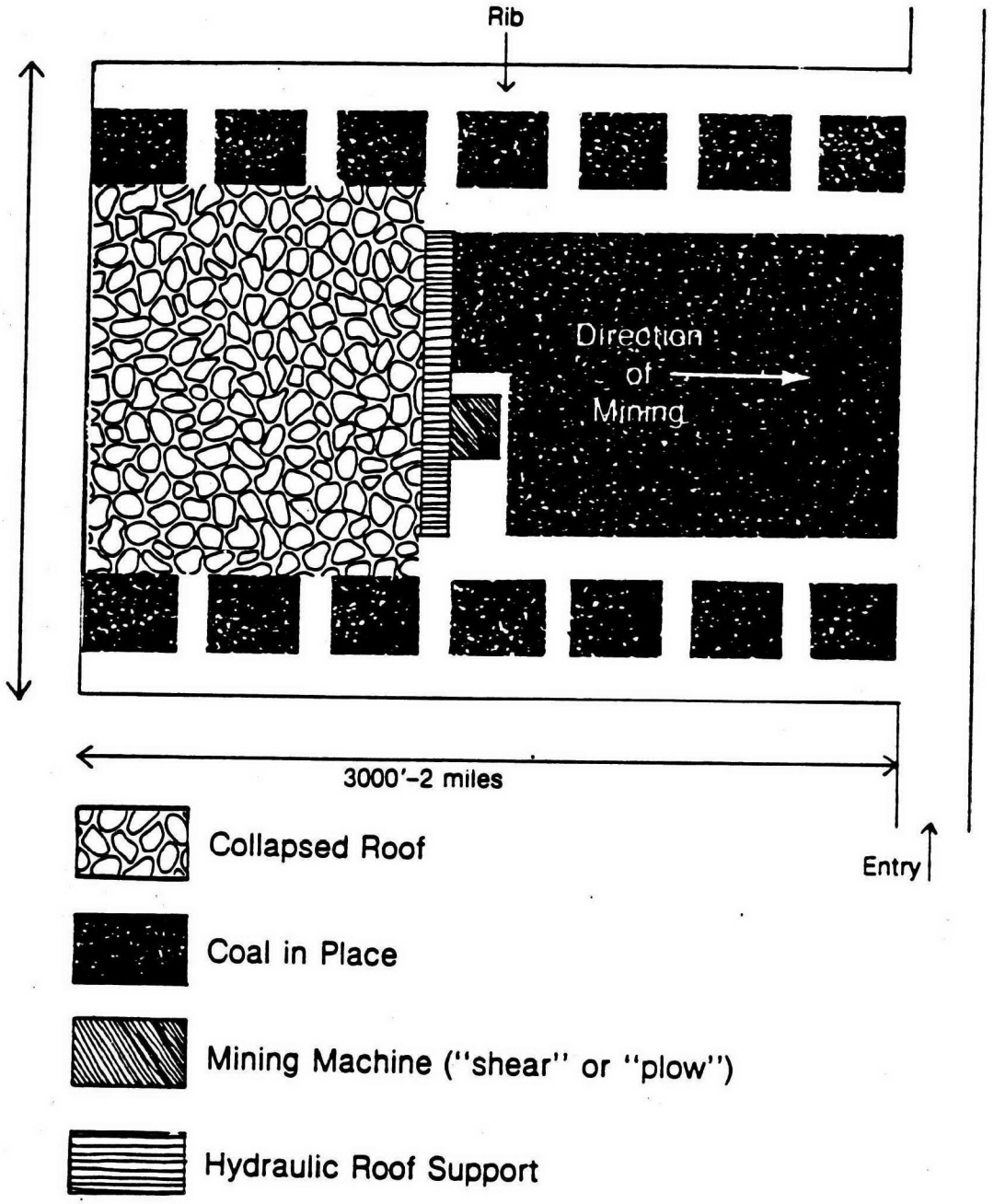
Continuous mining systems generally employ fewer workers per face and produce more tons per worker and per shift than conventional systems. The efficiency of continuous mining systems remains essentially unchanged with increasing seam height. Conventional systems reach a point of diminishing return as seam height reaches 1.8 m (6 ft).

Continuous mining systems use machinery to extract coal during room-and-pillar, shortwall, and longwall operations. Machinery and panel configurations are chosen within the constraints of the coal seam variables described previously.

Continuous room-and-pillar operations are based on the capabilities of coal cutting machinery to combine the unit operations of conventional mining techniques (cut, drill, shoot, and load) into one continuous operation; roof bolting may also proceed in conjunction (and slightly behind) continuous mining. The operation may be halted periodically for methane checks and the installation of electrical, conveyance, and ventilation services. Coal is cut from the face with cutters, borers, augers, and shearers that direct the cuttings to conveyor belts mounted inboard on the machine assembly. These inboard conveyors feed the coal to the mobile conveyor belts, shuttlecars, or load-haul-dump (LHD) vehicles that transport the coal to the permanent haulage system, which may be another conveyor or a train of mine cars pulled by a locomotive.

Longwall mining systems employ one or more parallel entryways located approximately 90 to 180 m (300 to 600 ft) apart and connected by a cross cut (Exhibit 3-21). The equipment necessary to conduct the operation including the cutter, conveyor, shield, and roof supports are inserted through the crosscut. Coal is sheared or planed from the face and then directed onto the conveyor, which feeds the coal to a semi-stationary haulage system located in an adjacent entryway. Roof supports advance toward the cut face hydraulically, leaving the roof of the mined area (gob) to collapse as the

Exhibit 3-21. Longwall Mining System



unsupported overburden subsides into the mined-out chamber. When longwall mining methods are used, there is a clear potential for surface subsidence, as described in section 4.8.

Longwall systems are typically applied in situations where uniformity exists throughout the coal seam in terms of height, bottom and roof conditions, hardness, and areal distribution. Longwall mining of multiple seams is possible under some conditions. Shallow seams are mined first, followed by progressively deeper seams. Overburden structures and lithologic characteristics influence the rate and form of the resultant caving and should be considered in the design/development phase.

Longwall mining systems offer the following advantages over other mining systems (DOE, 1978):

- Lower cost per ton of coal produced
- Higher productivity per worker hour
- Higher percentage of recovery of coal resource
- Predictable subsidence
- Adaptability to thick and multiple seams
- Capability to mine at great depths.

Shortwall mining systems are similar in principle to longwall systems. During shortwall mining, coal is cut from a panel approximately 45 m (150 ft) long. Roof supports advance toward the panel as mining progresses. The unsupported, undermined areas subside into the void behind the advancing roof supports. The panel length is short enough to be worked economically with the conventional mining machinery used in room-and-pillar systems, although automated shearers also are available for shortwall systems.

Shortwall systems can be used to change existing mining operations from room-and-pillar techniques to wall-type mining techniques without additional costs for the replacement of machinery or revision of plans for mine development. Advanceable roof supports may be the only additional equipment required to consummate the change-over. Shortwall operations also offer the advantage of flexibility in selecting the locations of mining panels or walls to minimize the interruptions in production that result from changes in seam height and the presence of want areas, unsuitable roof and bottom conditions, and gas and oil wells.

3.4.3.3 Abandonment

The techniques that are appropriate for the abandonment of an underground mine generally reflect the manner in which the mine was developed. Water infiltrates to the mine void through overlying and adjacent strata. Drift entryways that are advanced up the dip of the coal seam will allow this water to drain freely from the mine, unless suitable seals are installed at the drift mouth. Entryways that are advanced down the dip of the seam must be pumped during mine operation. After abandonment,

water drains to the depths of the mine, forming a subterranean pool that may slowly drain to the surface through channels, fractures, and other small voids.

The following kinds of seals frequently are installed at mine openings during abandonment:

- Dry seals to prevent the entrance of air and water into mine portals where there is little or no flow of water and minimal potential to develop hydrostatic pressure against the seal.
- Air seals to reduce the flow of air into the mine while allowing water to drain from the mine. Even these mines can still "breathe" through minute cracks and fissures because of continued changes in atmospheric air pressure. Enough oxygen usually is available under these conditions for formation of acid drainage if sufficient pyrite and water are present.
- Hydraulic seals which plug the discharge from flooded mine voids and exclude air from the mine, thus retarding the oxidation of sulfide minerals.

Hydraulic seals may be employed to seal the drift mouths of entryways that were developed up the dip of the coal seam. A hydraulic seal may include one or more bulkheads constructed with timbers, walls of concrete block, backfilled material, and grout curtains injected through boreholes from the surface. These abandonment techniques and others are thoroughly described in other EPA publications (EPA, 1973 and 1975).

3.4.3.4 Pollution Control

Significant advances have been made in pollution control techniques used in the surface coal mining industry. Evolving technologies include:

- Alternate mining methods, emphasizing controlled spoil placement and reclamation concurrent with extraction
- Wastewater treatment systems, emphasizing innovative techniques to replace limestone treatment systems and rapid-filling sediment ponds, both of which suffer from reduced treatment cost ratios as a result of recent regulations
- Revegetation systems, emphasizing the replanting of reclaimed areas with plant species which have been specially bred for replanting of local minespoils
- Soil stabilization systems, emphasizing (1) the use of soil mechanics in slope design, and (2) soil covering agents such as stubble mulches, cover crops, artificial soil amendments and chemical binders, and mulches to prevent wind and water erosion of recently backfilled areas or temporarily stockpiled soils.

3.4.3.5 Environmental Effects

The physical disturbance associated with surface coal mining and the surface aspects of underground mining are the same as those of other mining sectors. Surface disturbance reduces the cover and primary productivity of the land. The loss of vegetation cover results in an increase in erosion and without adequate control, sediment concentrations are likely to increase in nearby streams. Ground disturbance and constant movement by vehicles also increases fugitive dust carried in the wind.

Wildlife habitat is lost at least temporarily with surface disturbance while noise and human activity create additional impacts in the immediate vicinity of mining operations. Although these impacts are to be expected with any mining or other surface-disturbing activity, they may be particularly acute when mining operations are being conducted on adjacent parcels of land over an extended period of time.

Other environmental effects resulting from coal mines depend on the nature of the operation (surface versus underground) and to some extent, its location (east versus west). In addition to the surface water impacts associated with most mining activities, surface coal mining operations may also impact groundwater. In the east, particularly, acid mine drainage remains a problem despite developments in the technology surrounding prediction and control. Acid mine drainage is discussed in Section 4.1 and will not be discussed further here. Subsidence is a response to underground mining activities. Although concentrated in the east and midwest, impacts from subsidence have also occurred in Wyoming and Colorado. A discussion of subsidence is presented in Section 4.8.

The extent of impacts to groundwater depends primarily on the premining hydrologic system and the chemical constituents of the overburden. As with other forms of surface mining, the geologic strata overlying the coal (or ore) are removed during extraction. Non-coal mining operations typically store this material in waste rock piles outside the pit while coal mining operations are required to place overburden back into the mined-out portions of the mine. As overburden is placed into the pit the hydrologic setting is changed from consolidated, heterogeneous strata to a highly permeable, homogeneous mass. The groundwater level and flow rate can be affected by the increased permeability of the backfill in the pit. The potentiometric surface will eventually stabilize, however the new surface may not reflect the premining water level.

3.5 COAL PROCESSING

3.5.1 BASIC PRINCIPLES

Coal preparation is a critical technology supporting both the mining and end-use of coal. The output of a coal mine consists not only of coal but also non-combustible mineral matter. This mineral matter ranges in size from large rocks to extremely small grains dispersed throughout the coal seam. The primary objective of coal beneficiation is the separation and removal of mineral matter from coal to

reduce transportation costs, and improve product quality by reducing ash loading in the boiler. Burning coal with less ash increases boiler efficiency, boiler capacity, plant availability, and net heat rate. Reductions in auxiliary power consumption, forced outages, particulate emissions and capital costs of new power plants all accompany the use of lower ash coals. Additionally, as-mined raw coal often fluctuates in quality and this is detrimental to boiler operation. Coal beneficiation produces a relatively uniform product and therefore assures stable boiler operation.

Concerns over the environmental effects of coal burning expanded the objective of coal beneficiation to include removal of inorganic sulfur in coal. More recently, researchers are examining coal preparation as a means of reducing air toxic precursors. As New Source Performance Standards (NSPS) were developed for coal-fired utility boilers, advanced coal cleaning technologies were simultaneously developed to remove 70 to 80 percent of the pyritic sulfur present in coal and recover 70 to 80 percent of the combustible matter. The Clean Air Act Amendments of 1990 (CAAA) provided further impetus for coal preparation. Utilities could now choose between several compliance options such as switching to premium low-sulfur coals, emission allowance trading, or post-combustion clean up. Risk averse utilities could choose to pursue a mixed CAA compliance strategy because of the volatility of stand-alone strategies. Coal preparation became another viable option to meet compliance regulations by its ability to convert high and medium-sulfur/ash coals to low-sulfur/ash coals.

The types of equipment used to remove mineral matter from raw coal are numerous and the configurations in which they are used in cleaning plants can be complex. Despite the complexity of actual operating plans, there are only two underlying principles upon which all physical cleaning plants operate: (1) differences in specific gravity between the organic, combustible matter and the inorganic mineral matter present in coal, and (2) differences in surface properties between organic and inorganic matter. Conventional coal cleaning processes are based on the former principle, whereas advanced cleaning processes are based on the later principle.

Conventional coal cleaning involves the immersion of raw coal in a medium that simulates a predetermined specific gravity. The lighter material is removed as a clean "float" product, while the heavier material or "sink" is rejected as refuse. The majority of coal mined in the United States is cleaned using this principle. A small percentage of coal consisting of very fine particles in the raw product cannot be cleaned using gravity methods. With fine particles in aqueous systems, surface forces become comparable with gravity forces and hence, gravity-based separation becomes ineffective. Consequently, these fine particles, being only a small portion of the raw coal, are usually discarded. Alternatively, a technique known as froth flotation may be used to clean these fine particles. Unlike specific gravity separation which exploits differences in the specific gravities of particles, froth flotation is based on differences in the surface properties of coal and mineral matter. Coal surfaces are typically hydrophobic but the surfaces of the refuse material associated with coal are

hydrophilic. By passing air bubbles through a coal-water suspension, coal and refuse particles can be separated; the refuse material sinks while the air bubbles attach themselves to the coal particles and buoy them to the surface where they are collected in a froth.

The actual process of separating raw coal from its associated impurities, using either the specific gravity separation principle or froth flotation, is only one of the four processes that coal cleaning can involve. The other three processes are crushing, screening, and dewatering. Crushing serves to break down large heterogeneous particles into smaller, purer particles prior to separation. The extent to which crushing can liberate coal from impurities depends in large part on the depositional characteristics of the coal seam. For example, if the impurities are finely disseminated throughout the seam, liberation may be relatively difficult. If, on the other hand, the impurities exist as thick bands of rock within the seam, with weak bonds to the coal, then the raw particles will tend to break along the weak bonding planes during crushing, resulting in extensive liberation of the coal from the rock. In any event, the success of the subsequent separation process depends in large part on the degree of liberation achieved through the crushing process. All particles must report to either a float or a sink fraction during the separation process; thus, the existence of heterogeneous particles means that the clean float particles will contain mineral impurities, and the rejected sink material will contain coal. Coal cannot be completely liberated from its associated impurities through crushing—some heterogeneous particles will remain. Whether any given heterogeneous particle reports to the float or sink depends on the overall specific gravity (or, in the case of froth flotation, the overall hydrophilic tendencies) of the particle.

Following crushing, but prior to separation, the raw coal is typically screened. Screening is used to divide the raw particles into pre-defined size ranges. The various types of equipment used in the separation process typically achieve maximum efficiency when processing feed of a relatively uniform, narrowly-defined size range. For example, equipment based on the specific gravity separation principle fails below a minimum particle size; for coal particles this is usually 25 mesh (575 microns) or 100 mesh (149 microns). For finer particles froth flotation must be used. Thus, the separation process typically consists of two or three separate circuits, each using a different equipment type designed to handle a specific size range of particles. Screening is used to direct the raw coal particles to the proper circuits.

Finally, after separation, the clean coal and refuse are generally dewatered. Moisture, like ash and sulfur, is an undesirable impurity; through the dewatering process the moisture content of the clean coal can be reduced.

A perfect separation of coal from its associated impurities is not possible using either the specific gravity separation or froth flotation. This is because, in practice the separation process is

fundamentally stochastic in nature. As mentioned earlier, some composite particles consisting of mineral matter and coal will remain even after crushing.

Sulfur occurs in coal in both pyritic and organic form. Pyrite is a mineral that is not an integral part of coal, but is normally associated with it. Hence, it is possible to separate coal and pyrite using a physical cleaning technique. Organic sulfur on the other hand, is an integral chemical component of coal and cannot be separated through physical cleaning.[2] The theoretical limit to the amount of sulfur that can be removed from a given coal through physical cleaning is equivalent to the amount of sulfur occurring in pyritic form.

The degree to which the separation falls short of perfection is dependent on the raw coal qualities, the cleaning equipment used, plant operating conditions, and the washability of the coal. Coal washability can be roughly defined in terms of the degree to which a coal can be separated from its associated impurities.

Raw coal feed consists of particles combining coal and impurities in various proportions; thus, the particles cover a wide spectrum of specific gravities. The washability of a coal defines this spectrum and consists of the percentage (or cumulative percentage), by weight, of the raw coal comprising contiguous specific gravity intervals, along with the quality (Btu, sulfur, and ash contents) of each specific gravity fraction. Exhibit 3-22 is an example of washability data for a sample of a bituminous, high volatile A coal from the Pittsburgh bed in Jefferson County, Ohio.[3] The data are divided into three size ranges of coal. Within each size category, the percentages (by weight) of the raw coal with specific gravities less than 1.3, 1.4, and 1.5 are given (e.g., 48.6 percent of the raw coal in the 1½ inch × 100 mesh size range has a specific gravity less than 1.3). Also, the Btu content, ash content, and sulfur content corresponding to each specific gravity fraction are given; in the previous example, that portion of the raw coal with a specific gravity less than 1.3 has a Btu content of 14,146 (per pound basis).

Washability data are developed experimentally. A sample of coal is collected, crushed to a given topsize, and screened into separate particle size ranges. A sample from each size range is immersed in organic liquids possessing definite, precise specific gravities. The material that floats at each specific gravity is weighted and analyzed to determine its Btu, sulfur and ash content. Returning to our previous example, 48.6 percent of the 1½ inch × 100 mesh sample floated when place in a liquid

[2]Organic sulfur can be removed through chemical cleaning. However, chemical cleaning is not a commercially viable option at present.

[3]Sulfur and Ash Reduction Potential of United States Coals, Vol. 1, p. 395, Eastern Region, U.S. Dept. of Energy, DOE/PETC/TR-90/7.

Exhibit 3-22. Ash and Sulfur Reduction Potential of U.S. Coals, Vol. I p. 395, Eastern Regions U.S. Department of Energy

State: Ohio County: Jefferson			BRD: Pittsburgh Rank: High Volatile A				BRD Code: 35 Sample No: 135
Cumulative Washability Data (Dry Basis)							
Sample Crushed to Pass 1-1/2" (Float-Sink Performed on 1-2/2" X 100 M Material)							
Product	Recovery, Percent		ASH, %	Sulfur, Percent		Heating Value BTU/LB	SO2 Emission LB/MM STD
	Weight	STU		Pyritic	Total		
Float 1.30	48.6	53.1	4.6	0.82	1.82	14,146	2.6
Float 1.40	83.8	49.8	6.2	1.34	2.34	13,670	3.4
Float 1.60	92.6	97.5	7.5	2.60	2.54	13,645	3.7
COM (1-1/2" x 100M)	100.0	100.0	11.6	2.10	3.05	12,936	4.7
100M x 0	1.3	1.2	17.7	5.13	5.58	12,086	9.3
Total (1-1/2" x 0)	100.0	100.0	11.7	2.22	3.08	12,925	4.8
SAMPLE CRUSHED TO PASS 3/8: (FLOAT-SINK PERFORMED ON 3/8" x 100M MATERIAL)							
Float 1.30	54.9	60.9	3.9	0.74	1.65	14,267	2.3
Float 1.40	82.3	89.9	3.4	1.13	2.04	14,000	2.9
Float 1.60	90.9	97.0	6.8	1.38	2.26	13,767	3.3
COM (3/8" x 100M)	100.0	100.0	11.9	1.98	2.79	12,904	4.3
100M x 0	4.6	4.5	13.3	4.03	4.56	12,645	7.2
Total (3/8" x 0)	100.0	100.0	11.9	2.07	2.87	12,092	4.5
SAMPLE CRUSHED TO PASS 14H (FLOAT-SINK PERFORMED ON 14H" x 0 MATERIAL)							
Float 1.30	41.9	49.9	2.9	0.38	1.33	14,439	1.4
Float 1.40	78.7	85.6	4.7	0.73	1.35	14,129	2.2
Float 1.60	89.9	96.4	6.2	0.94	1.78	13,870	2.6
COM (14H x 0)	100.0	100.0	11.3	2.05	2.82	12,990	4.3

RAM COAL SIZE AND MOISTURE ANALYSES			
Size Distribution, Percent; Sample Crushed to Pass 1-1/2"		Moisture, Percent	
1-1/2" x 3/8"	77.1	Total	5.1
3/4" x 14M	17.2	As Received	4.2
14M x 100M	4.4		
100M x 0	1.3		

with a specific gravity of 1.3; this "float" had a Btu content of 14,146 (per pound basis). The specific gravity of the bath (1.3 in the example) is referred to as the specific gravity of separation.

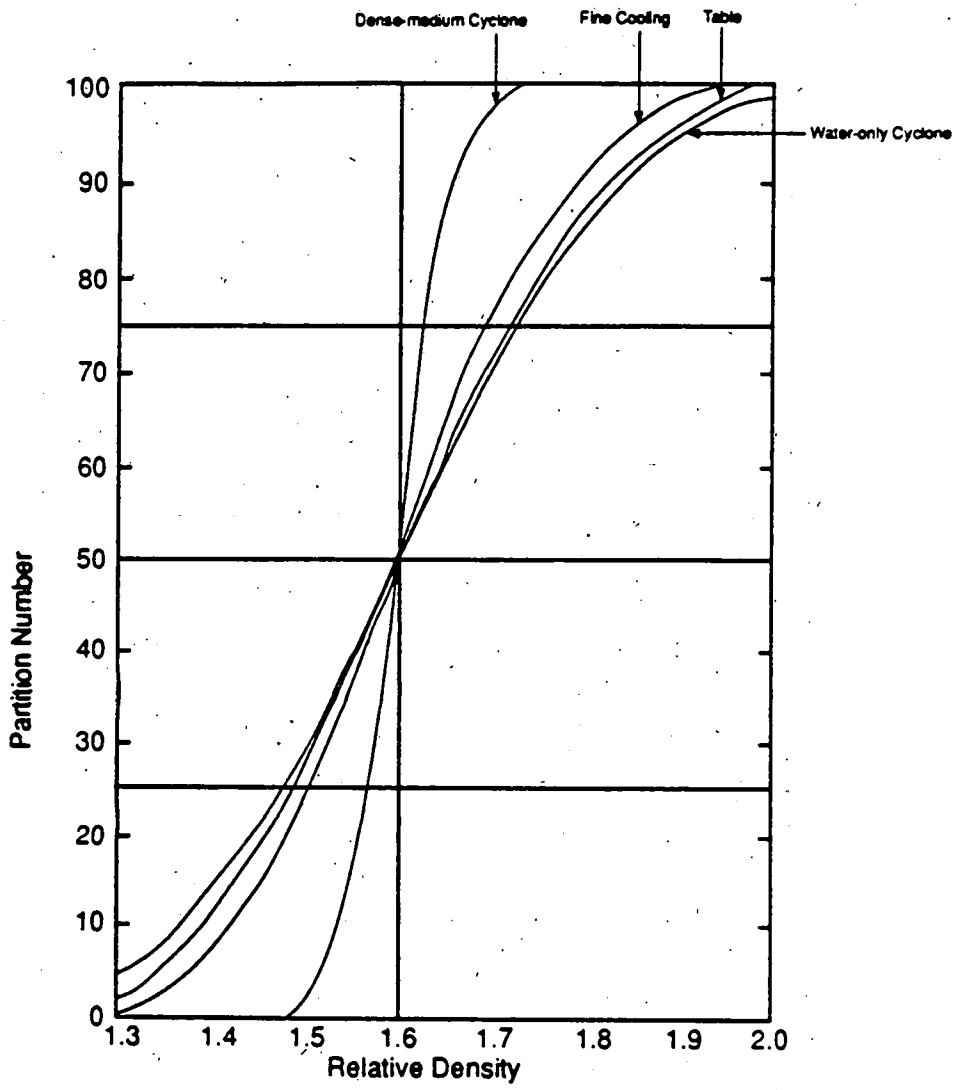
Commercial cleaning plants achieve gravity separations by employing various techniques (including, e.g., suspensions of ground solids in water) to simulate the heavy liquid media used in the laboratory. The behavior of a coal sample in a laboratory bath, as measured during washability tests, provides a theoretical limit of how the coal will behave in a commercial cleaning plant.[4] Washability data, like those presented in Exhibit 3-22, are used to estimate the yield and clean coal quality for a given coal cleaned at a given specific gravity of separation. For example, if the 1½ inch × 100 mesh coal from the earlier example is to be cleaned at a specific gravity of separation of 1.6, Exhibit 3-22 predicts that the yield will be 92.4 percent. The clean product will have a Btu content of 13,646 (per pound basis), an ash content of 7.5 percent, and a total sulfur content of 2.54 percent. Commercial cleaning plants rarely reach these theoretical levels of product quality. Computer models for simulating coal preparation can be used to estimate commercial plant performance. Such models use washability data to predict the yields associated with cleaning various coals to meet predefined quality specifications.

An important characteristic of all washability data is the trade-off between coal quality and quantity. From Exhibit 3-22, for all three particle size fractions, Btu content increases and ash and sulfur content decrease as the yield decreases. Thus, improvements in coal quality can be obtained only at the expense of reductions in yield; this is true of all coals including the sample represented in Exhibit 3-22. Not only are there technical limits to the percentage of ash and sulfur that can be removed from coal through cleaning, there are economic limits as well. For example, referring to Exhibit 3-22, we can see that it is technically feasible to reduce the sulfur content of 1½ inch × 100 mesh coal to 1.82 percent; however, the resulting yield would be 8.6 percent. From an economic standpoint, it is unlikely that the benefits obtained by reducing the sulfur content to 1.82 percent would outweigh the costs associated with the loss of 51.4 percent of the coal.

The common way of assessing or evaluating coal cleaning systems that use gravity separation techniques is to determine the sharpness of separation achieved. This is done using partition curves. The partition curve of any given equipment that separates coal and mineral matter is essentially a histogram of the distribution of coal groups of different densities in the product. Typically the histogram is represented in the form of a cumulative curve with the partition coefficient on abscissa and relative density on the ordinate. Such a curve is shown in Exhibit 3-23. In an ideal separation the curve is parallel to the abscissa at the density of separation . The partition curve is typically characterized by two parameters d_p and e_p. d_p is the relative density corresponding to partition coefficient 50. This is the relative density at which an infinitesimal increment of raw feed is equally

[4]Laboratory washability data represents separation at ideal (equilibrium) conditions, whereas separations in an actual plant do not have sufficient time to reach equilibrium and conditions for separation are non-ideal.

Exhibit 3-23. Washability Partition Curve



divided between clean coal and refuse. e_p, the probable error, gives an indication of the deviation from ideal separation and is calculated as the slope of the curve around d_p. e_p is also a function of the particle size and the density of separation. Each equipment in a coal preparation plant operates at a particular d_p and e_p.

Although washability data provide an indication of how coal will respond when cleaned using gravity-based equipment, they do not indicate how coal will respond to surface-based separation equipment, such as froth floatation.

Coarse ore tailings or coal refuse can be used to construct an impounding dam, typically within a drainageway or narrow valley. Then, a slurry of finer tailings or refuse can be pumped into the impoundment area for settling (similar to tailings impoundments described for metal mining above). As with other tailings impoundments, these can be quite large, with impoundments reaching over 100 feet high and 1,000 feet long. Both NPDES and Clean Water Act §404 regulations can, in some situations, prevent the construction of such impoundments. When they are allowed, the major environmental concern is the destruction of the drainage that is being filled. States generally require that existing instream uses of surface waters be protected and maintained (generally known as "non-degradation" policies), and these often prevent such impoundments.

3.5.2 Coal Cleaning Technology

EPA has an ongoing research and applications program that may significantly affect the future form and economics of current and developing coal cleaning technologies (Section 1.3.3.). Reports of this program describe in detail the coal cleaning technologies currently used by the mining industry (Nunenkamp, 1976; McCandless and Shaver, 1978). The engineering principles of mechanical coal cleaning also are described more thoroughly in other sources (Leonard and Mitchell, 1968; Cummins and Given, 1973; Merritt, 1978). The following discussion of coal cleaning technology summarizes the elements of mechanical coal preparation in the detail necessary to identify the impacts and pollution control strategies associated with proposed projects.

The mechanical cleaning of coal generally includes the five basic stages (Exhibit 3-24) described below. The number of stages employed and the unit operations that comprise each stage may vary among individual operations, although Stages 1, 2, and 3 are common to most of the Nation's coal cleaning facilities (Exhibit 25).

- **Stage 1—Plant Feed Preparation.** Material larger than 21 cm (6 in) is screened from the ROM coal on a grizzly. The properly sized feed coal is ground to an initial size by one or more crushers and fed to the preparation plant.

- **Stage 2—Raw Coal Sizing.** Primary sizing on a screen or a scalping deck separates the coal into coarse- and intermediate-sized fractions (Exhibit 3-26). The coarse fraction is

Exhibit 3-24. Coal Preparation Plant Processes

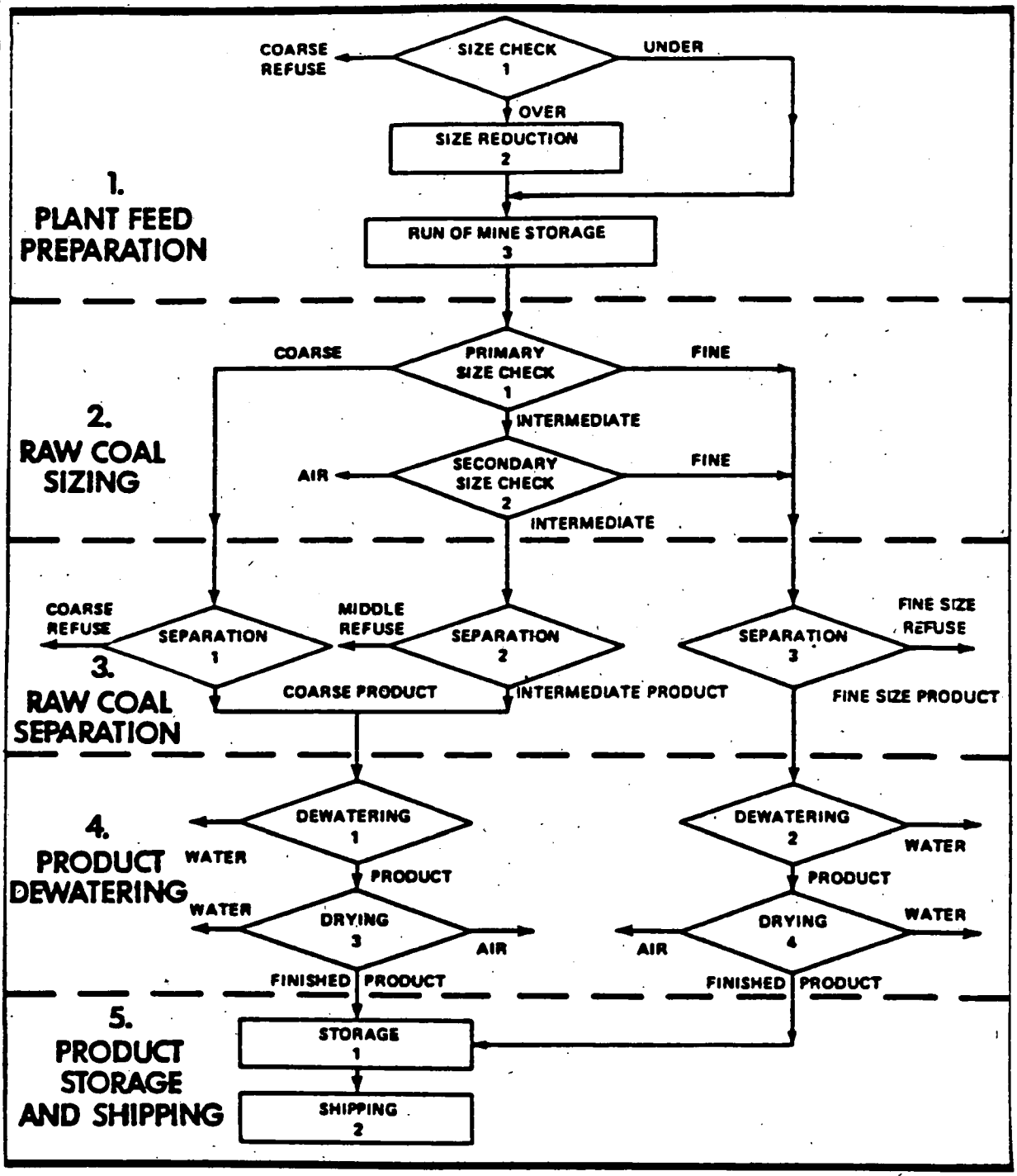
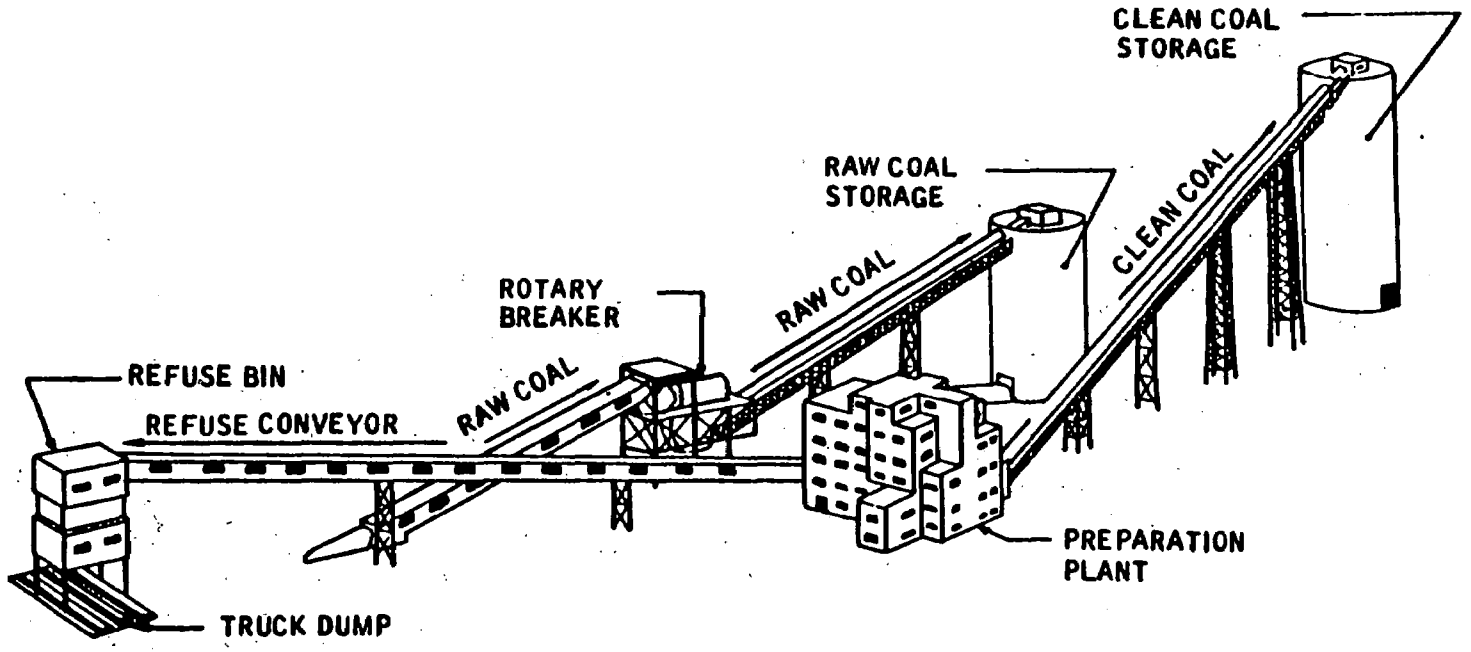
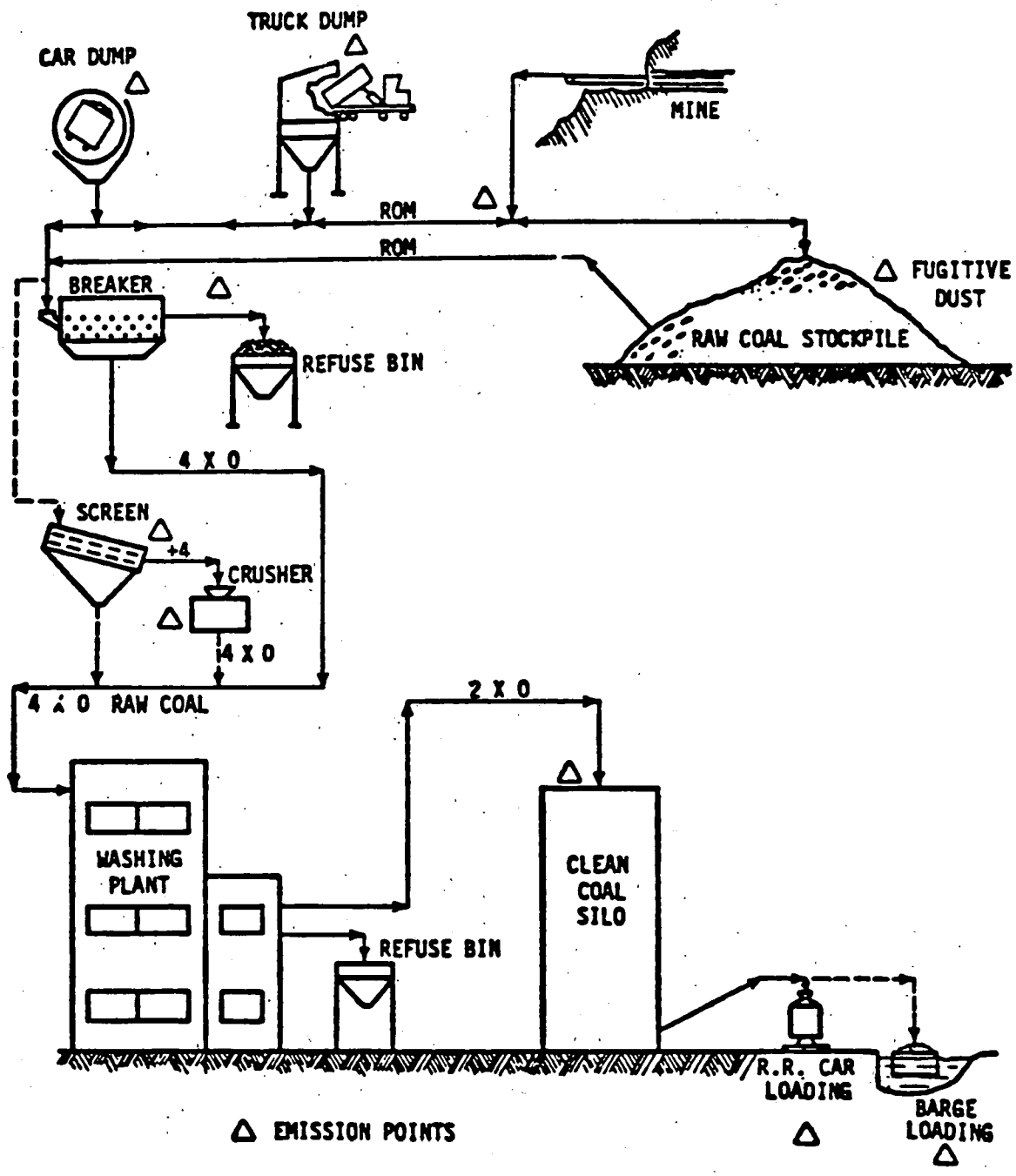


Exhibit 3-25. Typical Coal Cleaning Facility



Source: Nunenkamp, David C., 1976.

Exhibit 3-26. Typical Circuit for Coal Sizing Stage



Source: EPA, 1977.

crushed again if necessary and subsequently is re-sized for cycling to the raw coal separation step. The intermediate fraction undergoes secondary sizing on wet or dry vibrating screens to remove fines, which may undergo further processing. The intermediate fraction then is fed to the raw coal separator. Coal sizes generally are expressed in inches or mesh size (Exhibit 3-27). In Exhibit 3-26, the notation 4 × 0 indicates that all of the coal is smaller than 10 cm (4 in). A notation such as 4 × 2 indicates that the coal is sized between 5 and 10 cm (2 and 4 in). The notation 4+ indicates that the coal is larger than 10 cm (4 in).

Exhibit 3-27. Metric and English Equivalents of U.S. Standard Sieve Sizes and Tyler Mesh Sizes

U.S. Standard Sieve No.	Mesh Size		Tyler Mesh No.
	cm	inches	
4	.475	.187	4
6	.335	.132	6
8	.236	.0937	8
10	.200	.0787	9
12	.170	.0661	10
14	.140	.0555	12
16	.118	.0469	14
18	.100	.0394	16
20	.085	.0331	20
30	.060	.0234	28
35	.050	.0197	32
40	.0425	.0165	35
45	.0355	.0139	42
50	.030	.0117	48
60	.025	.0098	60
70	.0212	.0083	65
80	.0180	.0070	80
100	.015	.0059	100
120	.0125	.0049	115
140	.0106	.0041	150
170	.009	.0035	170
200	.0075	.0029	200
230	.0063	.0025	250
270	.0053	.0021	270
325	.0045	.0017	325

- **Stage 3—Raw Coal Separation.** Approximately 97.5 percent of the U.S. coal subjected to raw coal separation undergoes wet processes, including dense media separation, hydraulic separation, and froth flotation. Pneumatic separation is applied to the remaining 2.5 percent (DOE, 1978b). The coarse-, intermediate-, and fine-sized fractions are processed separately by equipment uniquely suited for each size fraction. Refuse (generally shale and sandstone), middlings (carbonaceous material denser than the desired product), and cleaned coal are separated for the dewatering stage.

- **Stage 4—Product Dewatering and/or Drying.** Coarse- and intermediate-sized coal generally are dewatered on screens. Fine coal may be dewatered in centrifuges and thickening ponds and dried in thermal dryers.

- **Stage 5—Product Storage and Shipping.** Size fractions may be stored separately in silos, bins, or open air stockpiles. The method of storage generally depends on the method of loading for transport and the type of carrier chosen.

For a typical coal cleaning plant with 910 MT (1,000 T) per hour capacity, approximately 70 percent of the crushed coal reports to the coarse cleaning circuit. Sizing and recrushing of the coarse coal result in the cycling of 34 percent of the coarse coal charge to the fine and intermediate cleaning circuits. Approximately 27 percent of the coarse charge is removed as refuse. The remaining 39 percent is removed as clean product. Process quantities for the fine and intermediate cleaning circuits appear in Exhibit 3-28.

Exhibit 3-28. Typical Process Quantities for a 910 MT (1,000 T) per Hour Coal Cleaning Facility

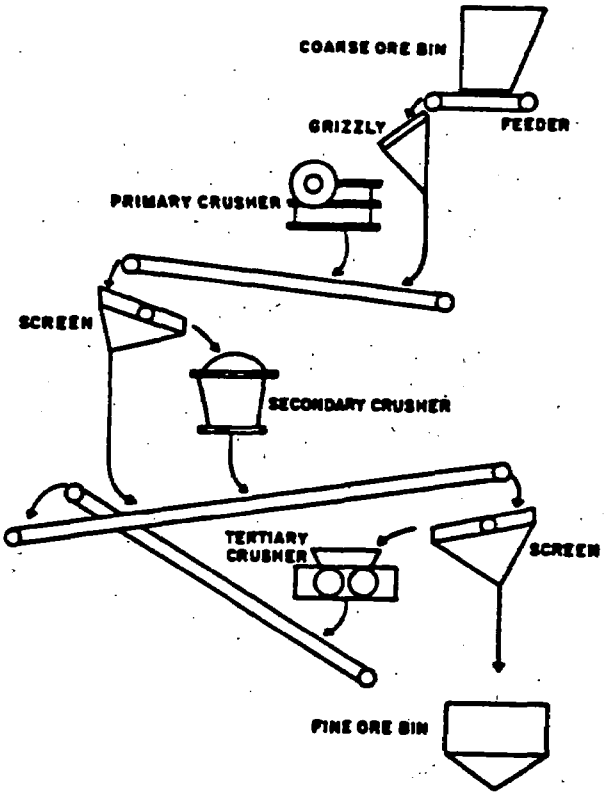
	Washing Circuit		Dewatering Circuit		Process Water		Refuse Recovery	
	MT/hr	%	MT/hr	%	MT/hr	%	MT/hr	%
Coarse coal fraction	630	69	245	39	3,293	12	173	63
Intermediate coal fraction	190	21	330	52	7,040	26	82	30
Fine coal fraction	90	10	58	9	16,427	61	19	6
Thermal dryer dust							3	1
Total	910	100	633	100	26,760	100	277	100

Source: Nunenkamp, David C. 1976. Coal Preparation Environmental Engineering Manual. EPA, Office of Research and Development, EPA-600/2-76-138, Washington, D.C., 727 p.

3.5.2.1 Stage Descriptions

The initial screening and crushing of ROM coal at Stage 1 (Exhibit 3-24) may be accomplished in one or more substages (Exhibit 3-29). The grizzly can be a set of iron bars, welded on 21 cm (6 in) centers to a rectangular frame. Oversized material that would otherwise inhibit the operation of the primary crusher is scalped from the feed coal on the grizzly bars. In a multicrusher system, the output from the primary crusher is screened. Over-sized coal is fed next to a series of crushers, and finer material reports directly to sizing and separation stages.

Exhibit 3-29. Typical Three-Stage Crusher System for Raw Coal Crushing

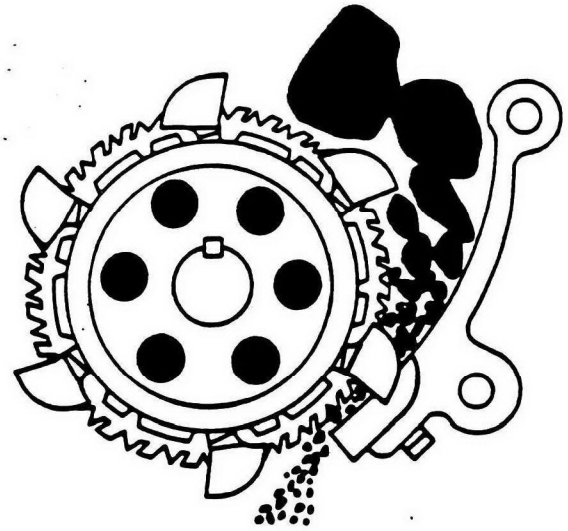


The types of mills that are available for Stage 1 crushing include rotary breakers, single and double roll crushers, hammermills, and ring crushers. Each type of mill is available in various models which crush the ROM coal at different rates to different sizes. The general characteristics of crushing mills appear below (McClung, 1968).

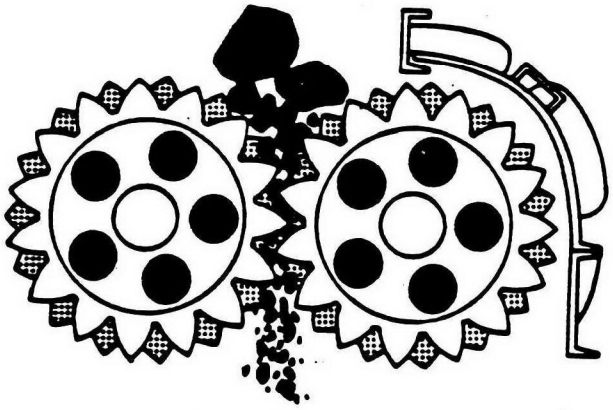
- **Rotary breaker.** Often called the Bradford breaker after its inventor, this large, rotating cylinder is driven at 12 to 18 revolutions per minute by an electric motor via a chain and reducer drive. ROM coal is introduced through one end of the cylinder and is crushed against the encircling steel plates. The crushed coal exits the breaker through the precut holes in the plates and feeds to a conveyor. Slate, overburden, rock, and other gangue materials that resist breakage are carried by a series of baffles to the far end of the cylinder, where they are removed from the mill by a continuously rotating plow.

- **Single- and Double-Roll Crushers.** A roll crusher comprises one or two steel rollers studded with two different lengths of heavy teeth. The long teeth slice the large pieces of coal into fragments and feed the flow of coal into the smaller teeth, which make the proper size reduction. In single-roll mills, the coal is crushed against a stationary breaker place (Exhibit 3-30a). Double-roll crushers also fragment the coal with specially designed teeth. Crushing action against the rollers (between the teeth) is minimal (Exhibit 3-30b). Both mills are fed through the top. Product exits through the bottom.

Exhibit 3-30. Single-Roll (a) and Double-Roll (b) Crushers for Sizing of Raw Coal



(A)



(B)

Source: McClung, J.D., 1968. Breaking and crushing. In Joseph W. Leonard and David R. Mitchell (eds.), 1968.

- **Hammermill.** This mill uses a set of hammers to strike the feed coal against a breaker base plate. The rebounding fragments are swept against a perforated steel plate or crushing grate and discharged to a bin or conveyor.

- **Ring crusher.** The principles of hammermill and ring crusher operations are similar. Instead of hammers, the ring crushers uses a set of smooth and toothed rings to drive the feed coal against the breaker plate.

The unit operations that commonly are employed at Stage 3 of Exhibit 3-24 (separation) vary considerably among modern cleaning installations nationwide. The choice of unit operations for a particular installation depends on a number of factors, including coal preparation objectives, availability and costs of equipment, and operator experience. Nine of the typical unit operations that currently are employed during the separation step are listed below (McCandless and Shaver, 1978). With the exception of froth flotation, all of these operations utilize the specific gravity principle to affect a coal/impurities separation. Water requirements, sizes and rates of feed, and dewatering efficiencies of selected unit processes are described in Exhibit 3-31.

- **Dense Media.** Light, float coal is continuously skimmed from a suspension of solids in water that separates from heavy liquid with a defined specific gravity (usually magnetite; Exhibit 3-32). Finely-ground magnetite is usually used in the suspension, in part because it can be easily recovered from the clean coal and refuse by magnets. Accuracy of separation is sharp from 0.059 to 20 cm. Quality and sizes of feed can fluctuate widely.

- **Froth Flotation.** A slurry of coal and collector agents is blended to induce water-attracting tendencies in selected fractions of the feed coal. After the addition of a frothing agent, finely disseminated air bubbles are passed through the slurry. Selected coal particles adhere to the air bubbles and float to the surface, to be skimmed off the top. The process can separate fractions in a band of 0.045 to 1.18 mm (0.002 to 0.05 in). Froth flotation affects a good separation between coal and ash, but does not successfully separate coal from pyrite, because the latter mineral is, like coal, hydrophobic. Better sulfur reduction results can be obtained using two-stage flotation. The first stage proceeds as described above. In the second stage, the float product is re-slurried and then treated with an organic colloid that selectively prevents the coal particles from floating to the top with the pyrite.

- **Humphrey Spiral.** A slurry of coal and water is fed into the top of a spiral conduit. The flowing particles are stratified by differences in density, with the denser fractions flowing closer to the wall of the conduit. A splitter at the end of the stream separates the stratified slurry into final product and middlings. These products are fed to separate dewatering facilities.

- **Hydrocyclones.** A slurry of coal and water is subjected to centrifugal forces in an ascending vortex. The denser refuse material forms a layer at the bottom of the vessel. Circulating water skims the clean coal from the top of the stratified slurry and directs the product to a vortex finder, which feeds the cyclone overflow into the product dewatering stage (Nunenkamp, 1976). Feed coal sizes range between 0.044 and 64 mm (0.002 and 2.5 in).

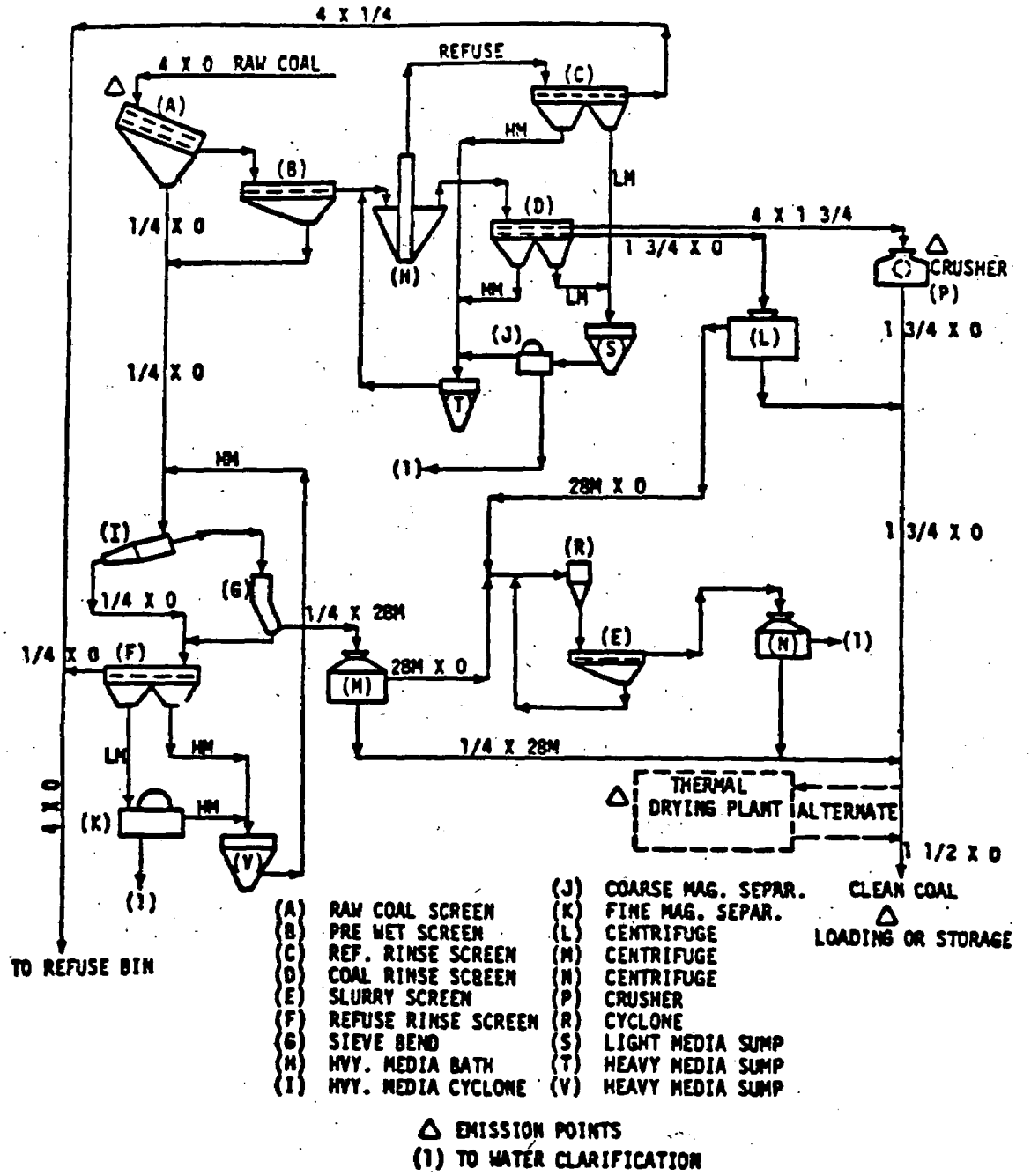
Exhibit 3-31. Feed Characteristics of Unit Cleaning Operations for Sizing and Separation of Crushed Coal

Coal Cleaning Unit	Water Required per MT of Feed (lph)	Maximum Feed Rate (MTph)	Range of Feed Sizes (cm)[1]	Percent Solids in Feed
Baum jig	12 to 21	9.8 to 48 per m^2 of jig area	0.3 to 20	85 to 90
Belknap washer	21	124	0.6 to 15	85 to 90
Chance cone	29 to 50	488 per m^2 of cone area	0.2 to 20	85 to 90
Concentrating table	50 to 67	9.1 to 14	0 to 0.6	20 to 35
DSM heavy media cyclone	83 to 125 (heavy media slurry)	4.5 to 32	0 to 0.6	12 to 16
Flotation cell	54 to 67	1.8 to 3.6	0.030 to 0.0075	20 to 30
Humphrey spiral	125	0.9 to 1.4	0.6 to 0.0075	15 to 20
Hydroseparator	58 to 75	1.4 per vertical cm of vessel	1.3 to 13	85 to 90
Hydrotator	50 to 67	49 per m^2 of surface	0 to 5.1	85 to 90
Menzies cone	58 to 75	273	1.3 to 13	85 to 90
Rheolaveur free discharge	12 to 17	1.1 to 1.8 per cm of vessel	0 to 0.6	15 to 30
Rheolaveur sealed discharge	25 to 50	2.9 to 3.6 per cm of vessel	0.6 to 10	15 to 30

[1]Range of feed sizes is listed for bituminous coal only. Anthracite feeds for Menzies cones and hydroseparators range between 0.08 and 13 cm. The DSM cyclone accepts anthracite feeds between 48 mesh and 0.75 in. The flotation cell accepts 200 to 28 mesh. The Belknap washer does not process anthracite.

Source: Aplan, F. F. and R. Hogg, 1979. Characterization of Solid Constituents in Blackwater Effluents From Coal Preparation Plants. Prepared for the EPA and U.S. DOE, EPA-600/7-79-006, FE-9002-1, Washington, D.C., 203 p.

Exhibit 3-32. Typical Circuit for Dense Media Coal Cleaning



Source: EPA, 1977.

- **Jiggings.** A slurry of coal and water is stratified by pulsating fluid. Clean, low density coal is skimmed from the top of the vessel. The accuracy of separation is low. Sizes of feed coal range between 3.4 and 76 mm (0.1 and 3 in; Exhibit 3-33).

- **Launders.** Raw coal is fed with a steam of water into the high end of a trough. The coal-water stream stratifies as it flows down the incline. The denser refuse material forms the bed load of the trough while the less dense coal is suspended in the stream. The cleaned product is split from the stream at the low end of the trough. Feed coal sizes range between 4.76 and 76 mm (0.19 and 3 in).

- **Pneumatic.** Streams of pulsating air stratify the feed coal across a table equipped with alternating decks and wells (Exhibit 3-34). Refuse is pushed into the wells and withdrawn under the table. The cleaned product rides over the refuse and is withdrawn at the discharge end of the table. Feed coal sizes range to a maximum of 9.5 mm (0.38 in; Exhibit 3-35).

- **Wet tables.** A slurry of coal and water is floated over a table that pulsates with a reciprocating motion. Denser refuse materials flow toward the sides of the table, while the cleaned coal is skimmed from the center. Feed coal sizes range between 0.15 and 6.4 mm (100 mesh and 0.25 in).

The process waters used during the coal separation stage generally are maintained between pH 6.0 and 7.5. Waters with lower pH inhibit the flotation of both coal and ash-forming substances. As pH increases, the percentage of floating coal maximizes, but the percentage of floating refuse also increases. The pH of process waters may be elevated with lime. Reagents may be added to control the percentage of suspended fines (Zimmerman, 1968).

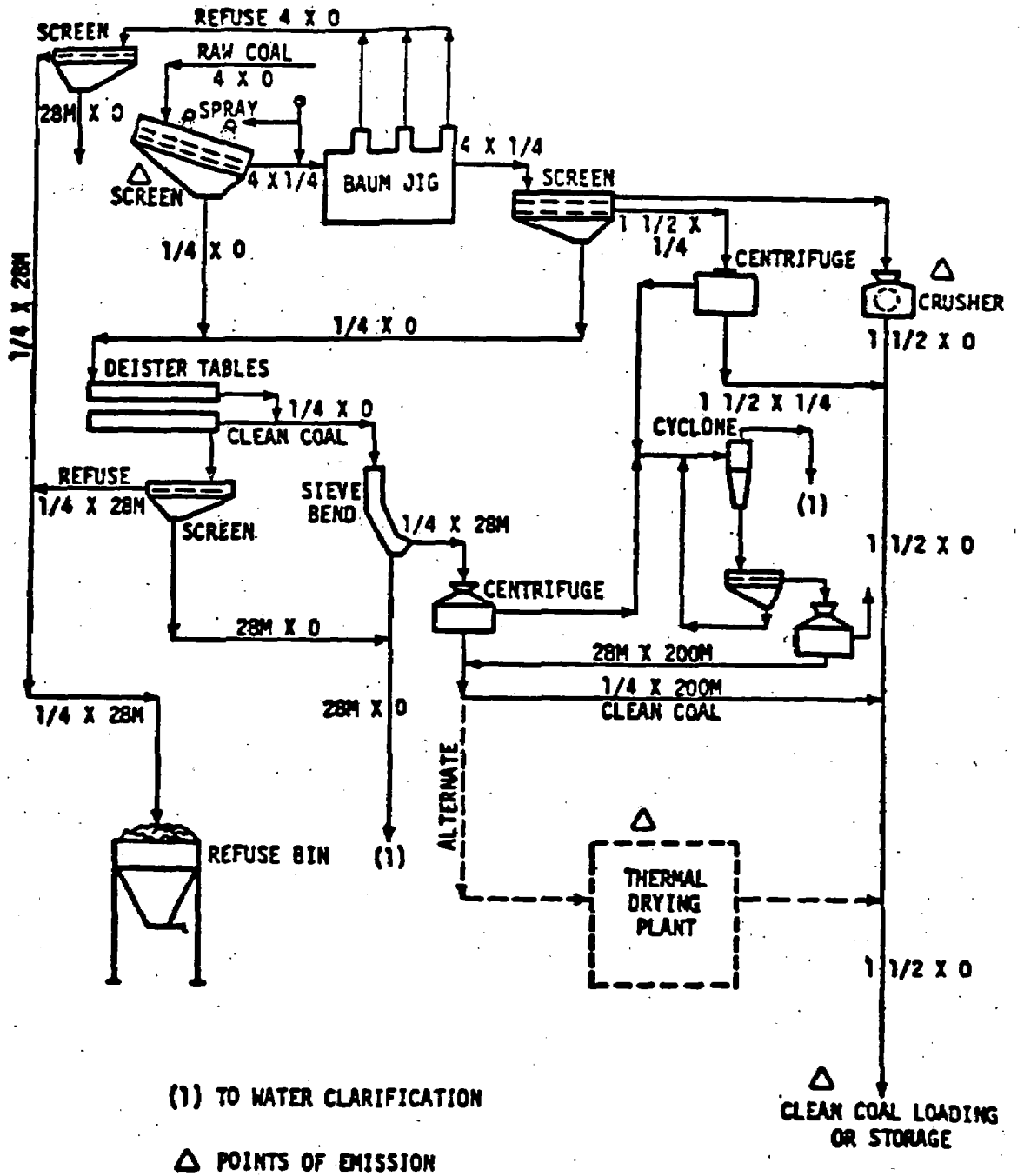
Make-up water for cleaning plant operation ideally has a neutral pH, low conductivity, and low bicarbonate content. The water preferably is free from contamination by sewage, organic material, and acid mine drainage. Other dissolved constituents also should occur in low concentrations (Exhibit 3-36).

Product dewatering (Stage 4 of Exhibit 3-24) includes the use of mechanical devises, thermal dryers, and agglomeration processes to reduce the moisture contents of processed coal and refuse (McCandless and Shaver, 1978; Exhibit 3-37). The moisture contents of products dried by typical processes appear in Exhibit 3-38. Mechanical processes are of two general types:

- In-stream process that do not produce a final product (hydrocyclones and static thickeners). These processes remove approximately 30 to 60 percent of the moisture in feed material. Thickeners and cyclones usually are placed on line with other drying devices that reduce the moisture contents further.

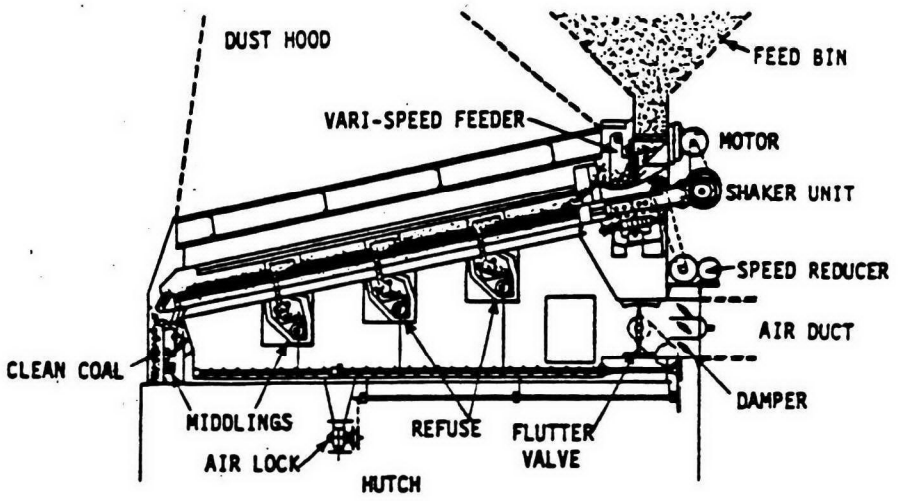
- End-of-stream processes that produce a final product (screens, centrifuges, spiral classifiers, and filters).

Exhibit 3-33. Typical Circuit for Jig Table Coal Cleaning



Source: EPA. 1977.

Exhibit 3-34. Typical Air Table for Pneumatic Coal Cleaning



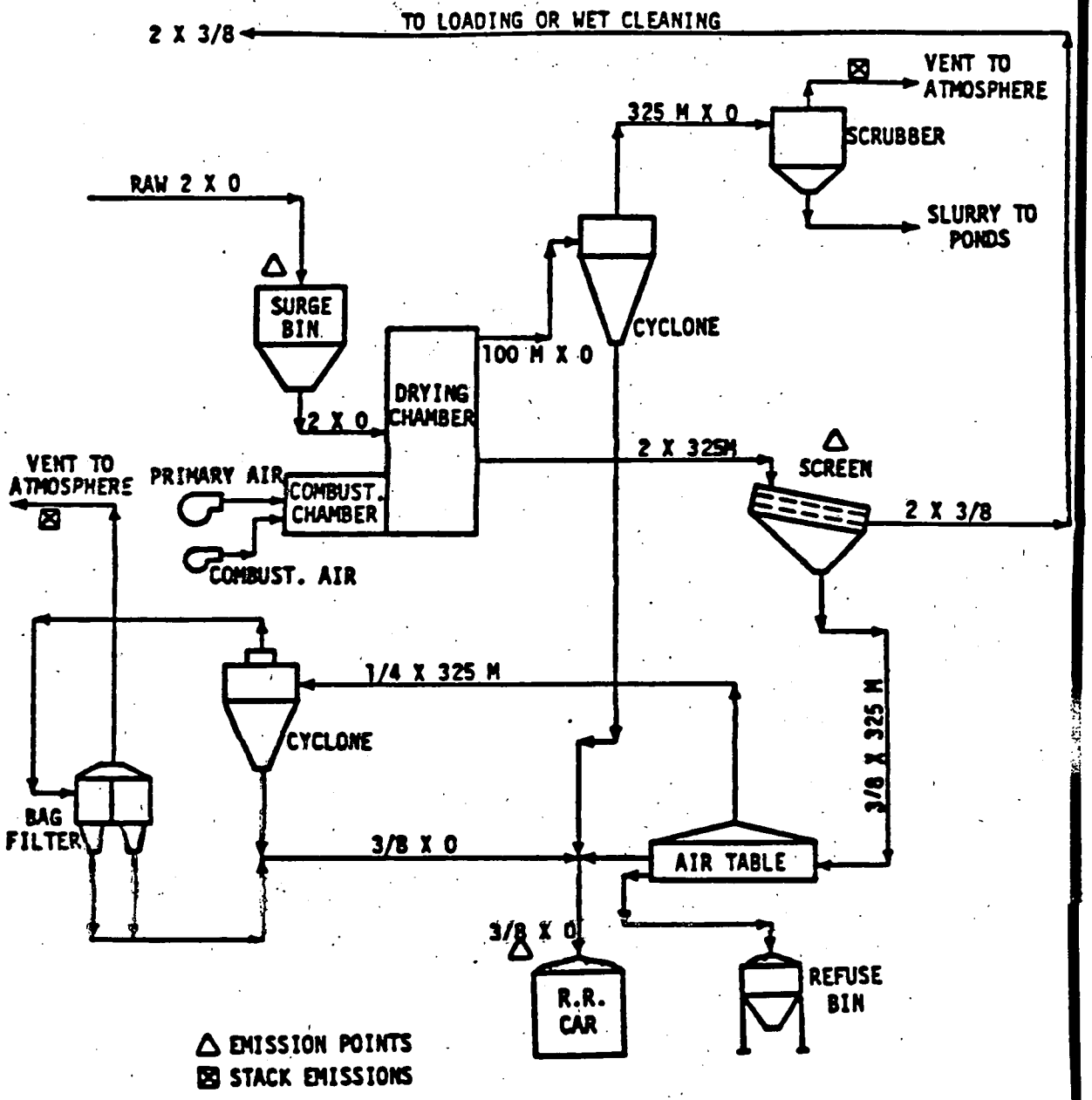
Several of the process that are used for Stage 3 separation also are used for Stage 4 dewatering, including hydrocyclones, centrifuges, and spiral classifiers. These processes are described above. Static thickeners, screens, and filters may also have a separation function, but are more appropriately described as dewatering processes.

- Static thickeners generally are used in conjunction with flocculants to settle the fines from a static pool of preparation plant refuse water (blackwater). A typical thickener feed contains 1 to 5 percent solids; thickened underflow contains 20 to 35 percent solids. Common flocculants include inorganic electrolytes such as lime and alum, and organic polymers such as starches and polyacrylamide (Aplan and Hogg, 1977). Sludge from the thickener underflow may be dewatered further by mechanical devices, thermal drying, or agglomeration. A typical thickener vessel appears in Exhibit 3-39.

- Screens serve dual functions of dewatering and sizing. The mode of operation (fixed or vibrating), mesh size, and bed depth of feed material are chosen on the basis of raw feed characteristics (gradation and moisture content), feed rates, and the desired efficiency of sizing and dewatering. The sieve bend, a typical dewatering and sizing screen, appears in Exhibit 3-40 (Nunenkamp, 1976).

- Filters are of two types—pressure and vacuum. Both types generally accept a feed with 30 percent solids at 27 dry MT (30 T) per hour. Pressure filters produce a cake with 20 to 23 percent moisture. Product cake from vacuum filters may contain 34 to 40 percent moisture. The moisture removal efficiency of the pressure filter is offset by its higher capital cost relative to vacuum filter systems. A typical vacuum filter appears in Exhibit 3-41 (Nunenkamp, 1976).

Exhibit 3-35. Typical Circuit for Pneumatic Coal Cleaning



Source: EPA. 1977.

Exhibit 3-36. Desirable Chemical Characteristics of Make-Up Water for Coal Cleaning Processes

Parameter	Concentration[a] (mg/l)
pH	7.8
Hardness as $CaCO_3$	190
Ca	64
Mg	7.5
Na	19
K	4.7
NH_4	0.4
CO_3	0
HCO_3	157
Cl	35
SO_4	49
NO_3	15
NO_2	Trace
PO_4	0.5
SiO_2	7.2

[1] pH expressed in standard units.

Source: Lucas, J. Richard, David R. Maneval, and W. E. Formean. 1968. Plant Waste Contaminants. *In*: Leonard, Joseph W. and David R. Mitchell. 1968. Coal Preparation. American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., New York, New York, 926 p.

Most thermal dryers at coal cleaning facilities use coal as the combustion feed stock. Thermal dryers include two general types.

- Direct heat dryers use the products of combustion to dry the coal. The direct heat concept is used in most U.S. thermal drying facilities (Nunenkamp, 1976).
- Indirect heat dryers circulate the products of combustion around the drying coal, avoiding direct contact with the coal.

Direct heat thermal dryers fall into six categories (McCandless and Shaver, 1978):

- Fluidized bed dryers use a constriction plate fitted to a housing that forces the drying air to pass uniformly through the plate (Exhibit 3-42). Feed coal enters the plate while hot air is lifted through the plate by a fan. The air currents thus produced cause the feed coal to float above the plate and flow toward the discharge point. Fine material is scrubbed from the exhaust gases, and the resultant residue reports to a thickening and dewatering step.

Exhibit 3-37. Typical Product Dewatering Circuit for Coal Cleaning

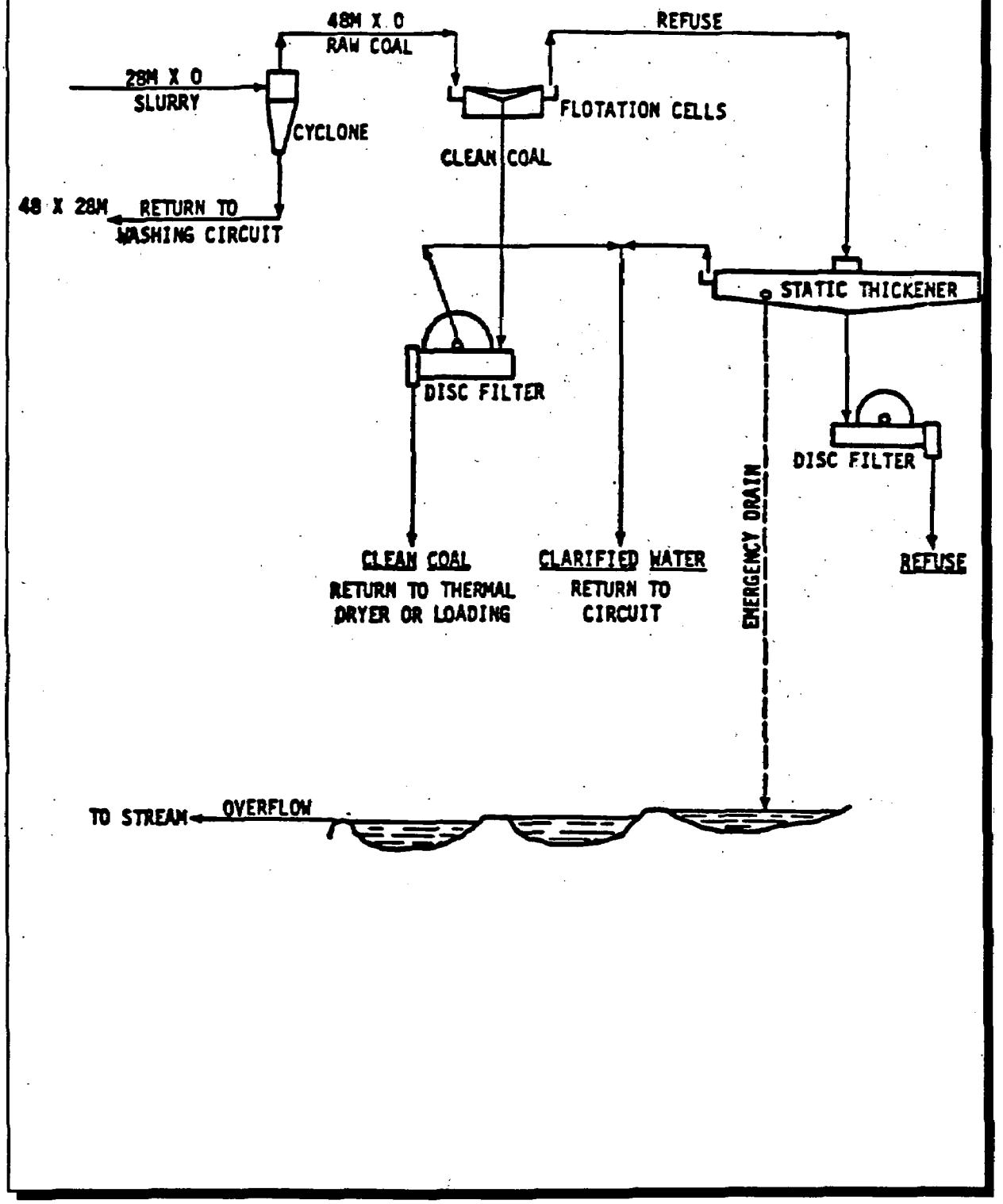


Exhibit 3-38. Typical Moisture Contents of Dried Product from Selected Drying Operations in Coal Cleaning Facilities

Type of Equipment or Process	Moisture Content of Discharge Product (%)
Dewatering screens	8 to 20
Centrifuges	10 to 20
Filters	20 to 50
Hydraulic cyclones	40 to 60
Static thickeners	60 to 70
Thermal dryers	6 to 7.5
Oil agglomeration	8 to 12

Source: McCandless, Lee C., and Robert B. Shaver. 1978. Assessment of Coal Cleaning Technology: First Annual Report. EPA, Office of Research and Development, Washington, D.C., EPA-600/7-78-150, 153 p.

- Multilouver dryers comprise two concentric, revolving cylindrical shells, each fitted with louvers that support the bed of feed coal and direct it toward the discharge point. Multilouver dryers can handle large volumes of wet material that require a relatively short drying time to minimize the potential for in-dryer combustion of the feed product.

- Rotary dryers consist of a solid outer cylinder and an inner shell of overlapping louvers that support and cascade the drying coal toward the discharge end. Drying action can be direct (using the products of combustion), or indirect (using an intermediate fluid for heat transfer between the shells).

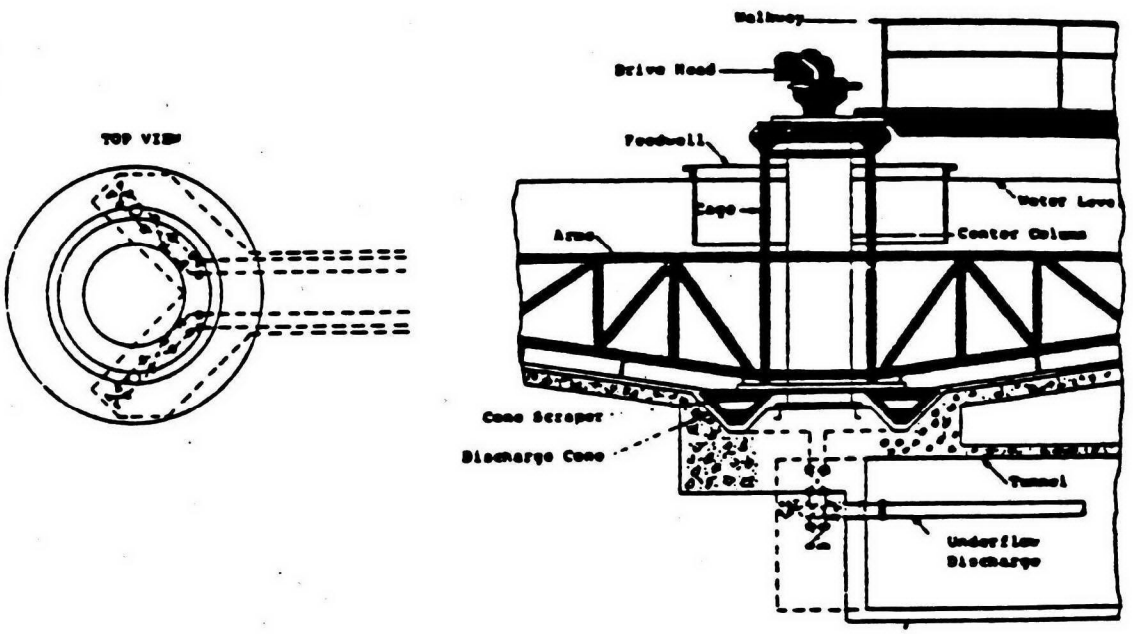
- Screen dryers apply gas pressure from combustion to squeeze the moisture mechanically from the feed coal through the supporting screens. A lower percentage of coal fines (relative to other drying processes) thus may be lifted from the bed. Coal is exposed to drying heat for approximately 50 seconds.

- Suspension or flash dryers continuously introduce feed coal into a column of high temperature gases (Exhibit 3-43). Surface moisture is dried almost instantaneously (flash dried). Coal is exposed to the drying gases for approximately 5 seconds.

- Turbo-dryers contain an inert nitrogen atmosphere (less than 3 percent oxygen) that prevents the explosion or ignition of coal fines in the sealed drying compartment. Wet coal enters a stack of rotating circular trays that successively feed the coal to lower trays using stationary wiper blades.

Indirect heat dryers use heat transfer agents (including oil, water, or steam) that do not come into contact with the feed coal. Drying coal is circulated through the heating chamber on covered conveyors that may be equipped with helical (worm) screws, fines, paddles, or discs. The drying fluid circulates around the conveyor and through the hollow screws.

Exhibit 3-39. Thickener Vessel for Dewatering of Coal Cleaning Products



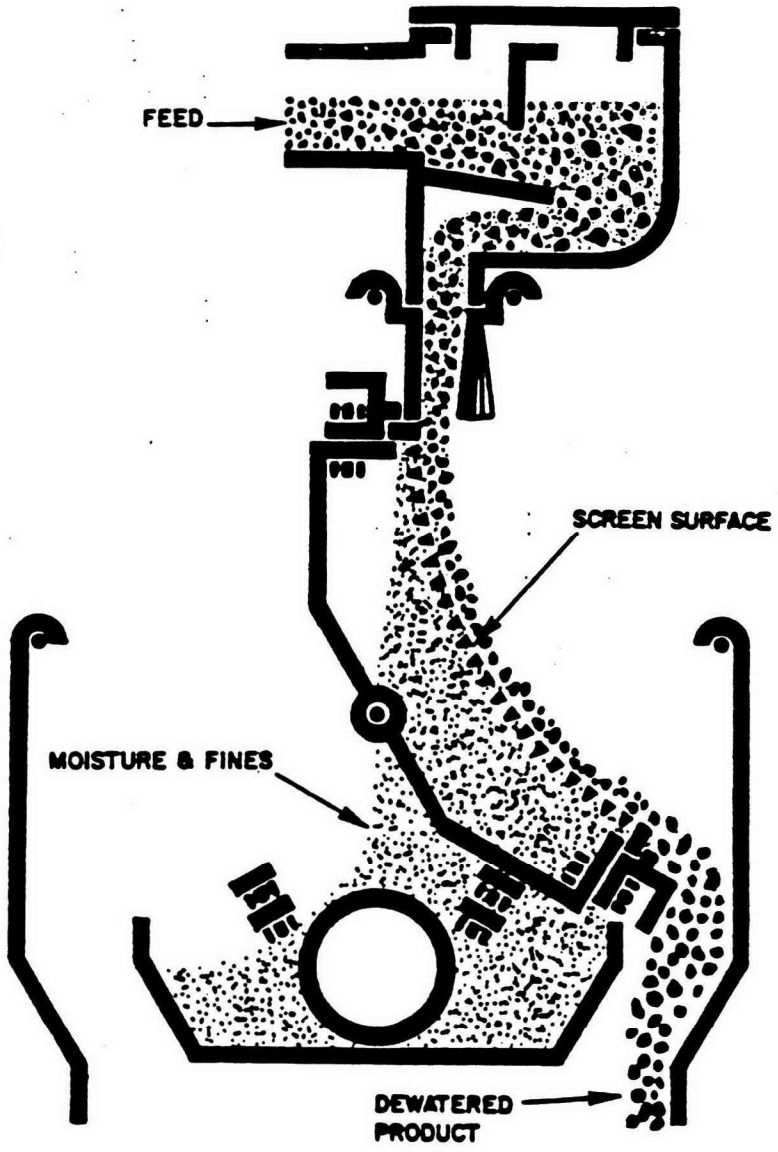
Source: Nunenkamp, David C., 1976.

Coal storage and shipment operations (Stage 5 of Exhibit 3-24) are discussed more thoroughly in subsequent sections of this document. The degree of sophistication in individual storage and loading systems reflects in part the volume of coal being processed, stored, and shipped, as well as the kinds of coal transportation services available. Some systems can load a moving train directly from overhead storage. Other systems may be intermittent, using bucket loaders and dump trucks to feed hoppers that load trains either directly or via conveyors.

3.5.2.2 Process Flow Sheet for Typical Operations

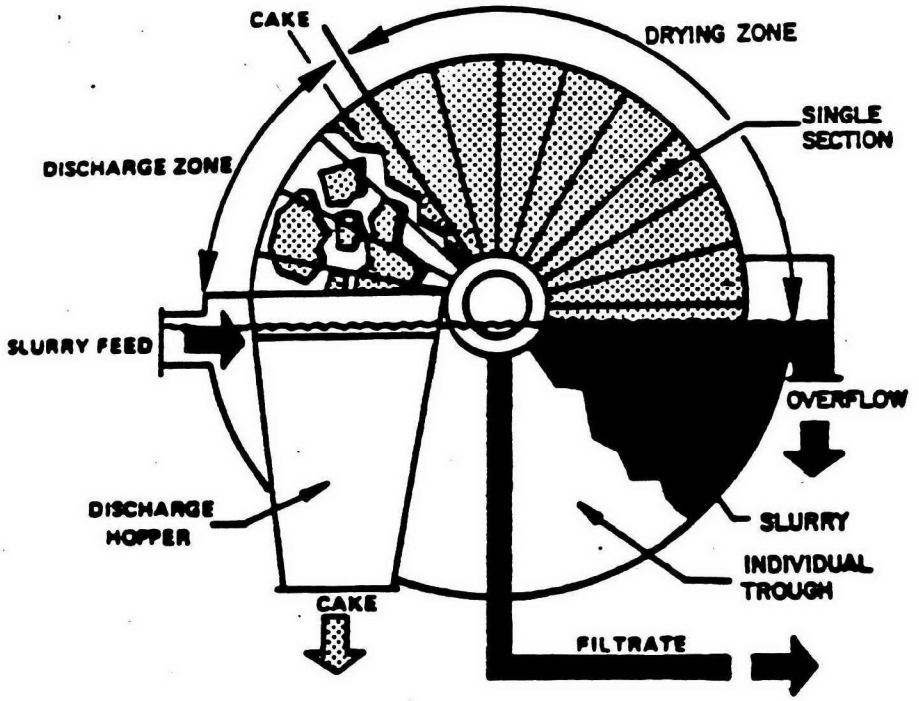
The complete coal cleaning plant utilizes a series of unit processes to prepare ROM coal for storage and shipment. These processes must be mutually compatible for proper operation of the plant. Rates and sizes of feed for one unit process should compliment the capabilities of other in-line processes. Process water generally is recycled, especially in operations that use heavy media such as magnetite

Exhibit 3-40. Schematic Profile of a Sieve Bend Used for Coal Sizing and Dewatering



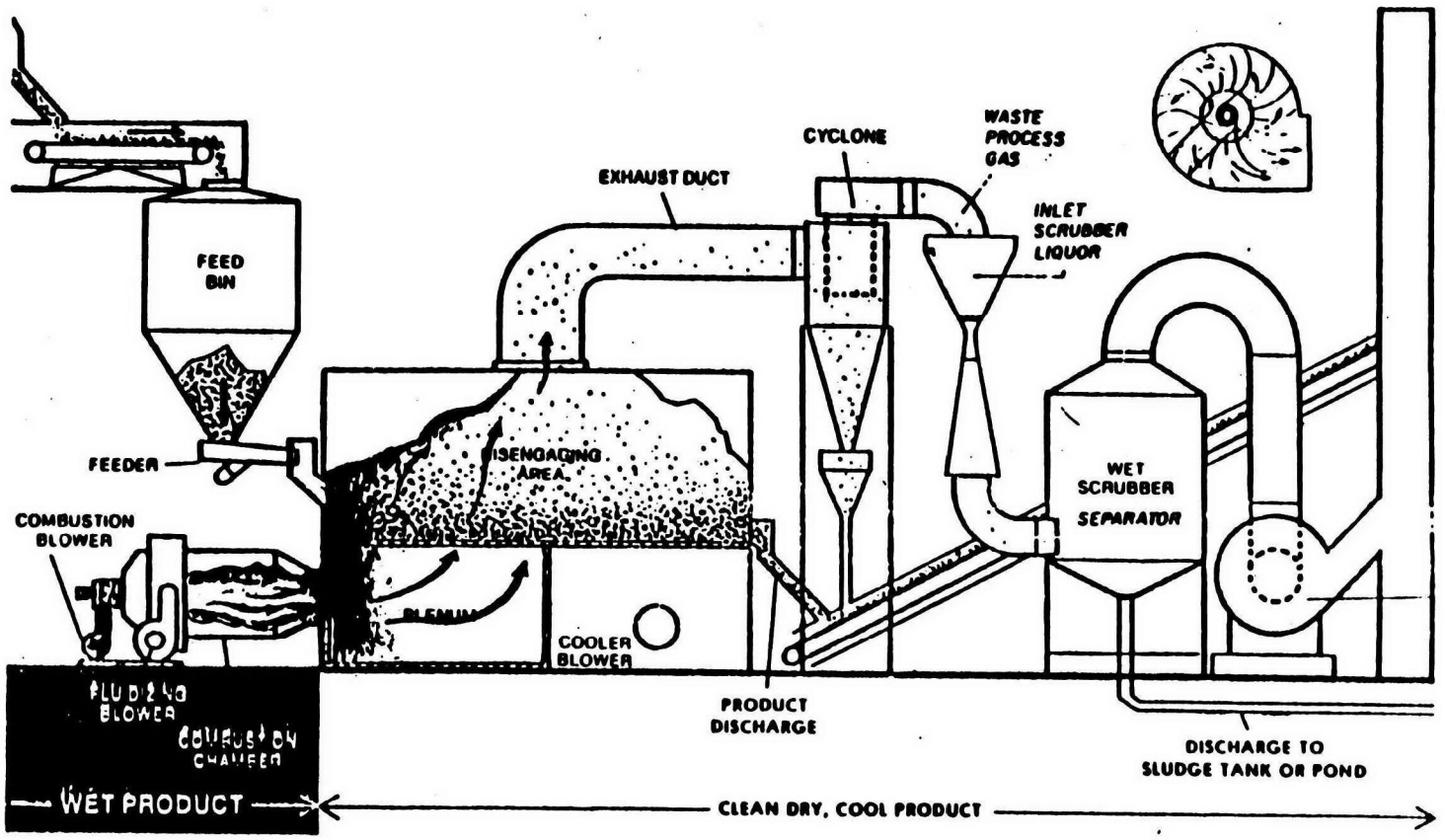
Source: Nunenkamp, David C., 1976.

Exhibit 3-41. Profile View of a Coal Vacuum Filter



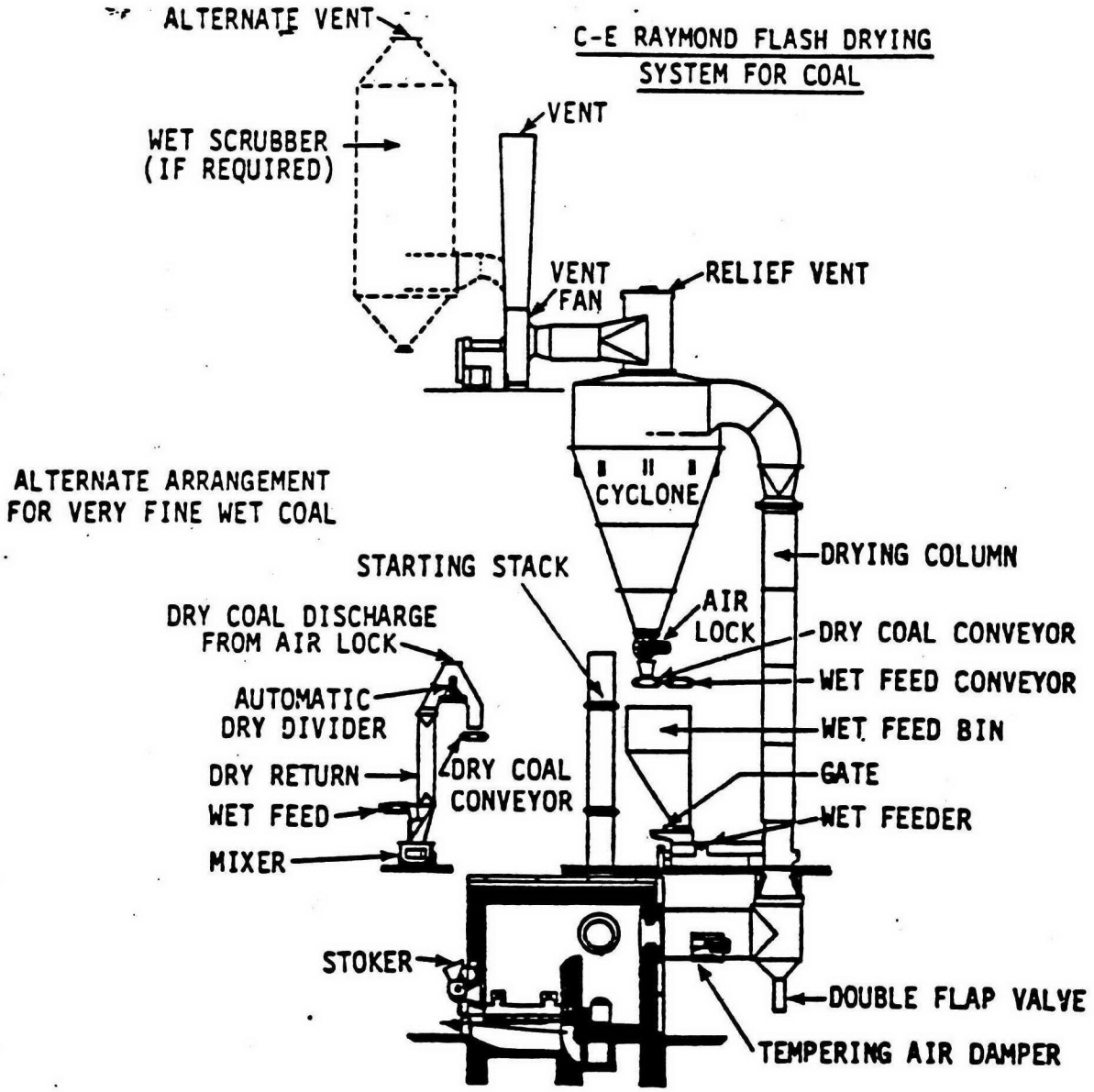
Source: Nunenkamp, David C., 1976.

Exhibit 3-42. Thermal Dryer and Exhaust Scrubber



Source: Nunenkamp, David C., 1976.

Exhibit 3-43. Typical Flash Dryer



Source: EPA, 1977.

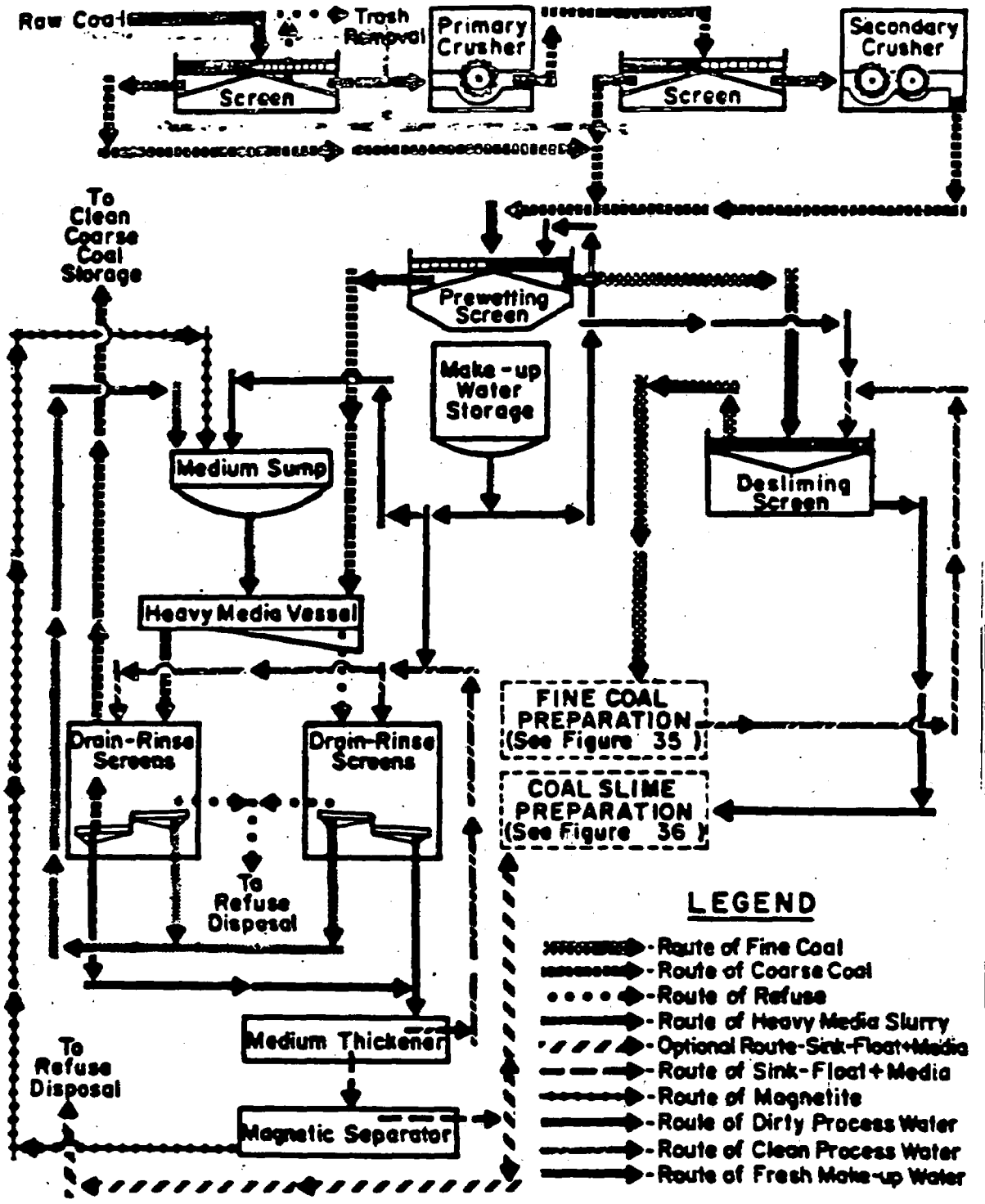
slurries for the separation of product from refuse. Evaporation and consumptive water use may require the introduction of make-up water to the process cycle.

A complete process flow sheet can be broken into three parts:

- Coarse stage (Exhibit 3-44)
- Fine stage (Exhibit 3-45)
- Sludge stage (Exhibit 3-46).

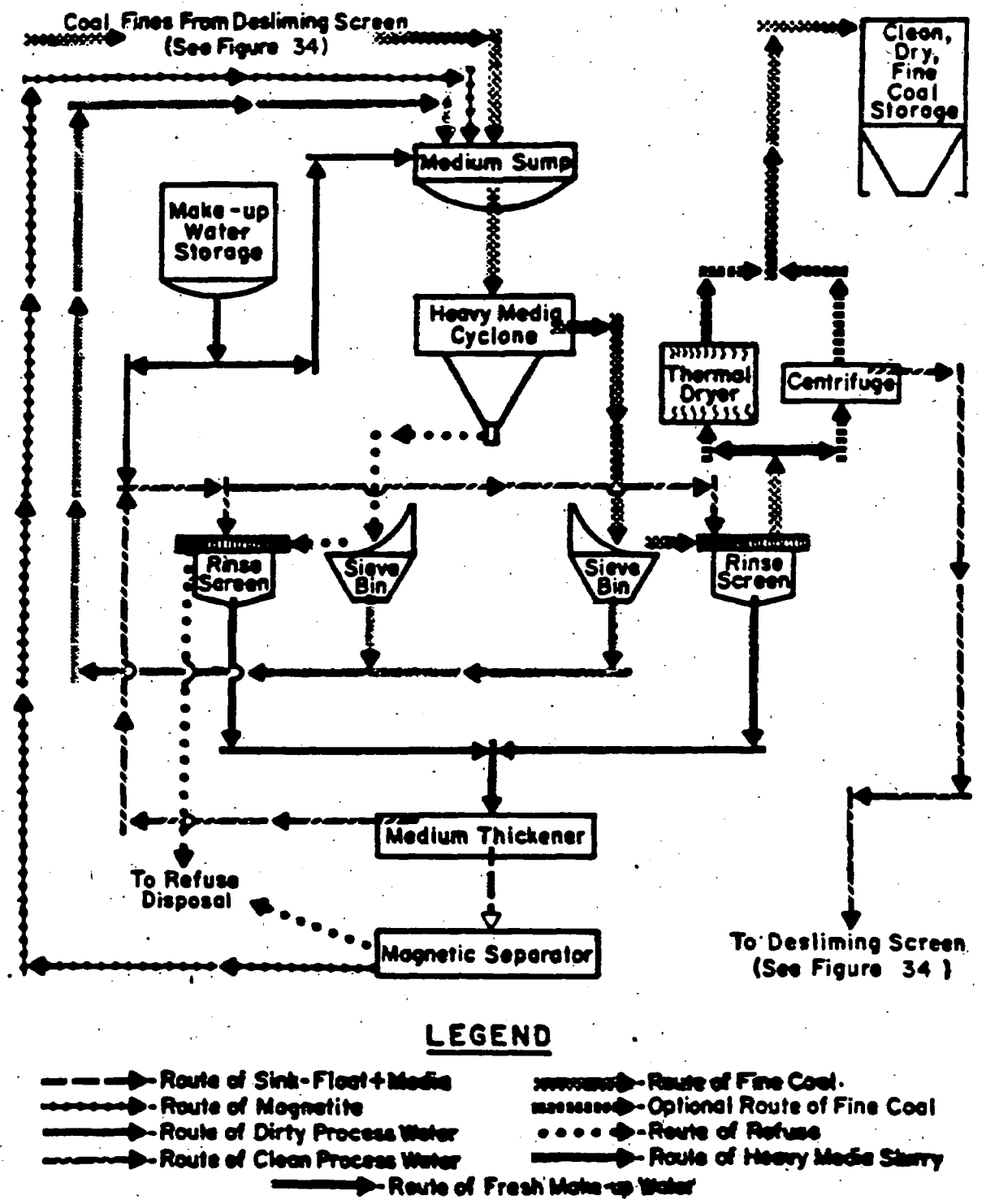
The coarse stage feed fine coal and refuse to the fine stage. Coal slime, which includes fine coal and refuse, is fed to the sludge stage. Each stage produces characteristic blackwater and refuse. Process waters from the fine coal and sludge processing stages generally contain higher proportions of fines, especially clay-size particles, than coarse stage process waters. A series of thickeners, cyclones, screens, filters, and dryers may be used to recover a maximum percentage of solids from the recycled process waters.

Exhibit 3-44. Coal Cleaning Plant Flow Sheet for Coarse Stage Separation and Dewatering



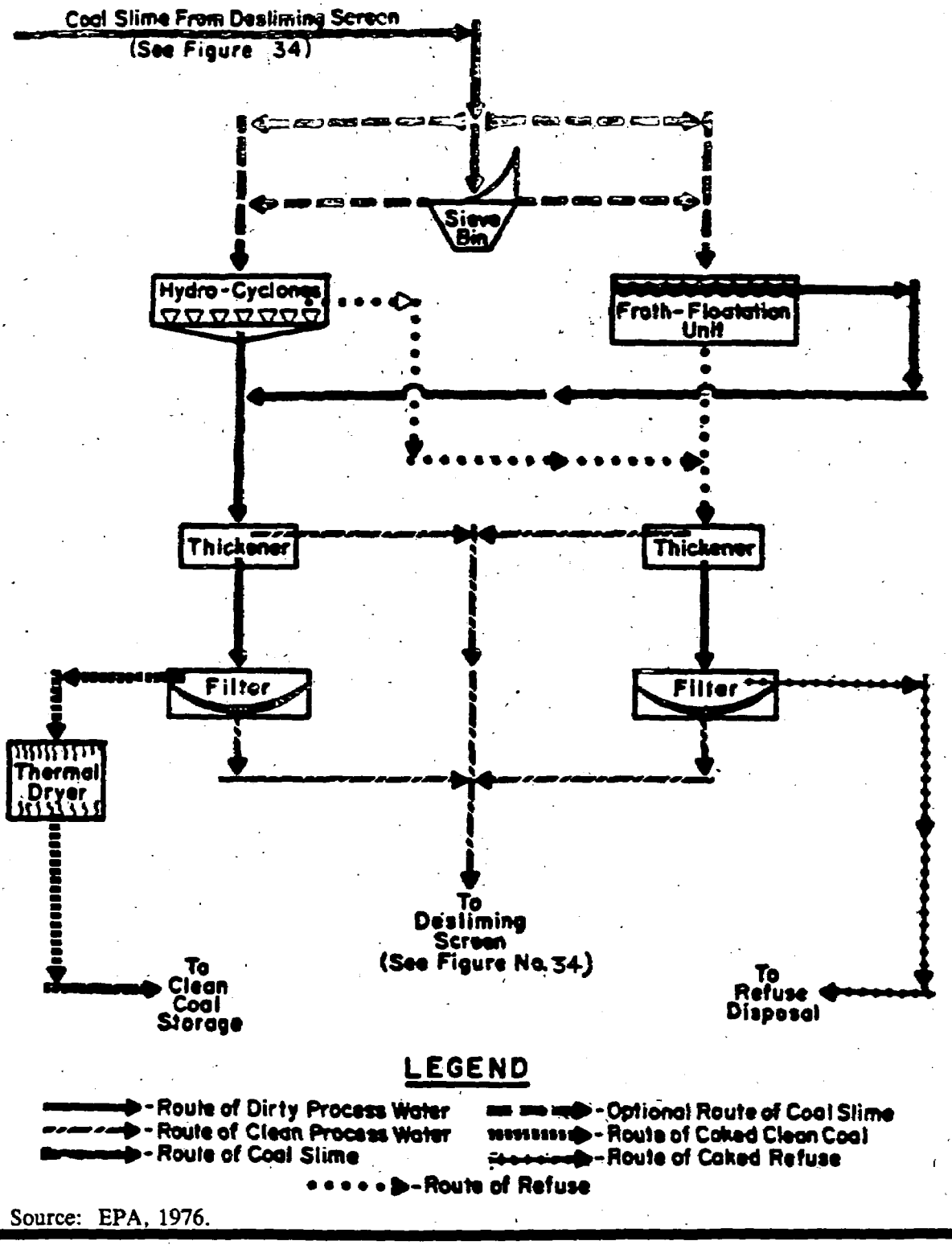
Source: EPA, 1976.

Exhibit 3-45. Coal Cleaning Plant Flow Sheet for Fine Stage Separation and Dewatering



Source: EPA, 1976.

Exhibit 3-46. Coal Cleaning Plant Flow Sheet for Sludge (Slime) Separation and Dewatering



Source: EPA, 1976.

4. ENVIRONMENTAL ISSUES

This section describes the environmental impacts associated with new source mining operations. The mining industry and its potential environmental impacts are unusual in a number of ways, of which three may be the most important. First, many of the potential impacts are unique to the industry (acid rock drainage, releases from cyanide leaching units, structural failure, etc.). Second, many of the impacts may be those manifested years or decades after mining ends and can intensify over time. Finally, the nature and extent of impacts from mining operations, perhaps more than any other industrial category, are based on factors that are specific to the location (including geology, hydrogeology, climate, human and wildlife populations, etc.). Impacts from similar types of operations can range from minimal to extensive depending on local conditions. These factors emphasize the need for full understanding of baseline conditions and careful planning to avoid/ mitigate potential impacts.

As in all major industrial operations, careful design and planning play a critical role in reducing or mitigating potential impacts. In the case of the mining industry, the three characteristics that distinguish it from other industries (unique impacts, often delayed, that depend on site-specific factors) make initial design and planning even more crucial. This in turn makes any assessment of potential impacts, both immediate and long-term, reliant on detailed information on site-specific conditions, and on the design and operation of the facility. Site-specific information is generally incomplete at the time of permitting. Design and operation plans, including operations to mitigate potential environmental impacts, are often only conceptual at the time of permitting. This makes it extremely difficult to delineate the types of information and analyses that are necessary to assess potential impacts.

The following subsections are organized according to the major environmental issues that are raised by mining operations. These include:

- Acid rock drainage
- Cyanide
- Structural stability of tailings impoundments
- Natural resources and land uses
- Sedimentation/erosion
- Metals and dissolved pollutants
- Air quality
- Subsidence
- Methane releases from coal mining and preparation.

The discussion of each of these subjects includes a description of the topic and of the types of information that are necessary to determine potential impacts.

4.1 ACID ROCK DRAINAGE

The formation of acid drainage and the contaminants associated with it has been described as the largest environmental problem facing the U.S. mining industry (U.S. Forest Service, 1993; Ferguson and Erickson, 1988; Lapakko, 1993b). Commonly referred to as acid rock drainage (ARD) or acid mine drainage (AMD), acid drainage from mine waste rock, tailings, and mine structures such as pits and underground workings is primarily a function of the mineralogy of the rock material and the availability of water and oxygen. While acid may be neutralized by the receiving water, dissolved metals can remain in solution. Dissolved metals in acid drainage may include the full suite of heavy metals, including lead, copper, silver, manganese, cadmium, iron, and zinc. Elevated concentrations of metals in surface water and groundwater can preclude their use as drinking water supplies. Further, low pH levels and high metals concentrations can have acute and chronic effects on aquatic life/biota.

Acid drainage from coal and mineral mining operations is a difficult and costly problem. In the eastern United States, more than 7,000 kilometers of streams are affected by acid drainage from coal mines (Kim et al., 1982). Similar impacts are observed in coal mining areas of the Midwest. As one of many examples of historic coal mining areas, 2,400 acres of abandoned surface mine land northwest of Montrose, Missouri, are impacted by acid mine drainage. More than half of the 100 lakes in the areas have a pH less than 4 and there are 1,200 acres of "barren, acidic spoil." Overland runoff from mine spoil has pH values between 2.9 and 3.5 (Blevins, 1990). In the western United States, the Forest Service estimates that between 20,000 and 50,000 mines are currently generating acid on Forest Service lands, and that drainage from these mines is impacting between 8,000 and 16,000 kilometers of streams (U.S. Forest Service, 1993).

Acid generation prediction tests are increasingly relied upon to assess the long-term potential of a material or waste to generate acid. Because mineralogy and other factors affecting the potential for ARD formation are highly variable from site to site, predicting the potential for ARD is currently difficult, costly, and of questionable reliability. Further, concern has developed because of the lag time at existing mines between waste emplacement and observation of an acid drainage problem (University of California, Berkeley, 1988). With acid generation, there is no general method to predict its long-term duration (in some cases necessitating perpetual care). The issue of long-term or perpetual care of acid drainage at historic mines and some active mines has focused attention on the need for improving prediction methods and for early assessment of the potential during the exploratory phase of mine development. The U.S. Forest Service sees the absence of acid prediction technology, especially in the context of new mining ventures, as a major problem facing the future of metal mining in the western United States (U.S. Forest Service, 1993).

The problems presented by acid drainage are encountered worldwide, and there is a growing body of literature that documents examinations of all aspects of the phenomenon, from the genesis of acid drainage to prediction of the timing of its occurrence to prevention. The most recent advances in the field are compiled in the proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Mine Drainage, which was held in April 1994 (U.S. Bureau of Mines 1994).

The remainder of this section addresses the major topics related to understanding how acid rock drainage is generated, how to predict it during mine planning, how to detect it during operations, and approaches to mitigating its impacts.

4.1.1 Nature of Acid Rock Drainage

4.1.1.1 Acid Rock Drainage/Oxidation of Metal Sulfides

Acid is generated at mine sites when metal sulfide minerals are oxidized. Metal sulfide minerals are common constituents in the host rock associated with metal mining activity. Prior to mining, oxidation of these minerals and the formation of sulfuric acid is a function of natural weathering processes. The oxidation of undisturbed ore bodies followed by release of acid and mobilization of metals is slow. Natural discharge from such deposits poses little threat to receiving aquatic ecosystems except in rare instances. Mining and beneficiation operations greatly increase the rate of these same chemical reactions by removing large volumes of sulfide rock material and exposing increased surface area to air and water. Materials/wastes that have the potential to generate acid as a result of metal mining activity include mined material such as spent ore from heap and dump leach operations, tailings, and waste rock units, including overburden material. Equally or more important at some mines are the pit walls in the case of surface mining operations, and the underground workings associated with underground mines.

The oxidation of sulfide minerals consists of several reactions. Each sulfide mineral has a different oxidation rate. For example, marcasite and framboidal pyrite will oxidize quickly while crystalline pyrite will oxidize slowly. For discussion purposes, the oxidation of pyrite (FeS_2) will be examined (Manahan, 1991):

$$2FeS_2(s) + 2H_2O + 7O_2 \rightarrow 4H^+ + 4SO_4^{2-} + 2Fe^{2+}$$

In this step, S_2^{2-} is oxidized to form hydrogen ions and sulfate, the dissociation products of sulfuric acid in solution. Soluble Fe^{2+} is also free to react further. Oxidation of the ferrous ion to ferric ion occurs more slowly at lower pH values:

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O$$

At pH levels between 3.5 and 4.5, iron oxidation is catalyzed by a variety of *Metallogenium*, a naturally occurring filamentous bacterium. Below a pH of 3.5 the same reaction is catalyzed by the naturally occurring iron bacterium *Thiobacillus ferrooxidans*. If the ferric ion is formed in contact with pyrite the following reaction can occur, dissolving the pyrite:

$$2FeS_2(s) + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

This reaction generates more acid. The dissolution of pyrite by ferric iron (Fe^{3+}), in conjunction with the oxidation of the ferrous ion constitutes a cycle of dissolution of pyrite. Ferric iron precipitates as hydrated iron oxide as indicated in the following reaction:

$$Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3(s) + 3H^+$$

$Fe(OH)_3$ precipitates and is identifiable as the deposit of amorphous, yellow, orange, or red deposit on stream bottoms ("yellow boy").

4.1.1.2 Source of Acid and Contributing Factors

The potential for a mine or its associated waste to generate acid and release contaminants is dependent on many factors and is site-specific. Ferguson and Erickson (1988) identified primary, secondary, and tertiary factors that control acid drainage. These factors provide a convenient structure for organizing the discussion of acid formation in the mining environment. Primary factors involve production of the acid, such as the oxidation reactions. Secondary factors act to control the products of the oxidation reaction, such as reactions with other minerals that consume acid. Secondary factors may either neutralize acid or react with other minerals, thereby releasing contaminants. Tertiary factors refer to the physical aspects of the structure or waste management unit (e.g., pit walls, waste rock piles, or tailings impoundments) that influence the oxidation reaction, migration of the acid, and consumption. Other downstream factors change the character of the drainage by chemical reaction or dilution.

Primary factors of acid generation include sulfide minerals, water, oxygen, ferric iron, bacteria to catalyze the oxidation reaction, and generated heat. Some sulfide minerals are more easily oxidized (e.g., framboidal pyrite, marcasite, and pyrrhotite) and hence, may have a greater impact on timing and magnitude during acid prediction analysis compared to other metal sulfides. Also important is the physical occurrence of the sulfide mineral. Well crystallized (euhedral) minerals will have smaller exposed surface areas than those that are disseminated.

Both water and oxygen are necessary to generate acid drainage. Water serves as both a reactant and a medium for bacteria in the oxidation process. Water also transports the oxidation products. A ready supply of atmospheric oxygen is required to drive the oxidation reaction. Oxygen is particularly

important to maintain the rapid bacterially catalyzed oxidation at pH values below 3.5. Oxidation of sulfides is significantly reduced when the concentration of oxygen in the pore spaces of mining waste units is less than 1 or 2 percent. Different bacteria are better suited to different pH levels and other edaphic factors (edaphic factors pertain to the chemical and physical characteristics of the soil and water environments). The type of bacteria and their population sizes change as their growth conditions are optimized (Ferguson and Erickson, 1988).

The oxidation reaction is exothermic, with the potential to generate a large amount of heat, and therefore thermal gradients form within the waste unit. Heat from the reaction is dissipated by thermal conduction or convection. Research by Lu and Zhang (undated) on waste rock using stability analysis indicates that convective flow can occur because of the high porosity of the material. Convection cells formed in waste rock would draw in atmospheric air and continue to drive the oxidation reaction. Convection gas flow due to oxidation of sulfide minerals depends on the maximum temperature in the waste rock. The maximum temperature depends on ambient atmospheric temperature, strength of the heat source, and the nature of the upper boundary. If the sulfide waste is concentrated in one area, as is the case with encapsulation, the heat source may be very strong. Lower ambient air temperatures improve conditions for convective gas flow. If the upper boundary is covered, convection is less likely.

Secondary factors act to either neutralize the acid produced by oxidation of sulfides or to change the effluent character by adding metals ions mobilized by residual acid. Neutralization of acid by the alkalinity released when acid reacts with carbonate minerals is an important means of moderating acid production. The most common neutralizing minerals are calcite and dolomite. Products from the oxidation reaction (hydrogen ions, metal ions, etc.) may also react with other non-neutralizing constituents. Possible reactions include ion exchange on clay particles, gypsum precipitation, and dissolution of other minerals. Dissolution of other minerals contributes to the contaminant load in the acid drainage. Examples of metals occurring in the dissolved form include aluminum, manganese, copper, lead, zinc, and others (Ferguson and Erickson, 1988).

Some of the tertiary factors affecting acid drainage are the physical characteristics of the waste or structure, how acid-generating and acid-neutralizing wastes are placed in the waste unit, and the hydrologic regime in the vicinity. The physical nature of the waste, such as particle size, permeability, and physical weathering characteristics, is important to the acid generation potential. Particle size is a fundamental concern since it affects the surface area exposed to weathering and oxidation. Surface area is inversely proportional to particle size. Very coarse grain material, as is found in waste rock dumps, exposes less surface area but may allow air and water to penetrate deeper into the unit, exposing more material to oxidation and ultimately producing more acid. Air circulation in coarse material is aided by wind, changes in barometric pressure, and possibly convective gas flow caused by heat generated by the oxidation reaction. In contrast, fine-grain

material (e.g., tailings) may retard air and very fine material may limit water flow; however, finer grains expose more surface area to oxidation. The relationships between particle size, surface area, and oxidation play a prominent role in acid prediction methods and in mining waste management units. As waste material weathers with time, particle size is reduced, exposing more surface area and changing physical characteristics of the waste unit. Though difficult to weigh, each of these factors influences the potential for acid generation and are therefore important considerations for long term waste management (Ferguson and Erickson, 1988; Lu and Zhang, undated).

The hydrology of the area surrounding mine workings and waste units is important in the analysis of acid generation potential. When acid generating material occurs below the water table, the slow diffusion of oxygen in water retards acid production. This is reflected in the portion of pits or underground workings located below the water table. Where mine walls and underground workings extend above the water table, the flow of water and oxygen in joints may be a source of acid. A similar relationship is evident with tailings, which are typically fine grained and disposed of subaqueously; the slow diffusion of oxygen inhibits formation of acid. However, since tailings are typically placed in either raised or valley impoundments, they are likely to remain saturated for only a limited period of time during mine operation. Following mine closure, the free water surface in the impoundment may be drawn down substantially, favoring ARD conditions. (Also, as tailings dry over time, previously impermeable layers of fine material may develop cracks or fissures, providing a conduit for air and water.)

The spatial distribution of mining wastes in units, or waste placement, affects acid generation potential. For example, the distribution of acid generating wastes with neutralizing wastes may be controlled by the stacking sequence. Calcareous material may be mixed with or placed above sulfidic wastes to buffer acid production or provide alkalinity to infiltrating solution prior to contact with acid generating wastes. An alternative to layering or mixing is encapsulation. This technique attempts to isolate acid generating wastes from oxygen and water, thereby reducing its potential to produce acid. Both these techniques are currently being used in waste rock dumps. It is unclear if they are effective over the long-term, since highly acidic material may overwhelm the buffering capacity of calcareous material or other alkaline sources.

Wetting and drying cycles in any of the mine workings or other waste management units will affect the character of any acid drainage produced. Frequent wetting will tend to generate a more constant volume of acid and other contaminants as water moves through and flushes oxidation products out of the system. The build-up of contaminants in the system is proportional to the length of time between wetting cycles (Ferguson and Erickson, 1988; Doepker, 1993). As the length of the dry cycle increases, oxidation products will tend to accumulate in the system. A high magnitude wetting event will then flush accumulated contaminants out of the system. This relationship is typical of the

increase in contaminant load observed following heavy precipitation for those areas having a wet season.

4.1.2 ACID GENERATION PREDICTION

The objectives of predictive testing are to (1) determine if a discrete volume of mining waste will generate acid, and (2) predict the quality of the drainage based on the rate of acid formation measured (California Mining Association, 1991). There are two important points that must be considered when evaluating the acid generation potential of a rock material. The first is how to collect samples from the field for use in analytical testing. The second is which analytic test method should be used. Both points have a profound impact on the reliability of analytical tests. Results from any analytical test are only as reliable as the samples used for the test. Once the sampling strategy is selected, an appropriate analytical method or methods can be selected. Methods used to predict the acid generation potential are classified as either static or kinetic. Factors affecting the selection of sampling regime and analytical method include an existing knowledge of the geology, costs, and length of time available to conduct the test. This section will examine sample methodology and analytic tests used to predict acid generation potential.

The following list of components describes the solid phase composition and reaction environment of sulfide minerals. Potential contaminants are included to indicate their importance in the scope of acid generation. These components should be kept in mind while evaluating information on acid generation potential.

Components affecting the total capacity to generate acid are characterized by:

- Amount of acid generating (sulfide) minerals present (assuming total reaction of sulfide minerals)
- Amount of acid neutralizing minerals present
- Amount and type of potential contaminants present.

Components affecting the rate of acid generation include:

- Type of sulfide mineral present (including crystal form)
- Type of carbonate mineral present (and other neutralizing minerals, as appropriate)
- Mineral surface area available for reaction
  - Occurrence of the mineral grains in the waste (i.e., included, liberated)
  - Particle size of the waste

- Available water and oxygen
- Bacteria.

Analytical tests used to assess a material's acid generation potential are either static or kinetic in nature. A static test determines both the total acid-generating and total acid-neutralizing potential of a sample. The capacity of the sample to generate acidic drainage is calculated as either the difference of the values or as a ratio of the values. These tests are not intended to predict the rate of acid generation, only the potential to produce acid. Static tests can be conducted quickly and are inexpensive compared to kinetic tests. Kinetic tests are intended to mimic the processes found in the waste unit environment, usually at an accelerated rate. These tests require more time and are considerably more expensive than static tests. Data from the tests are used to classify wastes according to their acid generating potential. This information can be collected and evaluated during the economic analysis of mines in their exploratory phases. Based on this information, management decisions can be made with respect to specific mitigation practices.

Efforts by both the mining industry and State regulatory agencies to develop the best protocols for sampling and/or analytical methods to predict acid generation potential have demonstrated that site-specific conditions (e.g., climate and geology) dictate a case-by-case approach when evaluating acid potential. This is complicated by the fact that a variety of research efforts on different methods by the Bureau of Mines, EPA, and the Canadian Mine Environment Neutral Drainage (MEND), as well as those used by mining companies and their consultants, make comparison of data difficult. Several researchers have conducted comparative evaluations of predictive tests (Lapakko, 1992; Bradham and Caruccio, 1990; Coastech, 1989). Lapakko, of the Minnesota Department of Natural Resources, has conducted comparative evaluations of static and kinetic test methods using a range of rock types. Bradham and Caruccio conducted a comparative study on tailings.

When evaluating the acid generation potential of a waste, a phased testing plan selects samples appropriate for the detail needed (California Mining Association, 1991). This approach allows investment in acid prediction testing to be commensurate with a deposit's economic potential and saves time and expense associated with unnecessary tests. Sampling and testing should be an iterative process, collecting, testing, and evaluating a small amount of information to establish the acid generation potential. Based on the preliminary findings, subsequent sampling and testing can be selected to refine the information as needed.

The typical steps in predicting the acid-forming potential of a waste, as compiled from summary documents on the subject, are listed below (California Mining Association, 1991; British Columbia AMD Task Force, 1989):

1. Define the geologic (or lithologic) units that will be encountered during mining. Describe the geology and mineralogy of these units in detail.

2. Develop a sampling plan based on understanding of geology (rock mass, etc.). Collect samples to represent ranges of compositional variation within a rock unit (see Lapakko, 1988, 1990a).

3. Select static or kinetic tests and evaluate potential for acid formation.

4. Evaluate sampling criteria and conduct additional kinetic tests as required.

5. Develop a model as appropriate.

6. Based on findings, classify geologic (lithologic) units as acid, non-acid forming, or uncertain. (Note: the potential to produce acid may vary within a given geologic unit.)

4.1.2.1 Sampling

Selection of samples has important implications for subsequent acid prediction. The purpose of testing rock material is to allow classification and planning for waste disposal based on the predicted drainage quality from that material. Samples must be selected to characterize both the type and volume of rock materials and also account for the variability of materials that will be exposed during mining. When to collect samples for testing is an equally important consideration.

Researchers agree that sampling and testing should be concurrent with resource evaluation and mine planning (Lapakko, 1990a; British Columbia AMD Task Force, 1989). Sampling techniques used to evaluate recoverable mineral resources (assay samples) are similar to those required for prediction of acid generation potential. Active mining operations for which predictive tests were not conducted in advance of mining lack the advantage of front end planning, but can still use sampling and other site-specific information (e.g., geology and mineralogy) to establish the acid generating potential.

The pressure is increasing for new operations or those in the exploratory phase to accurately predict future drainage water quality. By comparison, the acid drainage potential at old mines may be well established. Examples of information needed from existing operations are the quantity of existing acid products, the potential and stage of acid generation in each of the waste units, and the acid forming potential of future wastes to be generated. Broughton and Robertson recommend that the first two stages of an acid prediction analysis for either new or existing mines are (1) to review the geology and mineralogy and (2) classify the rock and collect samples (Robertson and Broughton, undated; Broughton and Robertson, 1992).

Sample collection for prediction tests for both old and new mines should consider both geologic and environmental factors. Geologic factors for sample selection are primarily a good understanding of the local geology. If available, this may include information from mines, core logs, or other sources

in the immediate area. This information is important to both the sampling program and application of test results. Environmental factors include consideration of the potential environmental contaminants in the rock and climatic variables. A quality assurance/quality control program should be developed and coordinated with the mine plan for sample collection and acid generation testing.

There are many opinions concerning the number of samples to be collected in a fixed-frequency sampling program. One mining consulting firm recommends about 8 - 12 samples of each significant rock type or a minimum of one sample for each one million tons (Schafer, 1993). In this case a significant rock type represents one or two percent of the total mine rock volume. A representative of the U.S. Forest Service suggests that one sample (about 1,500 grams) be collected per 20,000 tons of waste rock, or about 50 samples for each one million tons (U.S. Forest Service, 1992). These samples would be collected by compositing cuttings from individual drill holes made prior to blasting. The British Columbia AMD Task Force recommends a minimum number of samples based on the mass of the geologic unit. Their recommended minimum sample number is 25 for a one million ton geologic unit, or one sample for every 40,000 tons. Using the British Columbia method, as waste volume increases, the proportional number of samples decreases. For example, for a unit of 10 million tons, the minimum sample number is 80, or one sample for every 125,000 tons (British Columbia AMD Task Force, 1989).

There are reservations to prescribing a number of samples for collection per volume of material. This is particularly true for existing mines when collecting samples from waste rock dumps for acid generation potential tests. Waste rock dumps are usually constructed by end-dumping rock from trucks, creating heterogeneous deposits that are very difficult to sample with confidence. Tailings are comparatively more uniform due to milling and depositional methods used, and it is easier to characterize their variability. Fixed-frequency sampling does not rely on the use of best judgment on the part of the sample collector (typically a mining company). It also does not provide the statistical basis to account for variability among samples. Therefore, the actual numbers of samples to be collected should be determined on a site-specific basis.

Factors to consider in a sampling program for existing or planned mines include the method of sample collection, length of time samples are to be (or have been) stored, and the sample storage environment. Each of these can affect the physical and chemical characteristics of a sample. Samples collected from cores exposed to the environment may be physically and/or chemically altered. If samples are collected from a drill core, contamination may be a problem if a lubricant was used. At existing mines, tailings samples should be taken over a variety of depths to determine if oxidation of sulfide minerals is occurring. The influence of lime addition during milling may maintain alkaline conditions. Collecting samples of waste rock is difficult because of the variability inherent in these waste units. Drilling is considered to be the preferred method for collecting samples from waste rock dumps (Ferguson and Morin, 1991).

Since individual samples will be used to test and classify larger volumes of waste, it is important to consider how representative samples are to be collected. Compositing is a common practice used to sample large volumes of material. Typically, composite samples are collected from drill hole cuttings on benches prior to blasting. However, compositing merges information about the variation of sample that would be identified if more samples were collected and analyzed. Therefore, information about sample variability is lost (British Columbia AMD Task Force, 1990; Robertson and Broughton, undated). Composite sampling of tailings may be useful as a "first look" for characterizing tailings; compositing with stratification by lithology and alteration can help to avoid the problems of simple composite samples (Schafer, 1993).

To be most effective, sampling programs for acid generation prediction should not be confined to initial prediction during mine permitting. The uncertainties associated with sampling, analytical techniques, and prediction methods all serve to make continued sampling and prediction appropriate throughout the life of a mine. This can allow early identification of changed conditions that can lead to problems, and thus allow early intervention to prevent major impacts.

4.1.2.2 Static Tests

Static tests predict acid drainage by comparing the waste sample's maximum acid production potential (AP) with its maximum neutralization potential (NP). The AP is determined by multiplying the percent of total sulfur or sulfide sulfur (depending on the test) in the sample by a conversion factor ($AP = 31.25 \times \%S$). NP is a measure of the carbonate material available to neutralize acid. The value for NP is determined either by adding acid to a sample and back-titrating to determine the amount of acid consumed or by direct acid titration of the sample (the endpoint pH is dependent on the test method). The net neutralization potential (NNP), or acid/base account (ABA) is determined by subtracting the AP from the NP ($NNP = NP - AP$). A ratio of NP to AP is also used. An NNP of 0 is equivalent to an NP/AP ratio of 1 (Ferguson and Morin, 1991). Units for static test results (AP, NP, and NNP) are typically expressed in metric tons of calcium carbonate ($CaCO_3$) per 1,000 metric tons of rock.

If the difference between NP and AP (i.e., the NNP) is negative then the potential exists for the waste to form acid. If it is positive then there may be lower risk. Prediction of the acid potential when the NNP is near zero (between -20 and 20) is especially difficult (Brodie et al., 1991). Similar to Brodie, Smith and Barton-Bridges also suggest an NNP criteria of greater than 20 where the risk of acid generation is low (Smith and Barton-Bridges, 1991). Other studies conducted by the State of Pennsylvania on surface coal mine drainage suggest that sites with an NNP of greater than 10 exhibit alkaline drainage, with a gray zone ranging from 1 to 10 (Brady et al., 1994). Finally, the State of Tennessee has encountered acid generation (along with elevated iron and manganese levels) in backfilled portions of six area coal mines, where positive NNPs were initially observed (some samples had NPPs between 5 and 20, but averages were generally greater than 20). The

inconsistency between test results and actual conditions has been attributed to carbonate materials with slow dissolution rates, heterogeneity between carbonate and sulfidic materials, and the availability of large volumes of well-oxygenated water (that ultimately recharges surface water).

If ratios are used, Brodie indicated that when the ratio of a sample's neutralization potential to acid production potential is greater than 3:1, experience indicates that there is lower risk for acid drainage to develop. Those samples with a ratio of 1:1 or less are more likely to generate acid. Brodie refers to ratios between 3:1 and 1:1 as the zone of uncertainty, where additional kinetic testing is usually recommended and acid mitigation measures may be required (Brodie et al., 1991). Data from coal mines in the eastern United States indicate that an NP/AP of greater than 2.4 is required to ensure acid will not be released (Cravotta et al., 1990). Finally, data from a single Canadian mine show that an NP/AP of up to 4.0 must be maintained to provide for near neutral drainage. Morin and Hutt suggest that the criteria for determining ABA should be established based on site-specific conditions (Morin and Hutt, 1994).

The uncertainty in establishing "cutoff" levels for acid generation is due to several factors, including the heterogeneous distribution of sulfide and carbonate minerals, the slow dissolution of carbonate in non-acidic conditions (the early phases of ARD are often under pH neutral conditions), coating of carbonate grains by precipitated hydroxides, and climatic factors that lead to faster weathering of carbonaceous materials than sulfide materials (Day, 1994). When reviewing data on static tests, an important consideration is the particle size of the sample material and how it is different from the waste or material being characterized.

There are several different methods for conducting static testing. Five types of static tests are summarized in Exhibit 4-1. Comparative testing was performed by Lapakko (Lapakko, 1994a) on a wide range of samples using the ABA, the modified ABA, the BC method, and the modified BC test methods (proposed by Lapakko). Lapakko's results suggest that the ABA and modified ABA methods tend to overestimate actual neutralization potential (and potentially underestimate acid generation). The BC and modified BC methods results most closely correlate to the actual mineralogic NP. As shown in Exhibit 4-1, the modified BC process determines NP by titrating to pH = 6.0 rather than pH = 3.5 (the endpoint using the standard BC method). Lapakko noted that a pH of 6 (the typical water quality standard) better approximates the neutralization that would be required to meet applicable water quality standards (Lapakko, 1994a).

4.1.2.3 Kinetic Tests

Kinetic tests are distinguished from static tests in that they attempt to mimic the natural oxidation reactions of the field setting. The tests typically use a larger sample volume and require a much longer time for completion than do static tests. These tests provide information on the rate of sulfide mineral oxidation and therefore acid production, as well as an indication of drainage water quality.

Exhibit 4-1. Summary of Static Test Methods, Costs, Advantages, and Disadvantages

Acid Base Accounting (Sobek et al., 1978)	MODIFIED Acid Base Accounting (Coastech, 1989)	BC Research Initial (Duncan and Bruynesteyn, 1979)	MODIFIED BC Research Initial (Lapakko, 1994a)	Alkaline Production Potential: Sulfur (Caruccio et al., 1981)	Net Acid Production (Coastech, 1989)
ACID PRODUCTION DETERMINATION					
Acid Producing Potential = 31.25 * Total S	Acid Producing Potential = 31.25 * Total S	Total Acid Production = 31.25 * Total S	Total Acid Production = 31.25 * Total S	Total S used as indicator	300 mL H_2O_2 added to 5 g rock to directly oxidize sulfides present
NEUTRALIZATION POTENTIAL DETERMINATION					
-60 mesh (0.24 mm) sample	-60 mesh (0.24 mm) sample	-300 mesh (0.038 mm) sample	-300 mesh (0.038 mm) sample	-0.023 mm sample	particle size not presented
add HCl as indicated by fizz test, boil one minute then cool	add HCl as indicated by fizz test, agitate for 23 hours at room temperature pH 1.4 - 2.0 required after 6 hours agitation	titrate sample to pH 3.5 with 1.0 N H_2SO_3	titrate sample to pH 6.0 with 1.0 N H_2SO_3	20 mL 0.1 N HCl to 0.4g solid for 2 hours at room temperature	acid produced by iron sulfide oxidization dissolves buffering minerals
titration endpt pH 7.0	titration endpt pH 8.3	titration endpt not applicable	titration endpt not applicable	titration endpt pH 4.0	titration endpt pH 7.0
cost: 34-110	cost: 34-110	cost: 65-170	cost: unknown	cost: 34-110	cost: 25-68
ADVANTAGES AND DISADVANTAGES					
simple and short time,[1,3] no special equipment, and easy interpretation;[1] many samples can be tested[3]	simple, short time, no special equipment, and easy interpretation[1]	simple and fairly short time,[1,3] no special equipment, and easy interpretation;[1] many samples can be tested[3]	simple and fairly short time,[1,3] no special equipment and easy interpretation,[1] many samples can be tested[3]	simple, short time, and no special equipment[1]	simple, short time, no special equipment, and easy interpretation[1]
does not relate to kinetic;[2] assumes parallel acid/alkaline release;[2,3] if APP and NP are close, hard to interpret and different particle size not reflected[3]	does not relate to kinetic;[2] assumes parallel acid/alkaline release;[2,3] if AP and NP are close, hard to interpret and different particle size not reflected[3]	assumes parallel acid/alkaline release, different particle size not reflected, and if APP and NP are close, hard to interpret[3]	assumes parallel acid/alkaline release, different particle size not reflected, and if APP and NP are close, hard to interpret[3]	moderate interpretation[1]	limited reproducibility[4] uncertain if extent of sulfide oxidation simulates that in field

(Source: Lapakko, 1993b)

1 = Coastech 1989, as referenced in Lapakko 1993
2 = Bradham and Caruccio 1990, as referenced in Lapakko 1993
3 = Ferguson 1984, as referenced in Lapakko 1993
4 = Lawrence 1991, as referenced in Lapakko 1993

Of the different kinetic tests used, there is no one test that is preferred. The preference for tests changes with time as experience and understanding increase. In a 1988 summary article by Ferguson and Erickson, the B.C. Research Confirmation Test was considered to be the most widely used. A similar 1991 article by Ferguson and Morin stated that the use of modified humidity cells was becoming more common, and there seems to be a trend toward the preference for modified humidity cell and column type tests. Six types of kinetic tests are summarized in Exhibit 4-2.

Kinetic tests can be used to assess the impact of different variables on the potential to generate acid. For example, samples may be inoculated with bacteria (a requirement for some tests). The temperature of the sample environment may also be controlled during the test. Most tests require the sample particle size to be less than a specified sieve size (e.g., minus 200 mesh). Larger sample volumes and test equipment may examine acid potential from coarse particles. Acid drainage control mechanisms, such as increasing alkalinity by adding lime, may also be examined using kinetic tests.

It is helpful to supplement kinetic tests with an understanding of empirical data characterizing the sample. Examples include analysis of specific surface area, mineralogy, and metals. Such information may affect the interpretation of test data and are important when making spatial and temporal comparisons between samples based on the test data. As with static tests, it is important to consider the particle size of the test sample, particularly when comparing test results with field scale applications.

4.1.2.4 Application of Test Results in Prediction Analysis

Results from static and kinetic tests are used to classify mine wastes on the basis of their potential to generate acid. Static tests yield information about a sample's ability to neutralize acid and generate acid. The difference or ratio of these values becomes the basis of the classification. As discussed above, for samples with NNP values greater than 20 tons $CaCO_3$/1,000 tons of waste and/or NP/AP ratios of greater than 3.25:1, the potential to generate acid is low (Smith and Barton-Bridges, 1991). For NNP values between -20 and 20 (ratios between 1:1 and 3.25:1), the potential for acid generation remains, and uncertainty will exist. (It is important to note that each of these values are generalities and can be affected by a wide range of site-specific conditions that can either promote or retard ARD generation; the relative availability of surface areas of iron sulfides and calcium-magnesium carbonates, reaction rates, drying/wetting conditions, etc.)

The determination of AP based on estimated or reactive sulfur content in the sample has some inherent limitations. When total sulfur is used as the basis to estimate sulfide content, this uncertainty may be attributable to possible errors in (1) assessment of true acidity and neutralization in the sample; (2) calculated acidity based on total sulfur conversion value; and (3) analytical error. Similar errors exist for static tests that determine reactive sulfide mineral concentrations. Estimating long-

Exhibit 4-2. Summary of Some Kinetic Test Methods, Costs, Advantages, and Disadvantages

Humidity Cells (Sobek et al., 1978)	Soxhelet Extraction (Singleton and Lavkulich, 1978; Sullivan and Sobek, 1982)	Column Tests (Bruynesteyn and Hackl, 1982; Hood and Oertel, 1984)
SUMMARY OF TEST METHOD		
-2.38 mm particle size	particle size not presented	variable particle size
200g of rock exposed to three days dry air, 3 days humidified air, and rinsed with 200 mL on day 7	T=70°C (Singleton and Lavkulich, 1978); T=25°C (Sullivan and Sobek, 1982); water passed through sample is distilled and recycled through sample	columns containing mine waste are leached with discrete volumes or recirculating solutions
cost: 425-850	cost: 212-425	cost: dependent upon scale
ADVANTAGES AND DISADVANTAGES		
models AP and NP well and models wet/dry;[3] approximates field conditions and rate of acidity per unit of sample	simple, results in short time, and assessment of interaction between AP and NP[3]	models AP and NP, models effect of different rock types, models wet/dry, and models different grain sizes[3]
moderate to use, results take long time, and some special equipment[1]	moderate to use and need special equipment[1]	difficult interpretation, not practical for large number of samples[3]
moderate ease of interpretation;[1,3] large data set generated[2]	moderate interpretation[1,3] in developmental stage and relationship to natural processes not clear[3]	large volume of sample[2] lots of data generated, long time, and potential problems: uneven leachate application, channelization[2,3]

(Source: Lapakko, 1993b)

BC Research Confirmation (Duncan and Walden, 1975)	Batch Reactor (Halbert et al., 1983)	Field Tests (Eger and Lapakko, 1985)
METHOD		
-400 mesh particle size	-200 mesh particle size[1]	field scale particles
15-30g added to bacterially active solution at pH 2.2 to 2.5, T=35°C; if pH increases, sample is non acid producer; if pH decreases, 1/2 original sample mass is added in each of two increments	sample/water slurry is agitated 200g/500 mL[1]	800 to 1300 metric ton test piles constructed on liners flow and water quality data collected; tests began in 1977 and are ongoing
cost: 170-340	cost: 425-850	cost: initial construction is expensive, subsequent costs are comparable
ADVANTAGES AND DISADVANTAGES		
simple to use, low cost, assesses potential for biological leaching[3]	able to examine many samples simultaneously and relatively simple equipment[4]	uses actual mine waste under environmental conditions; can be used to determine drainage volume; mitigation methods can be tested
moderate to use, longer time needed, and some special equipment needed;[1] difficult interpretation if pH change is small, does not model initial AP step, and long time for pH to stabilize[3]	subject to large sampling errors and lack of precision[4]	expensive initial construction long time

(Source: Lapakko, 1993)

1 = Coastech 1989, as referenced in Lapakko 1993
2 = Bradham and Caruccio 1990, as referenced in Lapakko 1993
3 = Ferguson 1985, as referenced in Lapakko 1993
4 = Babij et al. 1980, as referenced in Lapakko 1993

term reactive sulfide based on short-term tests may result in uncertainty due to difficulties in making oxidation rate predictions (British Columbia AMD Task Force, 1989).

Acid base accounting tests conducted on an iterative basis, where the initial sample set is small, are helpful when establishing boundaries between lithologic units. As data from static tests is collected and evaluated, the sampling selection can be refined. The goal of sampling is to collect representative samples that define the variability of the lithologies present. If significant variability in the acid generation or neutralization potential is identified in the initial sample test results, additional sampling to refine lithologic boundaries is necessary (California Mining Association, 1991).

Kinetic tests are often conducted to confirm results of static tests, to test the potential for ARD in the uncertainty zones of static testing, and to estimate when and how fast acid generation will occur. These tests provide insight on the rate of acid production and the water quality potentially produced and are used to evaluate treatment and control measures. Unlike static tests, there is no standardized method for evaluating test results. Data are examined for changes through time and water quality characteristics. Kinetic tests tend to accelerate the natural oxidation rate over those observed in the field. This may have the advantage of condensing time, and providing earlier insight into the potential for acid generation.

Generally, kinetic tests are evaluated for changes in pH, sulfate, acidity and a host of potential metals. According to the British Columbia AMD Task Force (1989), samples with pH values less than 3 are considered strongly acid; between 3 and 5 the sample is acid-generating and there may be some neutralization occurring; at pH values >5, the sample is not significantly acid or an alkaline source is neutralizing the acid. Sulfate is a by-product of sulfide oxidation and can be used as a measure of the rate of oxidation and acid production. When evaluating test data it is important to examine the cumulative sulfate production curve as an indicator of sulfide oxidation, in addition to other parameters. An analysis of metals in the sample solution serves as an indicator of contaminant load but is not usually a good indicator of acid generation.

4.1.2.5 Experience With Static and Kinetic Tests

Ferguson estimated that for about 50 percent of mines it is easy to determine the likelihood for acid generation to be a problem. For some, acid generation would be expected; for others, it would definitely not be expected. Predicting the potential for the other 50 percent is more difficult (U.S. EPA, 1992). When data collected from static and kinetic tests is inconclusive, it may be necessary to extrapolate from existing data using oxidation rates and other factors and project how a sample may react. The soundness of the extrapolation is dependent on the representativeness of the sample, accuracy of the tests data, and the interpretation of the data.

Ferguson and Morin (1991) found that samples with an NP/AP ratio of less than 0.1 tended to produce acid during typical laboratory timeframes. They expected that if laboratory tests were conducted for longer time periods the NP/AP ratio would shift closer to 1 and did not speculate on what the values for NNP and NP/AP would be in the future. Extrapolating a sample's ability to generate acid was divided into short (less than one year), medium (a few years), and long term (many years) time frames. Short-term projections are based on laboratory data. Medium-term projections require knowledge of the neutralization process, primarily consumption of carbonate. Long-term extrapolations of acid generation potential will require an understanding of weathering rinds and diffusion of oxygen into and reaction products out of that rind. Long-term projections were identified as being extremely difficult.

Researchers in British Columbia have examined results of static and kinetic tests conducted on tailings and waste rock (Ferguson and Morin, 1991). The results are based on a study of 20 active or abandoned mines in British Columbia. Their findings indicate that for tailings, only those samples having a negative NNP produced acid. The test method was not identified and the limitations are therefore not discussed here. According to this report, waste rock data from static tests is very limited and demonstrates the variability expected with these waste units. They observed that samples of waste rock that had weathered for one month (prior to sample collection) needed to be flushed initially to remove existing oxidation products.

Lapakko (1990b) used solid phase characterization of the sample in conjunction with acid base accounting data and the rates of acid production and consumption to extrapolate information beyond the timeframe of kinetic tests. The rates of acid production and consumption were based on kinetic test results over a 20-week period. The time required to deplete sulfide and carbonate minerals was determined using rates established from kinetic tests. Based on these observations the time required to deplete the iron sulfide content was 950 weeks and the time to deplete the carbonate content was 40 weeks. This prediction agreed with an observed drop in pH between week 36 and week 56 from 8.7 to 6; after another 20 weeks the pH dropped below 5.

4.1.2.6 Mathematical Modeling of Acid Generation Potential

As the preceding discussion indicates, static and kinetic testing provide an incomplete picture of the potential for mine wastes to produce ARD. Static testing estimates the ultimate AP and NP of waste material but is generally silent with regard to the rates of generation of acidic and alkaline flows in actual waste matrices. Kinetic testing is more helpful with regard to estimating the rates of oxidation and neutralization within waste units. However, as discussed above, actual waste units can be very non-homogenous and anisotropic with respect to the distributions of mineral types, particle size, hydrologic conditions and so forth. Thus, while a given kinetic test may well approximate the potential for ARD in a portion of a waste unit, the result may not be representative of the "global" potential for ARD. Equally important is the practical limitation on the duration of kinetic tests:

because kinetic tests are generally short-lived with respect to the potential period of persistence of ARD, they inadequately mimic the evolutionary nature of the process of acid generation.

To overcome the uncertainties inherent in short-term testing, as well as avoid the prohibitive costs of very long term testing, some researchers have developed mathematical models to aid in predicting the long-term effects on mine waste water quality of acid generating wastes. Predictive modeling offers the hope of providing tools for estimating the potential extent of acid generation prior to its occurrence. Ideally, such information may be compared for scenarios entailing alternative management options to identify the design, operating, and closure methods that best meet economic and environmental objectives. As a practical matter, existing ARD models fall short of the ideal. Nevertheless, these models may provide valuable information for planning purposes, and may have an important role in understanding and predicting ARD.

Overview of Existing Models

A number of distinct approaches to modeling ARD have emerged to date. In general, all the models attempt to describe the time-dependant behavior of one or more variables of a mine waste geochemical system in terms of observed behavior trends (empirical models) or chemical and/or physical processes that are believed to control ARD (deterministic models). Empirical models extrapolate values for the desired output variables (e.g., acid generation) from laboratory or field data (British Columbia AMD Task Force, 1989). Deterministic models simulate the changes in system values according to the causal mechanisms relating each element of the system to the others.

It is important to remember that all ARD models are simplifications of reality. Simplification is required by incomplete understanding of all factors influencing AMD. Further, simplification can substantially reduce the cost and time required to model the system under study. However, simplifying assumptions can lead to erroneous conclusions if they result in the omission of important causal mechanisms. For instance, failure to consider the presence of neutralizing materials in a waste pile could result in an overestimation of the rate of acid generation. Similarly, failure to consider hydrogeochemical conditions within a waste pile may preclude consideration of adsorption/ precipitation reactions involving metals, thereby miscalculating the potential for metals loading in effluent streams. Because the importance of any given controlling factor may vary from site to site (and from time to time), the significance of a simplifying assumption for any particular modeling effort must be weighed carefully.

Empirical Models

As stated above, empirical models extrapolate values of sulfide oxidation from existing laboratory and field test data. The method of extrapolation typically involves determination of the "best-fit lines" through test data points (British Columbia AMD Task Force, 1989). The equations so derived may

then be solved to provide, for instance, the acid generation rate of a particular waste unit at some time in the future. Using the projected acid generation rate as an input to a separate hydrogeochemical model that accounts for attenuation of seepage constituents in soils and dilution in receiving waters, the estimated constituent loading rates and consequent receiving water quality at time T may be estimated (Broughton and Robertson, 1991).

Empirical models generally do not explicitly consider the causal mechanisms driving oxidation of sulfides and neutralization of seepage. Rather, such models assume that the operation of such controls is accurately represented in the test data. Therefore, the accuracy of empirical models in predicting ARD depends heavily on the quality of the test data used in the models. Principal sources of uncertainty may be expected to include variations in the spatial and particle size distribution of sulfide and alkaline minerals not captured by the data due to insufficient spacial distribution of samples; changes in the distribution of particle sizes throughout the waste unit (due to weathering) not captured by the data; and failure to accurately calibrate the model to reflect the actual quantity and type of materials (British Columbia AMD Task Force, 1989).

It is important to note that empirical models, by their nature, are site-specific. Because the models rely on actual trends observed at a specific site, rather than generic causal mechanisms, the best fit lines for one site cannot be assumed to be representative for another site. Further, significant changes in waste unit composition, geometry, or controls over time may invalidate previous representativeness of empirical models. Nevertheless, empirical models may provide cost-effective and reasonably reliable estimations of short-term future ARD conditions for sites with sufficient spatial and temporal data.

Deterministic Models

Deterministic models simulate ARD by solving systems of equations that represent the various controlling factors in the waste reaction process (Broughton and Robertson, 1991). The simulation approach allows the users to examine the potential sulfide oxidation rate and resulting seepage quality over periods of tens to hundreds of years in the future. The greatest promise of deterministic models is that they may allow the user to predict ARD as it evolves over time under the changing influence of rate-controlling factors. Existing models have built upon earlier work on acid releases from coal mine spoils as well as work on leachate quality in metals heap leach operations (Nicholson, 1992). The models may rely solely on the causal relationships described in the equations, or may include empirical data as exogenous drivers (outside the model structure) to solve for certain aspects of the system (Nicholson, 1992; Broughton and Robertson, 1991). The most important differences between the models lie in the particular causal mechanisms (e.g., oxygen diffusion, changing particle size, temperature variations due to exothermic reactions) addressed within each model structure.

Nicholson presents a review of ARD models. In that review, Shumaten (1971), as cited in Nicholson (1992), is credited with first recognizing that diffusion of oxygen within mine rock limits the overall rate of oxidation of sulfides (Nicholson, 1992). The first working models to incorporate this process (Morth, 1972; Rica and Chow 1974; both cited in Nicholson, 1992) used the acid generation rate to calculate resulting drainage water quality. Rittchie (1977), as cited in Nicholson (1992) added to this concept by explicitly accounting for the removal of oxidized sulfur from the store of available unreacted sulfide. Jaynes et al., working with a model of pyritic shale in coal mine spoils, assumed pyritic particles to oxidize as shrinking cores of unreacted material surrounded by an outer layer depleted of pyrite (Nicholson, 1992). The outer layer results in decreased diffusion rates of oxygen, while the shrinking core provides a smaller reactive surface area. Other models have included convection as a means of oxygen transport within waste piles (Lu and Zhang, undated). Convection may be influenced by changes in barometric pressure or by the release of heat from the exothermic oxidation of sulfides. Some researchers have modeled the feedback mechanisms operating between temperature and biological and chemical oxidation rates, noting that the mechanism is only significant where waste permeabilities are high enough to allow convective oxygen transport to occur (Nicholson, 1992).

More recent models have addressed the hydrologic and geochemical conditions in waste unit matrices, as well as reaction product transport, to more realistically represent changes in seepage quality (Nicholson, 1992). Bennett (1990) and others found that water flow through the waste pile strongly influences sulfide oxidation rates by acting as a heat sink and removing heat produced by oxidation.

Jaynes et al. and Schafer (as cited in Nicholson, 1992) have incorporated chemical equilibrium relationships of varying complexity to model the mobilization and attenuation of oxidation and dissolution products within the waste pile. These relationships drive the residence times of various constituents within "mixing cells" of the waste matrix, and, along with allowing for consumption of acid by alkaline materials, result in changes in effluent chemistry as conditions within the matrix evolve (Nicholson, 1992). The Bureau of Mines is currently developing a deterministic model where initial results have successfully matched humidity cell data (White, 1994).

Model developments such as those listed above have significantly contributed to understanding of the processes controlling ARD. For instance, explicit consideration of oxygen diffusion reveals that, in instances where diffusion is restricted, fast processes such as biologically catalyzed oxidation can be unimportant to the overall rate of oxidation. Similarly, consideration of hydrologic flow within the waste matrix shows that the rate of release of oxidation products from waste piles depends strongly on the flow characteristics within the wastes (Nicholson, 1992). More recent models have corroborated the proposition that waste dump geometry can be important to oxidation rates by influencing the surface area exposure and air infiltration rates (Nicholson, 1992).

Notwithstanding the understanding that existing models have provided, ARD models to date have not found extensive applications in predicting oxidation rates and effluent quality at operating or proposed sites (Ferguson and Erickson, 1988). As stated above, models are simplifications of reality, and consequently are subject to a high degree of uncertainty. Among the sources of uncertainty are incomplete or invalid model structure; natural variability of certain parameters; and lack of parameter calibration and model verification (British Columbia AMD Task Force, 1989).

Incomplete model structure leads to uncertainty in predictions by ignoring potentially important rate controlling factors. In general, incomplete model structure results from an incomplete understanding of the system being modeled, or the overuse of simplifying assumptions (British Columbia AMD Task Force, 1989). For example, failure to accurately account for water flow within the waste matrix prevents consideration of the thermal gradient within the pile, the transport of oxidation and dissolution products, and the conduction of oxygen via water. It is worth noting that modeling water flow in waste rock piles presents greater difficulties than in tailings piles, and has received little attention to date (Nicholson, 1992). For this reason (among others), waste rock pile models are subject to a higher level of uncertainty.

Natural variability of some parameters of a system can lead to uncertainty in model predictions. For example, changes in rainfall patterns, which directly effect the hydrologic conditions in the waste pile, are difficult to predict with certainty. Likewise, particle size distribution and mineral type distribution throughout the waste pile can be highly variable and difficult to predict.

Among the greatest concerns facing the reliability of predictive deterministic models are model calibration and validation. Model parameters must be adjusted to match the conditions prevailing at an actual site. Therefore, reliable waste characteristics, hydrologic and geochemical data must be collected and incorporated into the model structure. Validation requires comparison of model predictions with actual field sampling results. To date, the availability of field data for validation is very limited.

4.1.3 ARD Detection/Environmental Monitoring

Where there is the potential for encountering sulfide mineralization, an assessment of potential impacts should include appropriate testing for ARD potential (using one or more of the methods described in the previous section). Where testing results demonstrate potential for ARD generation or where such test results are inconclusive (particularly in sensitive environments), an applicant's environmental monitoring program should include specific testing directed at early identification of ARD. This should involve sampling of effluent streams as well as surface water and groundwater.

Existing data on ARD generation indicate that it is highly variable. (Mine discharge sampling data compiled by the British Columbia Acid Mine Drainage Task Force at sites with known ARD

generation show significant day-to-day variability in pH and concentrations of dissolved metals.) As a result, regular monthly or quarterly sampling (commonly used to monitor effluents/impacts from industrial operations) may not be adequate to detect ARD generation. Where ARD is a potential concern, baseline studies should be designed to establish conditions where ARD is likely to occur. Monitoring programs during and after operations should be tailored to address the factors that affect ARD generation. These factors include:

- **Seasonal Variability.** Most mines where ARD is observed exhibit seasonal variability in ARD generation (except underground adit discharges which are relatively unimpacted by changing seasonal conditions). Generally, either the first rain after a dry season or high snowmelt periods are most likely to produce ARD. (ARD generation can be specifically increased by the buildup of salts on rock surfaces during dry conditions.)

- **Treated Effluent Variability.** At mine sites, the treatment system effluent quality may be variable due to different influent volumes and characteristics—for example, where natural conditions affect the influent flow and composition. For example, potentially acidic mine water and runoff may be significant influents to the system under certain conditions.

- **Impacts on Aquatic Life.** The actual effects of ARD on a receiving water may be dependent on the behavior/occurrence of specific aquatic life within the watershed. For example, the presence of migratory species may suggest the need for monitoring during specific time periods. Similarly, seasonal releases of ARD may occur during critical life stages of individual species.

- **Stream and River Effects.** Streams and rivers may be heavily impacted due to sudden high releases of ARD (especially where there is limited dilution). In snowmelt areas, impacts can be particularly significant when a melting at the mine site occurs during a different time period than other areas within the watershed (thereby reducing dilution). Sampling plans should consider when "maximum" flows/discharges can be expected.

- **Lake Effects.** In lakes, the effects of ARD may be impacted by physical and biological conditions in the lake. In designing a monitoring plan, factors such as thermal stratification, turnover events, flushing rates, and seasonal cycles of aquatic life growth should be considered.

As stated above, baseline and operational monitoring programs should be designed to address each of the above factors. A reasonable, cost-saving option is to provide for frequent pH or other ARD indicator (sulfate, alkalinity, etc.) monitoring of effluent discharges and ground and surface water quality. When indicator parameters exceed thresholds, increased monitoring could be required for other parameters (including metals and toxicity) to determine the extent of ARD releases/impacts (British Columbia AMD Task Force, 1990).

4.1.4 Mitigation of ARD

There are two primary approaches to addressing ARD: avoiding mining deposits with high ARD potential; and isolating or otherwise special-handling wastes with ARD potential. In practice,

completely avoiding mining in areas with the potential to form ARD may be difficult due to the widespread distribution of sulfide minerals. The individual applicant's pre-project testing (using the methods described in the previous section) should be representative of each rock type, provide good spatial coverage, and be proportional to waste quantities. As discussed above, this may frequently require collection and analysis of an extensive number of samples. The results of truly representative sampling should allow the applicant to develop a mine plan to avoid, wherever possible, sulfide-bearing/acid-generating rock.

Effective isolation of wastes (backfill, waste rock, or tailings) with the potential to develop ARD is a key element to conducting mining activities while minimizing perpetual effects to surface water and groundwater. In isolating these wastes, the acid generation process is brought under control. The requirements for the formation of ARD, as discussed in previous sections, include the presence of sulfides, oxygen, and water. Control of materials with a potential for acid generation can therefore be implemented by preventing oxygen from contacting the material (or minimizing oxygen contact), preventing water from contacting the material, and/or ensuring that an adequate amount of natural or introduced material is available to neutralize any acid produced.

The following sections generally describe specific types of mitigation measures for ARD control. For the most part, only limited data are currently available to document their effectiveness. Further, individual site conditions significantly impact their feasibility and performance in the field. In many cases, the measures discussed below are most effective when used in combination and adapted to the situation existing at a specific site.

4.1.4.1 Subaqueous Disposal

Where fluctuations in water levels are not expected, placement of acid forming materials below the final potentiometric surface may be an effective means to exclude oxygen. Similarly, some dry waste management units can be closed by flooding/subaqueous disposal of potentially acid generating material. The water must be of a sufficient depth to ensure that it is not well oxygenated (since sulfide can oxidize in subaqueous environments) and it should not pass rapidly through the system. Wetting conditions must be permanent and physical mechanisms must not be present to allow entrainment of wastes in the water. Further, it should be noted that metals found in waste materials can dissolve into neutral waters. Both Lapakko (1994b) and St.-Arnaud (1994) have suggested placing protective layers over acid generating tailings disposed of in a subaqueous manner. Similarly, mine operations in upland conditions and in drier portions of the west may not be able to consider submersion as an effective mitigation tool for acid formation. (See also Section 3.2 above.)

4.1.4.2 Covers

Another common technique used to isolate water (and oxygen) from acid forming materials is the use of a low permeability cover. Covers may consist of compacted soils or synthetic materials. Proper function of covers requires that their integrity remain intact; those subject to erosion, weathering, cracking, settling, or penetration by plant roots may not provide adequate protection for an indefinite period of time. Most (if not all) cover materials are more effective at controlling infiltration of water than excluding oxygen. By reducing the amount of water infiltrating a covered system, the potential for migration of any acid drainage formed beneath the cover also is reduced. Similar to covers, subsurface seepage/grout walls can be installed near the highwall to isolate disturbed areas from inflows. Finally, during actual waste disposal, mines can segregate materials to minimize acid generation potential. For example, carbonate materials can be placed on the surface of piles, while potentially acid generating materials are placed below the surface.

The limitations imposed by covers are availability and costs of cover materials. If only limited volumes of material must be covered over the life of an operation, those wastes which require special handling must be precisely identified in the field. In coal mining operations, the complexity of the situation is compounded by the requirement that reclamation be contemporaneous. In these cases, a special waste disposal area is generally not permitted for extended periods of time.

4.1.4.3 Waste Blending

Blending activities during the mining operation may be used to mix alkaline materials with acid forming materials within the waste disposal unit. The effectiveness of blending wastes is directly related to the weathering properties of the alkaline materials; if a $CaCO_3$ equivalent is available at a rate equal to or exceeding the oxidation of sulfides, acid formation could be adequately controlled. Alkaline and phosphate materials such as lime and alkaline fly ash can also be added to selected wastes to provide the same function (as well as placement in surface and underground mines at closure). It should be noted, however, that the neutralization of acid may also lead to the precipitation of metals from solution. These metal precipitates may form crusts on the alkaline solids, reducing the surface area of the alkaline material available for further neutralization of the acid. In addition, it is difficult to accomplish heterogeneous mixing of sulfide and carbonate materials. This has led some government entities to require a 3:1 ratio of neutralizing material to acid generating material. In some cases, "neutralizing materials" that are used in blending consist of any waste rock that is not acid-forming (e.g., it is above the NP/AP ratio set by the regulatory agency). This material may or may not actually have adequate neutralizing capacity.

4.1.4.4 Hydrologic Controls

Hydrologic controls may be employed to some extent to reduce the amount of water percolating through acid forming wastes. Often, diversions are installed that direct surface flows around waste

disposal facilities. French drains may also be installed to promote ground and surface water flow underneath a disposal unit. However, french drains constructed under disposal units (waste rock dumps, head of hollow fills) that eventually generate acid can function as a conduit for acid rock drainage into surface waters.

At some metal mines, acid-forming waste rock is being "encapsulated" within larger waste rock dumps. Relatively low-permeability neutralizing material (often waste rock from other lithologic units that is compacted) is placed under and/or over sulfide rock. The intent is both to reduce water flow to and through the sulfide rock and to neutralize any acid that may form.

4.1.4.5 Bacteria Control

Thiobacillus ferrooxidans is the principal organism responsible for the bacterial oxidation of sulfides that may dramatically (up to a fivefold) increase the rate of acid formation. Studies using bactericides to control ARD have been conducted with some degree of success. A summary of the effectiveness of bactericides presented by the British Columbia Acid Mine Drainage Task Force indicates that these compounds can effectively reduce acidity by 50 to 90 percent (British Columbia AMD Task Force, 1989). However, bactericides are degraded and leached with time, ultimately having a limited life span. Additionally, if acid generation is occurring in an absence of bacteria, bactericides will only control the rate and not the presence of ARD.

4.1.4.6 Treatment

Mines currently in operation experiencing acid mine drainage may face a costly and long-term battle. If acid drainage develops (as it often has) unexpectedly, well after waste disposal units have been constructed, mitigation may require extensive earth moving activity, if sources are small enough to be pinpointed. Alkaline material (e.g., lime) may be added in solid form to flows moving into or out of the acid-forming area (the use of "sorbent" polymers and microorganisms is also being studied). The effectiveness of raising the pH of the water before or after contact with acid-forming material is limited by the chemistry of the constituents involved, and the volume of acid being produced. Demonstration projects have made use of injecting alkaline solutions into acid producing material; however, the long-term effectiveness of this treatment has not been documented (Bureau of Mines, 1985).

Anoxic limestone drains (ALDs) are currently being studied as passive treatment technologies. The Tennessee Valley Authority has successfully used ALDs to enhance the performance of constructed wetlands (Brodie, 1991). Combined ALD and wetland treatment systems have also been successfully tested in Pennsylvania (Hedin and Watzlaf, 1993; Rowley et al., 1994). However, limited data are currently available to assess the long-term effectiveness (including potential limiting factors, such as coating of limestone surfaces with iron and aluminum oxides) and widespread applicability of ALDs

in mitigating ARD, especially where they are used alone. In addition, design of ALDs or any other alkaline/precipitation treatment system must include a settling area. Hedin and Watzlaf (1993) provide additional information on the design and performance of ALDs.

In cases where mine drainage is only slightly acidic and metal loadings are low to moderate, natural and constructed wetlands show some ability to improve water quality (Brooks et al., 1990). In wetlands, "treatment" of ARD (and associated metals) occurs through physical (settling and adsorption), chemical (hydrolysis and oxidation), and biological (bacterial desulfurization) processes. Cohen and Staub (1992) provides technical guidance on the design and operation of wetlands treatment systems. Based on data from an operating wetlands treatment system at the Big Five Tunnel in Idaho Springs, Colorado, an effective life of approximately 4-6 years is projected for a single loading of substrate material (Cohen and Staub, 1992). At some sites, operators may need to provide separate areas for anaerobic (chemical/physical) and aerobic (biological) processes. Based on a study of six artificial wetlands constructed by the Commonwealth of Pennsylvania, a surface flow criteria of 6 grams/day/square per meter was recommended (Dietz et al., 1994).

Testing conducted by the Commonwealth of Pennsylvania has shown that passive wetlands treatment can be effective in mitigating ARD for coal mines, especially for mildly acidic drainage (performance of more than 73 wetlands was evaluated). However, it should be noted that study results generally showed that treatment levels for metals were lower than predicted (Hellier et al., 1994). Further, studies such as those performed by the State of Minnesota, have shown that the capacity of wetlands for metals removal is often limited. The Minnesota study found that metals removal was limited to the upper 20 centimeters of a constructed wetland and that limited flows/periodic maintenance would be necessary to provide long-term mitigation (Eger et al., 1994).

While combined ALD and wetland systems show some promise for passive treatment of highly acidic streams (Rowley et al., 1994), current data to support their widespread effectiveness and feasibility are limited. Therefore, where flows contain low pH values and high metals concentrations, active long-term treatment may be necessary to achieve acceptable water quality in the mine's discharge. A potential alternative to conventional active treatment practices (neutralization/precipitation with lime, etc.) involves the use of Sulfate Reducing Bacteria (SRB) to treat acid drainage. SRB decompose organic compounds and produce sulfide (which is either given off as hydrogen sulfide gas or reacts with metals to form metal sulfides). At a February 1994 EPA workshop on SRB treatment, several participants noted success in reducing metals levels. However, SRB performance data are still limited and results vary from site-to-site. Issues related to optimum design parameters, temperature and pH impacts, toxicity to organisms, and hydrogen sulfide control need to be address (U.S. EPA, 1994). Finally, Cohen and Staub note research indicating SRB are found in wetlands and are important for metals removal in wetlands treatment systems (Cohen and Staub, 1992).

4.1.5 Summary of Factors to be Considered in Evaluating Potential ARD Generation/Release

ARD from coal and hardrock mining operations has been shown to have significantly affected aquatic life in thousand of miles of stream segments throughout the country. These effects can be long-term and the costs of remediation are prohibitive where it is even feasible. While there is extensive ongoing research on ARD, there is substantial uncertainty associated with virtually every methodology used to predict, detect, and mitigate ARD. Further, the extent of ARD generation and the potential risks are generally dependent on a wide range of site-specific factors. No assessment of potential environmental impacts of a proposed mine should dismiss acid generation potential based on limited test data, especially where sulfide ore will be mined. In addition, care must be taken not to be overconfident in the efficacy of specific mitigation measures that may be used if ARD is encountered.

ARD-related factors to be considered in evaluating potential impacts include:

- Comprehensive baseline acid generation potential testing of the ore and waste materials. Where there is any historic basis for believing that ARD could occur and/or where new sources are proposed in particularly sensitive environment areas, the applicant should conduct testing of each geological unit as well as analysis of representative waste samples. Further, the applicant must be cognizant of the areas/ranges of uncertainty associated with static testing. Where there is evidence ARD can occur or where static test methods indicate uncertainty, kinetic testing should be performed to determine the drainage characteristics (and facilitate mine planning).

- An ongoing environmental monitoring program to detect ARD when it occurs. Sampling of wastes, discharges, and surface water/groundwater should be tailored to site-specific conditions that favor ARD generation (e.g., monitoring during or immediately after a major precipitation event after a long-term dry period). An effective monitoring program should emphasize the need for a full understanding of site conditions, including hydrology, geology, and climate. Typical one-time quarterly or bi-annual sampling events may not be adequate to detect ARD.

- Where ARD could be encountered, detailed information on the design and operation of proposed mitigation measures (including a quantitative engineering assessment of their likely effectiveness based on their historic use under similar conditions). If any uncertainties arise, operators should provide for contingencies if proposed measures are ineffective.

- An approach to reclamation bonding that accounts for the long-term impacts of ARD must be cognizant of the potential for a significant lag-time/delay in ARD observance (thus necessitating care in bond release). Also, the need for perpetual treatment measures (and/or perpetual maintenance of passive treatment techniques) should be considered.

While the potential for ARD generation is highly variable, extensive documentation is available on a wide range of site conditions. Further information is available from the references cited in this section and from many other sources. In addition, Canada's Laurentian University Library has

established the on-line Mining Database, which contains citations and abstracts related to ARD and reclamation. Finally, while there is no consistent National policy related to ARD, several regulatory entities have developed specific requirements to address ARD generation at new mining operations. For example, BLM has recently promulgated an ARD policy to guide approval of proposed operations (Williams, 1994). OSM requires acid-base accounting to assess acid generation potential. Similarly, the British Columbia government has specific requirements for ARD prediction, environmental monitoring, mitigation, and bonding (Price and Errington, 1994). Some States and National Forests also have policies related to prediction, monitoring, mitigation, and bonding.

4.2 CYANIDE HEAP LEACHING

Cyanide has long been used in the mining industry. For decades, it has been used as a pyrite depressant in base metal flotation. It also has been used for over a century in gold extraction. In the 1950s, technologies that allowed large-scale beneficiation of gold ores using cyanide (first demonstrated in Cripple Creek, Colorado) set the stage for the enormous increase in cyanide usage when gold prices skyrocketed in the late 1970s and 1980s. Continued improvements in cyanidation technology have allowed increasingly lower-grade gold ores to be mined economically. Together with continued high gold prices, this has resulted in increasing amounts of cyanide being used in mining. A substantial proportion of sodium cyanide produced in the U.S. is now used by the mining industry, with over 100 million pounds used by gold/silver leaching operations (both tank and heap leaching) in 1990, less than 5 million pounds for copper/molybdenum flotation, and much less than 5 million pounds in lead/zinc flotation.

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

Through the 1980s, as cyanidation operations and cyanide usage proliferated, there were a number of incidents where waterfowl were killed when they attempted to use tailings ponds or other cyanide-containing solution ponds (e.g., pregnant or barren ponds). For example, operators in Nevada, California, and Arizona reported to regulatory authorities on over 9,000 wildlife deaths, mostly waterfowl, that had occurred on Federal lands in those States from 1984 through 1989 (GAO, 1991). In addition, a number of major spills have occurred, including one in South Carolina in 1990, when a dam failure resulted in the release of over 10 million gallons of cyanide solution, causing fish kills for nearly 50 miles downstream of the operation.

In many cases, regulatory authorities—Federal land managers and States—have responded by developing increasingly stringent regulations or, in many or most cases, nonmandatory guidelines. These regulations and/or guidelines can address the design of facilities that use cyanide (e.g., requiring/recommending liners and site preparation for heap leach piles or tailings impoundments),

operational concerns (e.g., monitoring of solutions in processes and in ponds, and in some cases treatment requirements for cyanide-containing wastes), and closure/reclamation requirements (e.g., rinsing to a set cyanide concentration in rinsate before reclamation can begin).

There are a number of major issues associated with evaluating the potential impacts of cyanide operations on the environment. These include the complexity of cyanide's chemistry, uncertainties about its behavior in the environment, and inadequate laboratory analytical methods. These issues are discussed briefly below.

4.2.1 Uncertainties in Cyanide Behavior in the Environment

4.2.1.1 Cyanide in the Environment

Cyanide concentrations are generally measured as one of three forms: free, weak acid dissociable (WAD), and total. Free cyanide refers to the cyanide that is present in solution as CN^- or HCN, and includes cyanide-bonded sodium, potassium, calcium or magnesium. Free cyanide is very difficult to measure and its results are often unreliable, difficult to duplicate, or inaccurate. WAD cyanide is the fraction of cyanide that will volatilize to HCN in a weak acid solution at a pH of 4.5. WAD cyanide includes free cyanide, simple cyanide, and weak cyanide complexes of zinc, cadmium, silver, copper, and nickel. Total cyanide measures all of the cyanide present in any form, including iron, cobalt, and gold complexes. Exhibit 4-3 shows one means of classifying various forms of cyanide. Free cyanide would include the "readily soluble" simple compounds, and WAD cyanide would generally include all of the forms in the exhibit except the "strongly complexed cyanides."

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

Unsaturated soils provide significant attenuation capacity for cyanide. Within a short time and distance, for example, free cyanide can volatilize to HCN if solutions are buffered by the soil to a pH below about 8 s.u. Adsorption, precipitation, oxidation to cyanate, and biodegradation can also attenuate free (and dissociated complexed) cyanide in soils under appropriate conditions. WAD cyanide behavior is similar to that of free, although WAD cyanide also can react with other metals in soils to form insoluble salts. (Hutchison and Ellison, 1991)

Free cyanide is extremely toxic to most organisms, and this form has been most frequently regulated. Under the Safe Drinking Water Act, EPA has established a maximum contaminant level (MCL) of

Exhibit 4-3. Stability of Cyanide and Cyanide Compounds in Cyanidation Solutions

Classification	Compounds	Solution chemistry
Free cyanide	CN^-, HCN	Extremely toxic. In natural waters below pH about 8.3, HCN form is predominant.
Simple compounds a. Readily soluble b. Neutral insoluble salts	a. NaCn, KCN, $Ca(CN)$, $Hg(CN)_2$ b. $Zn(CN)_2$, $Cd(CN)_2$, CuCN, $Ni(CN)_2$, AgCN	Water soluble. Dissociate or ionize readily and completely to yield free cyanide and metal ion.
Weak complexes	$Zn(CN)_4^{-2}$, $Cd(CN)_3^{-1}$, $Cd(CN)_4^{-2}$	Rates of dissociation and release of free cyanide affected by light, water temperature, pH, total dissolved solids, and complex concentration. pH and concentration most affect stability and extent of dissociation (breakdown increases with decreases in pH, concentration).
Moderately strong complexes	$Cu(CN)_2^{-1}$, $Cu(CN)_3^{-2}$, $Ni(CN)_4^{-2}$, $Ag(CN)_2^{-1}$,	
Strong complexes	$Fe(CN)_6^{-4}$, $Co(CN)_6^{-4}$, $Au(CN)_2^{-1}$, $Fe(CN)_6^{-3}$,	Iron is most common/ important: Very stable in absence of light. Long-term stability uncertain.

Source: Column 3, Mudder and Smith 1989; columns 1 and 2 cited in Mudder and Smith.

0.2 mg/l free cyanide in drinking water. The Clean Water Act ambient water quality criterion recommended for protection of freshwater aquatic life from chronic effects is 0.0052 mg/l free cyanide; the acute criterion is 0.022 mg/l free cyanide. More recently developed mining-related standards and guidelines often specify weak acid dissociable (WAD) cyanide, largely because of the difficulty in measuring free cyanide at the low concentrations of regulatory concern (Mudder and Smith, 1992). Longer-term environmental concerns with cyanide, those not related to acute hazards from spills, revolve around the dissociation into toxic free cyanide of complexed cyanides in waste units and in the environment.

4.2.1.2 Analytical Issues

In developing the effluent limitation guidelines for the Ore Mining and Dressing Point Source Category (at 40 CFR Part 440), EPA established a technology-based standard for all discharges from mills that use the "cyanidation" process to recover gold and silver, and mills that use cyanide in froth flotation of copper, lead, zinc, and molybdenum ores. In this process, the Agency considered several treatment methods for reducing cyanide levels in mill wastewaters. However, EPA found that the cyanide levels in both treated and untreated mill wastewaters were below the 0.4 mg/l quantification limit for EPA-approved test methods (i.e., treatment performance could not be evaluated). Because of this, and because complete recycling of mill waters was practiced at many facilities, the Agency established a zero discharge requirement. EPA was aware of specific sites where laboratory methods

were effectively being used to quantify cyanide removal and suggested that these methods could be used by permit writers to establish cyanide limits in individual NPDES permits on a site-by-site basis.

Analytical methods used to determine cyanide concentrations in tailings and tailings solutions, effluents, and heap pore water are still being debated. At low concentrations, testing is inaccurate and measurements of cyanide may not be good predictors of actual cyanide concentrations in the field. (Durkin, 1990; Colorado, 1992a; U.S. EPA ORD, 1993) Many complex and cumbersome analytical methods have been developed as a result of the need for measuring cyanide in a variety of matrices. Many "random" modifications of procedures also have made it very difficult to interpret many analytical results (California Regional Water Quality Control Board, 1987).

EPA's Office of Research and Development (ORD) is currently evaluating cyanide test procedures and methods, and is investigating a proprietary, privately developed, distillation method that appears to be successful for cyanide analysis. One of ORD's activities includes revising the current methods for measuring and detecting cyanide fractions and eliminating interferrents. ORD is also reviewing performance data and problems of 17 currently used methods. Future efforts will involve continued evaluation of cyanide species (ORD, 1993).

Because of the uncertainty involving cyanide forms and analytical methods, regulatory standards and guidelines may not be clear on the form of cyanide being addressed. Nor, in many cases, do environmental monitoring data make clear which form or which analytical method has been used. This can make it difficult or impossible to evaluate the short- or long-term potential environmental impacts of a proposed (or an existing) operation. Thus, it is important that environmental documentation be clear as to the form of cyanide that is described and addressed, and that appropriate analytical methods be specified. Similarly, the types of cyanide complexes that are expected to occur in heap leach piles and tailings should be assessed, along with the rate and extent to which the complexes may break down to toxic forms upon their release (even in low concentrations) to receiving waters.

4.2.2 Potential Impacts and Approaches to Mitigation During Active Life

In general, cyanide can cause three major types of potential environmental impacts: first, cyanide-containing ponds and ditches can present an acute hazard to wildlife and birds. Less frequently (because of lower cyanide concentrations), tailings ponds present similar hazards. Second, spills can result in cyanide reaching surface water or groundwater and cause short-term (e.g., fish kills) or long-term (e.g., contamination of drinking water) impacts. Finally, cyanide in active heaps and ponds and in mining wastes—primarily heaps and dumps of spent ore and tailings impoundments—may be released and present hazards to surface water or groundwater, and there may be geochemical changes that affect the mobility of heavy metals. These impacts and the major issues and uncertainties associated with each are described briefly below.

4.2.2.1 Acute Hazards

The heightened awareness of the threat to wildlife and birds presented by cyanide-containing ponds and wastes have led regulatory authorities (generally, Federal land managers and States) to require operators to take steps either to reduce/eliminate access to cyanide solutions or to reduce cyanide concentrations in exposed materials to below lethal levels. Regulatory requirements and guidelines as to the allowable concentration of cyanide in exposed process solutions are widely variable (when numeric limitations are established, they generally range around 50 mg/l), as are the means by which operators comply. Operators reduce access in several ways, including covering solution ponds with netting or covers, using cannons and other hazing devices (e.g., decoy owls) to scare off waterfowl and other wildlife, and/or installing fencing to preclude access by large wildlife. At least one mine uses tanks to contain all solutions. In addition, operators may be required or may elect to treat tailings slurries to reduce cyanide concentrations, they may maintain higher fluid levels in impoundments so as to dilute concentrations, or they may reduce the amount of free liquids in impoundments to minimize pond surface area. Some facilities also provide "micro-nets" over ditches to keep out rodents and smaller wildlife not excluded by large fences. In evaluating the threat that cyanide usage at a proposed facility may pose to wildlife and birds, and the effectiveness of control and mitigation measures, environmental documentation should describe the standards that must be met, the types of organisms of most concern (e.g., waterfowl at an operation in a migratory flyway or near nesting or staging areas), and the specific measures that will be used to reduce exposures and mortality. The program by which the measures will be evaluated for effectiveness should also be described; it will generally involve monitoring and reporting deaths and supplementing existing methods as necessary.

4.2.2.2 Spills and Overflows

Most actual environmental impacts resulting from cyanide releases have been associated with spills and major failures of containment structures (e.g., dam failure, failure of heap slopes). Minor spills of cyanide are not uncommon at gold facilities. These occur typically when portions of a heap leach pile slumps into a drainage ditch or solution pond and cause an overflow of cyanide-containing solution or when a pipe carrying pregnant or barren solution, or tailings slurry, fails or is punctured/severed by mining equipment or vehicles. In all but a few major cases, cyanide spills have been contained on-site, and soils provide significant attenuation in most cases. Facilities routinely store hypochlorite or other oxidants for use in detoxifying such spills. In addition, some operators have increased the distance or placed barriers between pipelines and equipment routes. Others have reinforced pipelines in high-risk areas.

The proximity of sensitive environments—generally including any water bodies—may be the most important factor in assessing the potential impacts of spills. In all cases, environmental documentation should describe the practices or methods that will be used to reduce the risk of

ruptures and spills, and in responding to minor and major releases. More details would be necessary for operations in sensitive environments, including details on spill-prevention practices and on spill response procedures. Particularly when cyanide facilities and structures (e.g., pipelines, heaps, impoundments) are near streams or wetlands, extra precautions are appropriate, including double-walled pipelines, additional setbacks of heaped ore or intervening barriers between heaps and solution ponds, automatic pump shutoffs in the event of pressure loss, etc.

During facility operations, great attention is paid to the water balance and the efficient movement of solution through the system. Facilities are generally required to be able to contain at least the normal 24-hour process solution flow and the maximum volume from the 10-year/24-hour precipitation event. Many States require additional capacity, sufficient to contain the flows from the 100-year/24-hour event. Because of the size of mining operations and the large areas that can contribute flows, this can be an enormous volume, well beyond feasibility for many operations. Thus, most States allow an operation's required storage capacity to include the volume of precipitation and solution that can be held in heaps as well as in solution ponds and overflow ponds. As a result, continued circulation of solution is necessary to ensure that heaps do not dewater and overwhelm the capacity of ponds. Most States require onsite generators to ensure continued supply of electricity to pumps in the event of power failures. All details of storage capacity and solution management may not be available at the time environmental documentation is prepared. However, conceptual plans that identify most components of storage capacity and the means by which capacity will be ensured usually are.

Because miscalculations involving solution management can be catastrophic (for example, this was a major problem at the Summitville mine, now proposed for the National Priorities List), reviewing water balance plans, even conceptual plans, is crucial in assessing potential environmental impacts. This is particularly true when operations are in or near sensitive environments. Every aspect of water balance calculations should be assessed: the amount of precipitation and runon/runoff assumed to occur in the designated storm event, the area of the operation that will contribute flows and the amount, the amount that can be held in each component of the water management system (e.g., the saturation status of a heap under normal operating conditions), even the pumping capacities of solution recirculation pumps. In addition, some assessment should be made of water balances under conditions other than the designated storm event. For example, spring snowmelt can provide flows over several days that are more significant than long return-interval precipitation events. Similarly, a series of less significant storms (e.g., several 5- or 10-year events) can collectively be more significant than one extremely large storm. Meteorological data are often provided in environmental documentation (or in proposed operating plans submitted to States and/or Federal land managers), and these should be evaluated carefully to determine whether reasonable assumptions have been made regarding hypothetical worst-case events. Also of importance is how both operators and regulators may respond to unexpected water balance problems. In most cases, such problems are addressed as they arise, with never a reconsideration of the entire system and whether the original planning and

design were sound, and thus no re-evaluation of potential environmental impacts. It may be appropriate in some cases to require more formal contingency planning at the outset, with a reassessment of potential environmental impacts required when critical components of the water management system are modified.

4.2.2.3 Liner and Containment Leakage

As described in Chapter 3, heap leach operations use liner systems of various sorts under heaps and solution ponds. In general, liner systems consist of a prepared foundation (compacted subsurface, with large rocks and objects removed), a bedding layer (if used), synthetic or clay liner, seepage collection/detection layer (if used), and a cover layer of material to protect the liner. Perhaps the single most important factor in preserving the integrity of liner systems is their proper installation, including comprehensive construction QA/QC. The type of liner system that is used generally is based on site conditions, operator preference, and regulatory requirements (Van Zyl, 1991). Liners are usually of polyvinyl chloride (PVC) or high density polyethylene (HDPE); recently, very low density polyethylene (VLDPE) liners have emerged. Although there now is ultraviolet-resistant PVC, there have been some problems with older PVC liners degrading when pond or ditch liners are exposed to ultraviolet light. In most cases where there have been significant liner failures, they have been due to improper installation or accidents combined with inadequate construction QA/QC.

There is a clear economic incentive to minimize pregnant solution loss during operations; this is often cited as a reason why operators' design plans should be accepted as proposed. In practice, operators assess the optimum balance of economic and environmental considerations in design planning. Thus, the costs of actual containment technologies and practices are balanced with the economic losses associated with a certain amount of solution loss as well as regulatory and environmental considerations. As noted in Chapter 3, regulatory authorities (Federal land managers and States) are increasingly requiring solution ponds to be double-lined, often with a composite liner system that includes leak detection/collection. Requirements for heaps more often specify single liners, which may be synthetic or clay. In southern California, for example, the great depth to groundwater and the attenuation capacity of soils led the Regional Water Quality Control Board to specify single liners for heaps.

In many locations, however, heaps are located entirely or partially in drainageways (generally ephemeral) over shallow alluvial or shallow bedrock aquifers. This is usually the case for tailings impoundments, but these are infrequently lined; seepage through and under dams is generally collected in toe ponds, but some seepage may bypass such ponds. Should leaks occur through heap liners or should seepage bypass collection ponds, cyanide can reach the alluvium and/or shallow groundwater. This can then affect downgradient surface waters or springs or can reach bedrock aquifers. Whether subsurface materials can attenuate any such leaks and reduce cyanide levels depends on the nature of the materials and the location and extent of water present in the subsurface.

Evaluating the likelihood and the potential consequences of cyanide leaks is particularly dependent on detailed information on the subsurface and on proposed liner systems, and on construction QA/QC. Subsurface information of concern includes the nature and characteristics of the material (depth, mineral composition, compressibility, shear strength, seasonal saturation levels, presence of springs, etc.) Liner systems should be fully described, along with a clear justification for their selection (e.g., why PVC over VLDPE, why flexibility was or was not important, why and how their resistance to sunlight/punctures was considered, etc.). Detailed design and QA information is often not provided in great detail, but in some cases may be necessary. Information on the minimum standards that are imposed by applicable regulatory authorities can assist in determining if more detailed information is needed—if standards are very general, then more information may be appropriate, for example.

Should a proposed operation be located in an environment where leakage could be especially damaging, specific information on the subsurface, on site preparation, and on the liner system and installation and construction QA/QC are always necessary for an evaluation of potential impacts. Finally, the presence or absence of comprehensive monitoring programs (for example, monitoring of seepage detection/collection systems, if any; of bedrock and alluvial groundwater, of materials and pore water in heaps or impoundments themselves; of solution and slurries; of dam/heap stability; of the integrity of containment devices, etc.) and commitments to respond to unexpected events can be a significant determinant in the level of information needed. A sustained monitoring program, combined with financial commitments and/or regulatory guarantees that environmentally appropriate responses will be taken if necessary, can provide significant assurances that long-term impacts will be minimized, even in the absence of detailed information and analyses.

4.2.3 Closure/Reclamation and Long-Term Impacts

4.2.3.1 Closure and Reclamation

Until the recent past, reclamation (if required) commenced immediately upon cessation of operations. With increasing concern over environmental quality in general and toxic pollutants specifically in recent decades, however, the concept of pre-reclamation closure has received more attention by States and Federal land managers. However, relatively few cyanide operations have been completely reclaimed to date, since large-scale cyanidation operations are a phenomenon of recent vintage. Consequently, closure and reclamation measures are not yet well established.

Closure entails those activities conducted after a cyanide unit ceases operating in order to prepare the site for reclamation. Closure essentially consists of those activities that are required to remove a hazard or undesirable component, whether it be chemical or physical, to the extent required by States or Federal land managers. It can entail detoxification/neutralization of wastes, treatment and/or evaporation of rinse liquids and pond water, dismantling associated equipment and piping, removal or treatment of waste, reconstruction, grading or stabilizing, and/or chemical testing.

Reclamation consists of those activities that are undertaken to return the site to a condition suitable for the future uses specified by the State or land manager. Reclamation may involve regrading; backfilling ponds; removal of wastes; site drainage control such as diversions, channels, riprap, and collection basins; perforating liners to allow drainage through heaps; capping to reduce infiltration and/or to provide a substrate for revegetation; and revegetation to establish ground cover and protect against erosion.

4.2.3.2 Long-term Environmental Concerns and Issues

The principal concerns with closure of spent ore and tailings impoundments are long-term structural stability and potential to leach contaminants. Structural stability is dependent on the physical characteristics of the waste material (e.g., percent slimes vs. sands in impoundments), the physical configuration of the waste unit, and site conditions (e.g., timing and nature of precipitation, upstream/ uphill area that will provide inflows). The potential to leach contaminants is largely dependent on site conditions, including reclamation and mineral(s) geochemistry.

Cyanide is not the only contaminant that is present in tailings effluents or heaps; numerous other constituents may be present in the waste material and present potential problems following closure and reclamation. Nitrate (from cyanide degradation) and heavy metal (from trace heavy metal sulfides in the ore) migration are examples of other significant problems that can be faced at closure of cyanide operations. As noted above, testing and analysis of cyanide is a major issue because it is difficult to obtain consistent and reliable test results. Another significant concern is the generation of acid drainage, typically caused by the presence of iron sulfides that break down to form sulfuric acid.

Because of the great variability among cyanide operations, including ore characteristics and climatic conditions, adequate characterization of wastes and materials is an important consideration for site closure and reclamation. In part because few have been closed/reclaimed, there is limited information available on the mobility of cyanide and cyanide complexes in closed and/or reclaimed heaps and tailings impoundments. However, at several South Dakota sites, nitrate, one of the degradation products of cyanide, has been detected in areas beyond the heap . Operators were able to meet the 0.2 mg/l cyanide detoxification criteria, but elevated levels of nitrate have prevented the attainment of other criteria developed by the State for the site. The nitrate levels in surface runoff from the mine sites have exceeded treatment criteria and low levels of nitrate have been detected in downgradient wells. (Durkin, 1990)

In addition, the chemistry of a spent heap or tailings impoundment may change over time. Although effluent samples at closure/reclamation may meet State requirements, the effluent characteristics may be dependent on the pH. The question of what happens to the heap or impoundment when the pH or moisture content changes is one that is now being addressed by many operators and authorities. Modeling can be performed to assess the long-term geochemical conditions at the site taking into

consideration the chemistry of a spent heap over time, and be used to design closure and reclamation plans. Factors affecting chemical changes in a heap or tailings impoundment include pH, moisture, mobility, and geochemical stability of the material.

In addition to high cyanide concentrations, the post-leach solution (pre-cyanide treatment) at heap leach operations is likely to have the following characteristics (Mudder and Smith (1992):

- High pH (9.5 to 11 s.u.)
- Moderate to high dissolved species, mainly sodium, calcium (from added lime), and sulfate.
- Potentially elevated metals of ionic-forming complexes such as arsenic, molybdenum, and selenium
- Potentially elevated metals which form soluble metallo-cyanide complexes such as iron, copper, mercury, cadmium, and zinc.

Rinsing spent ore for detoxification typically takes from several weeks to several months; however, in some cases a site may require several rounds of rinsing in order to meet State or Federal standards. One problem that frequently has been encountered is that rinsing/treatment is conducted and effluent standards may be met, but subsequent rinsing or testing reveals increased cyanide and other constituent concentrations. (Nevada, 1993b) Spring snowmelt also has caused effluent concentrations to rise. Several States, as well as the Bureau of Land Management, now request follow-up effluent sampling after periods of rest or after rainy season/spring snowmelt prior to approving completion of detoxification. (BLM, 1992; Idaho, 1993, South Dakota, 1993) Although the reasons for incomplete or variable rinsing have not been confirmed, Durkin (1990) suggests that non-uniform neutralization or dilution may be factors. A number of facilities have had to switch treatment methods after a chosen method failed to reach the desired concentrations. Thus, in practice, rinsing may take many seasons, or years, to complete.

Agglomerated heaps are more difficult to rinse because aggregating the material prior to leaching (with lime or cement or other materials) keeps the pH elevated, which in turn makes reduction of pH and detoxification of cyanide more difficult. One Nevada mine (Trinity), for example, operated an agglomerated heap; when leaching ended, initial WAD cyanide concentrations were 400 - 500 mg/l and the facility proposed using natural degradation to reduce the cyanide concentrations but continued high pH has prevented this from being effective (Nevada, 1993c). As a result of this and many other site-specific circumstances that affect detoxification success, State-granted variances from rinsing criteria are not uncommon in many States.

One mine in Nevada encountered a major problem during rinsing of a spent heap. While recirculating the solution during leaching, gold was removed from the pregnant solution but other

metals and constituents continued to accumulate and were not removed from the solution. As a result, during rinsing, the mercury levels in the rinse water rose to 4.0 mg/l, three orders of magnitude higher than the primary drinking water standard of 0.002 mg/l. The tremendous amount of water required for consecutive rinses in order to reach the 0.2 mg/l cyanide standards has also been an issue in Nevada. (Nevada, 1993b)

Several mines in five western states have experienced elevated selenium levels (Altringer, 1991). The Bureau of Mines is investigating the use of biological and chemical reduction of selenium in cyanide tailings pond water. Although high costs may make the treatment prohibitive, the research study was successful in reducing selenium concentrations in the laboratory from up to 30 ppm selenium to 0.02 ppm.

Water balance is a major concern at some sites. In arid regions, with limited water resources, the amount of water that is necessary to rinse heaps to a required standard may be a significant concern. Conversely, in wet climates like South Carolina, excess water from heavy precipitation and/or snowmelt can place a strain on system operations and may make draining or revegetating a heap or impoundment very difficult (ELI, 1992).

Another potential problem may be caused by "blind-offs," less permeable lenses or isolated areas of a heap that affect percolation and flow through the heap, leading to preferential paths for fluid migration. Available research data suggest that preferential flow paths and blind-offs increase with time and volume of liquid. These preferential flow paths can limit the effectiveness of treatment/neutralization and may leave pockets of contaminants behind in a heap during closure, which then have the potential to leach out after reclamation.

Acid generation also may be a major problem facing many mines. At one time, acid generation at cyanide sites was not considered to be a potential problem as many mining facilities used only oxide ores (not sulfide ores). However, cyanide leaching facilities that mined predominantly oxide ores have reported cases of acid generation. Even tailings that were originally alkaline have subsequently experienced acid generation. Although lime may be added during cyanide leaching, with residuals existing in tailings or agglomerated heaps, the lime component may eventually wash away through weathering, leaving sulfide compounds to form acid drainage. (Ritcey, 1989; California, 1993b) As noted above, the reverse situation may also occur, when residual lime/cement can keep pH too high to allow cyanide to dissociate and degrade. This only emphasizes the extreme site-specific nature of operations and of potential and actual environmental impacts that may be expected to occur.

4.2.3.3 Assessments of Long-term Impacts

In general, cyanide is not believed to present a significant problem over the long term, particularly if the obstacles to detoxification and reclamation are overcome. As noted above, however, there are

many complexities with detoxification and reclamation and which if any difficulties will be encountered are seldom known at the time that the potential environmental impacts of a proposed mining operation are evaluated. As a result, environmental documentation should describe contingency plans for overcoming possible difficulties and potential impacts under these conditions.

If detoxification is successful, most residual cyanide in closed heaps and impoundments will be strongly complexed with iron. Although the stability of such complexes over long periods is not well understood, cyanide is generally considered to be much less of a long-term problem than acid generation, metals mobility, and stability (which are discussed elsewhere). Thus, evaluating the potential post-operational environmental impacts associated with cyanide in heaps, spent ore dumps, and tailings would involve assessing the means by which operators will ensure that cyanide and its breakdown products and metallic complexes are contained and reduced to environmentally benign levels prior to site abandonment. It also may involve an assessment of the ability and authority of applicable regulatory authorities to guarantee this. Conceptual plans for operators who will detoxify and reclaim heaps and tailings are generally available at the time environmental impact assessments are performed, but not the details. This may be sufficient, given that cyanide may not be an important environmental issue over the long term. What is important is that the plans describe not only what is anticipated to occur at closure and reclamation (e.g., continued recycling of rinse water until WAD cyanide levels reach regulatory standards) but also the implications for long-term environmental performance that potential difficulties and changes in plans could have.

4.3 STRUCTURAL STABILITY OF TAILINGS IMPOUNDMENTS

The most common method of tailings disposal is placement of tailings slurry in impoundments formed behind raised embankments. Modern tailings impoundments are engineered structures which serve the dual functions of permanent disposal of the tailings and conservation of water for use in the mine and mill. Impoundments are often favored over other tailings disposal methods (e.g., tailings piles, mine backfilling) because, among other things, they are "economically attractive and relatively easy to operate" (Environment Canada, 1987). Such economy derives in part from the fact that tailings and waste rock may account for a major part of the embankment construction materials. Additionally, the phased nature of embankment construction spreads the capital expense of disposal unit construction over the life of the project, reducing initial capital outlays. Section 3.2.6.2 discusses the types of tailings impoundments used and their construction methods.

The disposal of tailings behind earthen dams and embankments raises a number of concerns related to the stability and environmental performance of the units. In particular, tailings impoundments are nearly always accompanied by unavoidable and often necessary seepage of mill effluent through or beneath the dam structure. Such seepage results from the uncontrolled percolation of stored water downward through foundation materials or through the embankment as well as the controlled release of water in order to maintain embankment stability. Impoundment seepage raises the prospect of

surface water and groundwater contamination and, coupled with the potential for acid rock drainage (see above), may necessitate long-term water treatment well after the active life of the facility has passed. Moreover, failure to maintain hydrostatic pressure within and behind the embankment below critical levels may result in partial or complete failure of the structure, causing releases of tailings and contained mill effluent to surrounding areas.

Therefore, the challenge posed by raised embankment tailings impoundments is achieving a balance between cost, stability, and environmental performance objectives. Because raised embankments evolve over the life of the project they present the need and the opportunity to reevaluate design parameters to address changing conditions and project objectives over time. The evolving nature of raised embankments also means that finished impoundments often differ substantially from their initial plans. Accordingly, it can be very difficult to determine in advance the potential for environmental difficulties or the need for environmental controls.

4.3.1 Seepage and Stability

In general, tailings impoundments and the embankments that confine them are designed using information on tailings characteristics, available construction materials, site specific factors (such as topography, geology, hydrology and seismicity) and costs, with dynamic interplay between these factors influencing the location (or siting) and actual design of the impoundment.

The three methods of embankment construction (upstream, downstream, and centerline) differ with respect to the quantity of materials required for construction and the types of operational and designed controls that may be incorporated into the structures for stability and environmental performance. For instance, upstream embankments are the most economical but present difficulties in installation and operation of in-dam drainage systems. Downstream embankments require substantially more fill material than either of the other methods, but can readily be designed to include filters and drains, and hence are more appropriate when large water storage capacity in the impoundment is desired. Tailings present several disadvantages as dam-building material, including: high susceptibility to internal piping, highly erodible surfaces, and high susceptibility of the fine tailings to frost action. To overcome some of these disadvantages, the coarse fraction of tailings streams, the tailings sands, may be separated from the remaining fines and slimes by spigotting or cycloning of the tailings slurry. Additionally, compaction will substantially increase resistance to sliding and liquefaction.

A primary concern in the design of tailings impoundments is the control of pore water pressure within and beneath the embankment. Excessive pore pressure within the embankment may lead to exceedence of the sheer strength of the fill material, resulting in local or general slope failure. Additionally, high pore pressures within or beneath the embankment face may result in uncontrolled seepage at the dam face leading to piping failure (discussed below). Similarly, seepage through weak

permeable layers of the foundation may result in piping or exceedence of soil shear strength, causing foundation subsidence and compromising the stability of the overlying embankment.

The phreatic surface is the level of saturation in the impoundment and embankment (the surface along which pressure in the fluid equals atmospheric pressure (CANMET, 1977)); in natural systems it is often called the water table. Factors that affect the phreatic surface in the embankment include the depositional characteristics of the tailings (permeability, compressibility, grading, pulp density, etc.) and site-specific features such as foundation characteristics and the hydrology and hydrogeology of the impoundment area and its upstream catchment area. Changes to the phreatic surface can be caused by: malfunction of drainage systems, freezing of surface layers on the downstream slope of the dam, changes in construction method (including the characteristics of the placed material), and changes in the elevation of the pond. The level of the water table also may be altered by changes in the permeability of the underlying foundation material; sometimes these are caused by strains and subsidence induced by the weight of the impounded tailings (Vick, 1990).

Impoundment design must provide for a cost-effective and reliable containment system. Choices regarding materials, slope angles, drainage control, raising rates, etc., all affect the cost as well as the stability of the structure. Therefore, stability analysis is performed to optimize the structure with respect to cost and other objectives while maintaining reliability.

Slope stability analysis begins with an estimation of the reliability of the trial embankment. Typically, the embankment designer proposes the internal and external geometry of the trial embankment and then calculates the safety factor of the design. Using detailed information on the physical properties of the fill material and estimates of the volume of tailings and water to be contained in the impoundment, the phreatic surface is predicted. The designer then examines a wide range of failure modes to calculate the estimated stresses expressed at hypothetical failure surfaces. The safety factor for each failure mode is then calculated by dividing the estimated resistance of the embankment to stress along the failure surface by the stress load expressed at the failure surface. With this process the designer can look at changes in design parameters and the resulting influence of the safety factor to arrive at the least-cost option consistent with safety objectives (Inyang, 1993).

The major design precept is that the phreatic surface should not emerge from the embankment and should be as low as possible near the embankment face (Vick, 1990). The primary method of maintaining a low phreatic surface near the embankment face is to increase the relative permeability (or hydraulic conductivity) of the embankment in the direction of flow. This is accomplished by using progressively coarser material from upstream (i.e., the tailings side) to downstream and/or by incorporating drainage features (e.g., chimneys drains, blanket drains) in the dam itself to keep fluids away from the downstream face. Tailings slimes, clays, and/or synthetic liners (rarely) may be used to reduce permeability of the upstream face.

Other means that, in various combinations, are used to maintain a low phreatic surface near the dam include:

- Reducing the water content of tailings by dewatering prior to disposal.
- Reducing groundwater infiltration into the tailings. This can be a serious problem, at least seasonally, when tailings impoundments are placed over alluvial materials. Infiltration can be reduced by preparing the ground surface in the impoundment area: "lining" with compacted native soils and clays, imported clays, or even synthetic liners, and possibly including drains under these liners to convey the groundwater underneath the tailings.
- Incorporating drains underneath and through the dam to ensure that any seepage/drainage is controlled. This can include incorporating filters or filter zones upstream of drains to help prevent clogging and hence maintain differences in permeability across zones. Filter zones may be constructed of graded sands or synthetic filter fabrics (Vick, 1990).
- Maintaining as little free water in the impoundment as possible by recycling water to the mill or by decanting water and pumping it to an alternative fines settling and water storage impoundment.
- Maintaining free water as far behind the crest of the dam (i.e., as high in the catchment) as possible by sloping the surface of the tailings upstream away from the dam.
- Allowing fluids to escape into the subsurface. This is generally not an option since States generally impose strict groundwater protection standards.
- Diverting runon away from and around the impoundment and dam. This is accomplished with berms and other water diversion techniques.

4.3.2 Seepage/Releases and Environmental Performance

The selection of any of these approaches to embankment design has implications for the operational and long-term environmental performance of the impoundment system. For example, incorporation of drains within and beneath the dam structure to reduce pore pressure within the dam provides a conduit for release of contaminated fluids. Under existing NPDES effluent guidelines, such releases typically will require collection and return to the impoundment since discharges are prohibited from many tailings. The toe pond collection system may also require a liner to prevent downward migration of pollutants to shallow groundwater. Embankment drainage systems also create a post-closure environmental concern: because the impoundment is by design not impermeable, contaminated effluent, possibly including acid rock drainage, may be released from the impoundment after the active life of the project. If the active pump-back system for the toe pond is no longer in operation, such effluent may be released to area surface water. Accordingly, treatment-in-perpetuity or some alternative passive treatment or containment method may be necessary to prevent surface water releases.

Another trade-off between stability and environmental performance is the incorporation of liners. In areas of shallow alluvial groundwater, liners may be necessary to prevent intrusion of water into the impoundment. However, such liners will simultaneously increase the retention of impounded water behind the dam and reduce dam stability, all else being equal. On the other hand, the absence of a liner may increase the downward migration of impoundment constituents to shallow groundwater.

Surface water controls may be of particular importance in post-closure stability considerations. Surface water runoff diversions are generally employed to limit the intrusion of excessive amounts of water into the impoundment, which reduces dam stability and prevents drying of tailings. Failure of surface water controls after impoundment closure could result in an increase in pore water pressure within the impoundment, threatening the stability of the embankment. In general, active measures to control surface water runon and runoff during the operative life of the project may require alternative methods or long-term management after closure.

4.4 NATURAL RESOURCES AND LAND USES

The act of mining can result in major changes to all natural resources on and in the vicinity of the mine. This section describes several major natural resource systems that may potentially be impacted and the types of impacts that may occur.

4.4.1 GROUNDWATER

The potential impacts to the groundwater resources in the area of a mine are similar to those that can impact surface water quality. Acidic water from mine drainage, metals, cyanides, or other toxics from the mining operation may enter groundwater in the vicinity of the mine. Elevated pollutant levels can contaminate drinking water supply wells. Disturbance in groundwater flow regime may also affect the quantities of water available for other local uses. Further, the groundwater may recharge surface water downgradient of the mine, through contributions to base flow in a stream channel or springs. Conversely, surface water affected by mining operations can recharge groundwater, particularly alluvial aquifers.

An assessment of potential groundwater impacts requires that the baseline groundwater resources in the area of the mine be completely characterized, including descriptions of the aquifers (bedrock and alluvial systems), aquifer characteristics, flow regime (an understanding of the potentiometric surface for each aquifer), springs, and background groundwater quality. At least two years of groundwater quality data are generally needed (or an alternative interval that is sufficiently representative of likely variabilities in groundwater quality). The collection of baseline groundwater data should be described in study plans that ensure that useable data is being collected. The collection of these data usually requires the installation of a groundwater monitoring network of wells. Where wells are installed,

documentation should describe the location, depth, construction/completion data, and sampling and analytical methods.

In addition to the baseline characterization of the groundwater in the project area, the following information is generally needed to allow an assessment of potential impacts on groundwater resources:

- Location and construction design plans for toxic materials storage areas (cyanide, oil, etc.), waste management units (focusing on impoundments), leach units, solution transport ditches, process ponds, and surface and underground workings. These should be reviewed in conjunction with hydrogeologic data (particularly the potentiometric surface for each aquifer in the area of the proposed units). Any practices to be used to protect groundwater resources (liners, grouting, etc.) should be examined closely.

- Acid generation potential for the waste rock, tailings, and the mine workings.

- Whole rock geochemistry of the waste rock and ore to determine what metals and other pollutants may be present and available for leaching (under neutral conditions and acidic conditions, where applicable).

- If the rock has a net acid generation potential, mitigation measures should be outlined.

- Locations of and information on any local residential wells or well fields and an evaluation of how they may be impacted by the new source (both in terms of quantity and quality) liners, grout.

- Where there is a hydraulic connection between ground and surface water, an analysis of how potentially affected groundwater could affect surface water flow and quality (and vice versa). When dewatering can create a significant cone of depression and affect the availability of ground water for surface water recharge (see section 3.1.4.1), information on both short- and long-term effects would be necessary.

4.4.2 AQUATIC LIFE

The nature of mining is such that it causes massive land disturbances. These disturbances in turn can have two major types of impacts on aquatic resources, including aquatic life. The first type of impact would result from the contribution of eroded soil and material to streams and water bodies (see section 4.5) and from the release of pollutants from ore or waste rock (sections 4.1 and 4.6). The second would be the direct disruption of ephemeral, intermittent, or perennial streams; wetlands; or other water bodies. Temporary disruptions would occur from road construction and similar activities. Permanent impacts would be caused by actual mining of the area or by placement of refuse, tailings, or waste rock directly in the drainageway—more often than not, this is in the upper headwaters of intermittent or ephemeral streams. (Both types of activities are subject to §404 of the Clean Water Act—see section 6.1.)

Means to prevent future impacts from the release of pollutants to surface waters from waste materials or from mine workings should be addressed in a reclamation plan, and effective reclamation can provide substantial mitigation. As is noted elsewhere, however, reclamation plans for metal mines are often only conceptual at the time of mine permitting. Thus, preparers and reviewers of EAs and EISs often must rely on applicable reclamation requirements and on the processes that are in place to ensure that reclamation planning proceeds according to those requirements.

For impact assessment purposes, aquatic life is generally defined as fish and benthic macroinvertebrates; however, phytoplankton and other life forms may also be considered, depending on the type of aquatic habitat and the nature of impacts being assessed.

Impacts to relative abundance or biological diversity may occur as a result of chemical and physical changes or from direct removal or introduction of species.

A detailed discussion of the many approaches and methodologies that may be used to define and monitor aquatic resources is beyond the scope of this document. However, there are numerous reference documents that can be used in assessing the environmental impacts to aquatic life associated with a proposed action. Several examples include:

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique*. U.S. Department of Agriculture, U.S. Forest Service, Fort Collins, Colorado.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. General Technical Report INT-138. U.S. Department of Agriculture, U.S. Forest Service, Ogden, Utah.

U.S. Environmental Protection Agency. 1989. *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference*. EPA/600/3-89/013.

U.S. Environmental Protection Agency. 1989. *Rapid Bioassessment Protocols for Use in Streams and Rivers: Benthic Macroinvertebrates and Fish*. EPA/440/4-89/001.

U.S. Environmental Protection Agency. 1993. *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents*.

The impacts of a proposed action on aquatic resources can be either beneficial or adverse. It also may vary significantly, depending on the species. For example, increases in stream flow may preclude habitation of certain species of macroinvertebrates and/or fish but, at the same time, may also provide new habitat for other species of aquatic life. Too often, impact assessment is based on single species management. A more productive approach is to consider the entire ecosystem. Whether the analysis considers the entire ecosystem or an individual species, endpoints/criteria must

be established by which the impacts of the project will be evaluated. Assessment endpoints are environmental characteristics which, if they were found to be significantly affected, would indicate a need for potential mitigation/modification of proposed activities. For example, an endpoint/criteria for an ecosystem analysis might be: "The proposed project decreases the diversity of aquatic life in the stream proposed for discharge." Likewise, an endpoint for a single species analysis might be: "The proposed project decreases the number of individuals of a certain species of fish."

In many cases, impact assessments for proposed actions are based on what species are determined to be valuable to society (in the affected area). Value can be indicated by legal (e.g., listing as threatened or endangered), commercial, recreational, ecological, or scientific importance of the resource. Regardless of the approach taken, the interrelationships between species (in addition to their connection to their environment) should be considered. For example, an individual non-regulated species of macroinvertebrate may not be directly considered a valuable species but it could be an important component of the food chain and local ecosystem which contains other valuable species.

The impacts of a proposed action on aquatic life can most effectively be determined if sufficient baseline data are available. In general, baseline aquatic life studies of one or more years reflecting data from multiple seasons (e.g., spring, summer, fall) are needed to adequately describe reference conditions. Annual and seasonal variation in aquatic life populations (especially macroinvertebrates) are normal. Without adequate baseline data, it is not possible to measure if changes in abundance and/or diversity are due to natural conditions or impacts from anthropogenic activities (e.g., mining). Wherever possible, baseline data should be obtained directly from the drainage to be affected by the proposed action. If this is not feasible, background data should be collected from an unimpacted aquatic ecosystem (e.g., reference site) with similar characteristics to the proposed impact area. (In many areas, aquatic resources have been degraded by historic mining (or other) activity. There, it may be very difficult to determine the "natural" background status of water quality and aquatic life in the watershed of concern. Other nearby watersheds may not provide an adequate surrogate because even "natural" water chemistry in mineralized areas may be substantially different from that in other watersheds.)

To determine which techniques and tools should be used to sample aquatic life, the consideration must be given to the targeted organisms (e.g., fish, benthic macroinvertebrates, phytoplankton); the objective of the sampling program (qualitative versus quantitative); and numerous parameters such as substrate, water depth, flow, and type of water body. Benthic macroinvertebrates may be sampled using a variety of methods such as Surber sampler, Hester-Dendy sampler, activity traps, invertebrate box samplers, drift nets, kick nets, or any of a number of dredges. Fish sampling methods include electrofishing, seining, rotenoning, or using gill nets. Each method has advantages and disadvantages and selection is dependent upon site-specific conditions and the goals/requirements of the study. If

the primary purpose of a study is to determine the presence of a threatened or endangered fish species, for example, it would be inappropriate to use rotenone, which has a 100 percent mortality rate. The references cited above provide guidance on method selection and use (both for baseline and long-term monitoring). In addition, the potential presence and effect of metals such as mercury or selenium that are bioaccumulated should be addressed.

An important variable that the operator and the reviewer should consider in aquatic resource assessments is the duration and extent of the proposed impacts. For example, if the proposed action (or potential alternatives) will temporarily decrease stream flow during one season, the impacts on aquatic resources would be expected to be different than if the activity will lead to long-term effects (including post-mining conditions). The related indirect impacts of the activity should also be evaluated. For example, if development of a proposed mining operation provides access to an otherwise inaccessible land/drainage area, the potential affects of non-mining related human activity (e.g., recreation) should be considered. Another important consideration in an historically mined area would be the cumulative impacts of the proposed operation. Thus, the fact that the area to be mined was degraded from past mining activity would not eliminate the need for a full-scale assessment of the cumulative impacts of mining (and other) activities on the aquatic resources and of the incremental impacts of the proposed operation.

4.4.3 WILDLIFE

Similar to aquatic resource evaluations, numerous references are available to assist in evaluating potential impacts on wildlife or in evaluating data and studies that are submitted by applicants. Several examples include:

U.S. Environmental Protection Agency. 1993. *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents*.

U.S. Environmental Protection Agency. 1989. *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference*. EPA/600/3-89/013.

Wildlife Society, The. 1980. *Wildlife Management Techniques Manual. Fourth Edition: Revised*. Sanford D. Schemnitz (editor). Washington, D.C.

In general, many of the same concepts described above (section 4.4.2) for aquatic life apply to assessing impacts to terrestrial wildlife. The assessor/reviewer must still determine the endpoints for the assessment, including whether to consider impacts on individual species, populations, communities, and/or entire ecosystems In determining which species or communities are of concern in the affected area, there should be consultations with experts from State and Federal agencies. Species' importance/value may be defined by legal (e.g., threatened and endangered listing), commercial, recreational, ecological, or scientific value. In some instances, it may be desirable to

focus on certain species; however, it is usually preferable, to assess impacts on the overall ecosystem.

Biological diversity is often viewed as a way to measure the health of an ecosystem. For example, a decline in the species diversity of an area could indicate a deterioration in the quality, and possibly a decrease in the stability, of that ecosystem. Direct loss of individuals (mortality) or a decrease in fecundity may affect species diversity. The above references describe available methodologies for measuring biodiversity.

Similar to aquatic resources, the duration and extent of the impact is an important consideration for wildlife. Noise during the construction phase or during operations, for example, may displace local wildlife populations from otherwise undisturbed areas surrounding the site. Some individuals or species may rapidly acclimate to such disturbances and return while others may return during less disruptive operational activities. Still other individuals may be permanently displaced for the life of the project. Other key components of wildlife impact assessment include habitat loss, degradation, or alteration. The U.S. Fish and Wildlife Service (USFWS) Habitat Evaluation Procedure (HEP) measures the quality of habitat as it relates to certain species. Wildlife may be displaced into poorer quality habitat and therefore may experience a decrease in productivity or other adverse impact. Habitat loss may be temporary (e.g., construction-related impacts), long-term (e.g., over the life of a mine), or essentially permanent (e.g., the replacement of forested areas with waste rock piles).

Assessment/prediction of potential wildlife impacts requires an accurate description of baseline conditions (as well as a long-term monitoring program to identify any changes from the pre-disturbance environment). Wherever possible, quantitative assessments of wildlife populations and their habitat are always preferred. Quantitative assessment of impacts often includes comparison of pre- and post-impact species populations. This typically requires field surveys of local populations (and, as necessary, extrapolations to determine overall area populations).

In selecting techniques and tools to be used to survey or sample wildlife, the operator must consider the targeted animals (e.g., raptors, songbirds, big game, and small mammals); the objective of the program (qualitative versus quantitative); and numerous parameters such as the size of the project area, home range of the animal, and habitat and/or plant communities found in the project area. There are many methods that can be used to determine presence and relative abundance of wildlife. Small mammals may be surveyed using Sherman live traps, pit traps, and snap traps. Raptors may be surveyed from aircraft or on foot. Auditory surveys are often used to survey for wildlife which is difficult to observe (e.g., songbirds and frogs). Surveyors may count animals observed and/or rely on animal signs (tracks, scat, etc.). Use of signs is particularly helpful when surveying for animals which are rare or elusive.

The indirect impacts of a proposed action on wildlife near the project area should also be considered. For example, a mining operation may be located to avoid impacting an elk migration corridor. However, elk could be adversely affected by associated increases in housing construction which may result from an improved local economy.

NEPA documentation for proposed mining activities should include mitigation measures which may or will be used to minimize or avoid impacts to wildlife. Potential mitigation measures for use at mine sites include:

- Avoid construction or new disturbance during critical life stages. For example, delay construction activities until after sage grouse strutting occurs at nearby leks.

- Reduce the chance of cyanide poisoning of waterfowl and other wildlife, particularly in arid environments, by neutralizing cyanide in tailings ponds or by installing fences and netting to keep wildlife out of ponds. Explosive devices, radios, and other scare tactics have generally not been proven effective.

- Minimize use of fences or other such obstacles in big game migration corridors. If fences are necessary, use tunnels, gates, or ramps to allow passage of these animals.

- Utilize "raptor proof" techniques on power poles to prevent electrocution of raptors. For example, use anti-perching devices to discourage birds from perching or nesting on poles, or place conductors far enough apart to ensure both wings don't contact them at the same time.

- To minimize the number of animals killed on mine-related roadways, use buses to transport employees to and from the mine from an outer parking area.

- To limit impacts from habitat fragmentation, minimize the number of access roads and close and restore roads no longer in use.

- Prohibit use of firearms on site to minimize poaching.

As noted above, mining operations can have substantial impacts on terrestrial wildlife, ranging from temporary noise disturbances to destruction of food resources and breeding habitat. Unless closure and reclamation return the land essentially to its pre-mining state, at least some impacts to some individuals or species will be permanent. Coal mines, as discussed in chapter 6, must return the land to its "approximate original contour" and revegetate as part of reclamation. When successful, this can often minimize any long-term impacts. Metal mining, on the other hand, only rarely goes this far

in reclamation; although most disturbed areas are often returned to productive states following metal mining, there are usually significant differences in topography and in vegetation. These in turn result in long-term impacts to wildlife, in that they affect available food, water and cover. One of the major purposes of reclamation is to minimize permanent impacts, so reclamation plans are crucial to mitigation. Because reclamation plans are often (or usually) only conceptual at the time of metal mine permitting, preparers and reviewers of EAs and EISs must often rely on applicable reclamation requirements and on the processes that are in place to ensure that reclamation planning proceeds according to those requirements.

4.4.4 VEGETATION/WETLANDS

Vegetation consists of natural and managed plant communities. Native uplands consist of forests, shrublands and grasslands; managed uplands include agricultural lands, primarily croplands and pastures. Lowland vegetation occurring within drainages' forms riparian communities, including wetlands. The discussion below focuses on upland and lowland plant communities; the impact of mining on agricultural lands is discussed below in the Land Use section.

Native plant communities perform a number of functions in the landscape. As discussed previously, vegetation supports wildlife, with the diversity of vegetation strongly related to the diversity of wildlife within the area. Vegetation stabilizes the soil surface, holding soil in place and trapping sediment that may otherwise become mobilized; it also functions to modify microclimatic conditions, retaining soil moisture and lowering surface temperatures. A diverse landscape also provides some degree of aesthetic value. In the case of rangeland, native communities provide the primary production used to feed livestock. Riparian communities and wetlands provide additional functions as defined in *Wetland Evaluation Technique (WET) Volume II: Methodology* (Adamus et al., 1987): (1) groundwater recharge; (2) floodflow attenuation; (3) sediment stabilization; (4) sediment/toxicant retention; (5) nutrient removal/transformation; (6) primary production export; (7) wildlife diversity/ abundance; (8) recreation; and (9) uniqueness and heritage.

All vegetation within the active mining area is removed prior to and during mine development and operation. Vegetation immediately adjacent may be impacted by the roads, water diversions or other development. Vegetation further removed from activities may be impacted by sediment carried by overland flow and by fugitive dust.

Assessment of the extent of disturbance to vegetation typically involves a study describing the major plant communities or associations within the affected area. The description of each community should include the percent of vegetation cover, a measure of productivity (biomass production), a measure of plant species diversity, and a qualitative description of the dominant species. The extent of disturbance within each community should also be identified. Mitigation measures surrounding vegetation typically consist of reseeding the reclaimed area after mining is completed. In the case of

non-coal mines, the change in surface configuration may result in completely different plant communities being established. Coal mines, under the SMCRA requirement to restore the approximate original contour and premining land use, often attempt to establish plant communities that resemble those that existed prior to mining.

The requirements for defining and mitigating impacts to wetlands is more rigorous than other vegetation community types because of their protection under §404 of the Clean Water Act (see Section 6.1). The placement of dredged or fill materials into wetlands or other waters of the U.S. requires that a Section 404 permit be obtained from the U.S. Army Corps of Engineers (Corps). Permit applications must include a jurisdictional wetland delineation for each of the wetlands that may be impacted. Delineations are conducted as described in the *Corps of Engineers Wetlands Delineation Manual* (USACE, 1987), and are based on an assessment of vegetative, hydrologic and soils criteria. If "jurisdictional wetlands" are identified, the project must comply with the §404(b)(1) guidelines (40 CFR Part 230).

Compliance with the §404(b)(1) guidelines requires mitigation for any impacts to jurisdictional wetlands. The guidelines require that avoidance of impacts be considered as a first mitigation option. If avoidance is not possible, the guidelines further require the selection of an alternative that results in the least amount of impact to wetlands and that some measure of compensation be implemented for impacted areas. Under the guidelines, the Corps may not issue a permit if the discharge will substantially damage the aquatic ecosystem if practicable alternatives exist.

Development of a mitigation plan should include an evaluation of the functions and values provided by the wetland areas under analysis, the extent of proposed disturbance (acreage), and an assessment of potential cumulative impacts to surrounding wetlands. Based on these site-specific factors, mitigation requirements are usually established on a case-by-case basis. Mitigation may involve restoration, creation, enhancement, exchange, or in some cases, preservation of wetlands located either onsite or offsite.

The assessment of wetland functions and values, in the context of a mitigation plan, tend to be inherently subjective. While functions are tied to properties of the wetland itself, value tends to reflect societal influence and are necessarily subjective. However, the proximity of one wetland to others, the uniqueness of a particular wetland, and the number of functions it performs all influence a wetlands value. Mitigation considerations include whether the target is to be an "in-kind" or "out-of-kind" wetland in terms of functions or community types compared to the original. Location (onsite or offsite), timing (before, concurrent, or after), and mitigation type (restoration, creation, enhancement, exchange, or preservation) are other variables that must be considered in developing a mitigation plan. Depending on the variables involved, the ratio of the areal extent of compensation to disturbance can range from 1:1 to more than 3:1. Barring avoidance, the preferred approach would

be the restoration of a former wetland, in-kind and onsite, completed before development activities began. In such a case, the restored:impacted ratio may be close to 1:1. The ratios increase in situations where success can only be achieved through a greater degree of difficulty or when the mitigation cannot be completed before initiation of the project (Kruczynski, 1990).

Wetland restoration and creation tends to be as much art as science under the current state of knowledge. Therefore, success should be evaluated using a set of clearly defined goals to be achieved within a specific time frame. Goals should be established in the planning stages. A monitoring plan should be developed and implemented to ensure that newly restored/created wetlands progress toward the previously defined target in a timely manner. The establishment of clear goals and an effective monitoring plan are of key importance to project success but are often overlooked in the planning stages.

4.4.5 Land Use

Metal mining nearly always results in significant changes to beneficial uses of land after mining. A description of land use should identify the current use of land needed specifically for the mine and land use patterns in the nearby area that will be indirectly affected by the project. Particular emphasis should be placed on land uses that pose potential conflicts with mining operations—farming, timber, grazing, recreation—and on the local or regional zoning laws that may limit the development of mining operations.

4.4.5.1 Farmland

The U.S. Soil Conservation Service (SCS) is charged with identifying and locating Prime and Unique farmland under Public Law 95-87. The SCS works with State and local agencies, to identify farmland of statewide or local importance. Farmlands in the vicinity of the mining project under evaluation should be identified by SCS categories.

The SCS generally maintains lists of all soil series that fall into the categories of prime, unique, and State/locally important. Depending on location, lists may be generated and maintained on a county, district, or statewide basis. Where appropriate, the reviewer (or the applicant) should contact SCS (or the applicable State/local agencies) to verify the existence of designated farmland in the vicinity of a proposed mining action.

Prime farmland is defined as having the best combination of physical and chemical characteristics for producing food, feed, forage, fiber, and oilseed crops that is available for those uses. Prime farmland demonstrates particular physical characteristics and exists within favorable climatic conditions. Physical characteristics include a lack of rock fragments, a pH range of 4.5 to 8.4, water holding capacity to a depth of 40 inches and adequate to produce crops, and an average annual soil

temperature of greater that 32°F at a depth of 20 inches. The prime designation also relates to the availability of irrigation or a sufficient precipitation regime to sustain crop production.

Unique farmland demonstrates similar characteristics to prime soils and produce high value food or fiber crops. However, these soils lack a particular characteristic that separates them from prime - precipitation for example, may limit crop production to eight out of ten years. Soils of statewide or local importance are identified based on unique characteristics identified on a local basis. Local conditions or characteristics restrict production on these soils to a greater extent than soils classified as prime and unique.

In addition to prime, unique, and State/locally important farmland, EPA's September 1987 policy identifies three other types of environmentally significant agricultural lands for protection. These include: farmlands in or contiguous to environmentally sensitive areas, farmlands important for waste utilization, and farmlands with significant capital investments in best management practices. Such determinations are made on a site-by-site basis.

Potential impacts from proposed mining actions to farmlands can range from complete elimination of the land for farming use to temporal cessation in farmland production. Analysis under NEPA should specifically consider the effects of an activity on the important soil/farmland categories described above (as well as the feasibility and likely effectiveness of proposed mitigation measures). Wherever possible, mitigation measures should allow for returning the land to its previous productivity. For example, the operator could strip a particular soil series by horizon and stockpile each separately, with the intent of restoring the soil profile upon completion of mining. Under SMCRA, coal mines are required to restore *prime* farmland to its previous state (no such uniform requirements exists for noncoal mines).

4.4.5.2 Timber

Timber lands should be identified in the project area and the board feet of lumber represented by that timber should be estimated. Impacts to timber are typically the loss of the resource in the areas to be cleared for the mine. Mitigation of the loss of timber lands includes the economic harvest of the existing timber prior to clearing and construction of the mine. Reclamation of the mined areas may require the replanting of trees but the land may be rendered unusable for timber growth at the close of mining as a result of poor growing media, or the presence of large excavations. Any mitigation measure that calls for tree planting (or, indeed, any revegetation) should include monitoring for several years to verify its success.

4.4.5.3 Grazing

The extent of lands used for grazing should be identified within the vegetation survey conducted for the site. The areal extent of each plant community in which grazing occurs and the extent of disturbance within those communities should be reported. The animal unit months (AUMs) each community is able to support and vegetation biomass data should be included. Where slopes of pits, benches and highwalls do not prohibit it, reclamation in most cases will readily support grazing in the post-mining landscape.

4.4.5.4 Recreation

Lands in the area of proposed mining projects may be used for public recreation. The types of recreation provided by the lands in the vicinity of the project should be identified. Potential impacts should be described with respect to the current level of recreational use as well as opportunities for additional uses. The extent to which recreational uses will be restored after reclamation should also be discussed.

4.4.6 CULTURAL RESOURCES

Cultural resources encompass several areas relating to man's knowledge and appreciation of prehistoric and historic events. The location of a mine or beneficiation facility at or near significant historical and cultural sites can degrade the resource value or emotional impact of the historic or cultural site. The location of the following kinds of sites should be described in relation to the project site:

- Archeological sites (where man-made artifacts or other remains dating from prehistoric times are found). These are not uncommon, particularly in the west.
- Paleontological sites (where significant events happened or where well-known people lived or worked). Again, these frequently occur on proposed sites in the west.
- Sites of particular educational, religious, scientific, or cultural value. Once again, these are commonly encountered, particularly in the west. Native American values (including religious and cultural values associated with certain areas) are of particular concern. As noted in Chapter 5, artifacts and remnants of historic mining are also increasingly being protected as cultural resources.
- Properties on or eligible for listing on the National Register for protection under Section 106 of the National Historic Preservation Act.

In addition to identifying the location of each site in relation to the project, a discussion of mitigation measures should be presented if any of the sites will be directly impacted by the mining and beneficiation activities.

4.4.7 AESTHETICS

Aesthetics involve the general visual, aural, and tactile environment. A description of the aesthetic characteristic of the existing environment should include things that are seen, heard and smelled in and around the site and their emotional or psychological effect on people. Descriptions (or pictures) of views of the site, of unique features or features deemed of special value, and public use and appreciation of the site provide information that must be available for the assessment of impacts.

Potential aesthetic impacts include the loss of visually pleasing areas as ground is disturbed and previous surface expressions are eliminated or damaged. Mines typically create significant noise above the baseline conditions (from blasting, heavy equipment operation, materials/waste transport and disposal, etc.). Mitigation measures to address aesthetic impacts involve siting of mine features, as well as facility design and mining practices.

4.5 SEDIMENTATION/EROSION

Because of the large area of land that is disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion is frequently of primary concern at coal and hardrock mining sites. Erosion control must be considered from the beginning of operations through completion of reclamation. Erosion may cause significant loadings of sediments (and any entrained chemical pollutants) to nearby streams, especially during severe storm events, as well as high snowmelt periods.

Major sources of erosion/sediment loadings at mining sites can include:

- Open pit areas
- Heap and dump leaches
- Waste rock and overburden piles
- Tailings piles
- Haul roads and access roads
- Ore stockpiles
- Vehicle and equipment maintenance areas
- Exploration areas
- Reclamation areas.

The variability in natural site conditions (e.g., geology, vegetation, topography, climate, and proximity to and characteristics of surface waters) combined with significant differences in the quantities and characteristics of exposed materials at mines preclude any generalization of the quantities and characteristics of sediment loadings. Further, new sources are frequently located in areas with other active operations as well as historic mines (left in an unreclaimed state). There may

also be many other non-mining sources of erosions in the watershed (other types of industrial operations, naturally unstable areas, soil conditions, etc.). Therefore, in considering the erosion effects from a new mining source, the cumulative impacts of sediment loadings from all sources within a watershed need to be considered. An important element of this analysis is the potential for the new source to alter downstream flow conditions and thereby alter contributions from downstream sediment sources.

The following subsections describe: (1) the basic principles of erosion, (2) the impacts associated with erosion/runoff (i.e., the physical/chemical effects on the watershed), (3) approaches to establishing baseline conditions, (4) methodologies to determine the sediment contributions from a new source, and (5) measures to reduce/mitigate sediment loadings (i.e., best management practices and treatment technologies).

4.5.1 Basic Erosion Principles

Water erosion may be described as the process by which soil particles are detached, suspended, and transported from their source of origin. Sedimentation may be described as the by-product of erosion, whereby eroded particles are deposited at a different location than the source of origin. Soil detachment results from the energy of raindrops striking the soil surface or it results from suspension of soil particles from overland flow. Runoff may be the result of rainfall or snowmelt. Erosion occurs from the movement of water in sheet flow, in rills or gullies of ephemeral waterways, or through channel erosion in ditches and streams. Wind erosion occurs when wind energy exceeds the ability of soil to remain cohesive and the particles become detached. Typically, wind erosion is a problem in arid climates.

The factors influencing erosion and sedimentation are interrelated and all relate to either the impact of precipitation or runoff velocity and volume. Sedimentation is considered the final stage in the erosion process, thus the mechanisms affecting erosion also affect sedimentation. The main factors influencing erosion include:

- **Rainfall/Snowmelt Runoff.** The volume and velocity of runoff from storm events are determined by the rainfall intensity and the duration of the rainfall event. A more intense storm applies greater forces which results in greater displacement of soils; storms of longer duration naturally produce more runoff, and thus greater erosion. Runoff also occurs during snowmelt periods (with volume and velocity depending on melting conditions), including rainfall-induced melting.

- **Infiltration.** Infiltration is the rate by which water moves downward through the soil. Water that infiltrates does not become runoff, thus greater infiltration results in less erosion. Infiltration is a function of the soil type, with porous soils tending to have greater infiltration rates. Saturated and frozen ground impedes infiltration, resulting in greater runoff.

- **Soil Texture and Structure.** Soil texture describes the percentage composition sand, silt, and clay particles in a soil. Soil structure generally refers to the aggregation of soil particles. Sand particles are heavier, and disregarding aggregation are generally less susceptible to transport than are silt particles. Soils with high clay content are also less susceptible to erosion because the particles tend to stick together. Soils high in silt content, on the other hand, unless well aggregated, are the most erodible soils. The structure will influence the erodability of each type of soil. Well aggregated soils are less likely to detach. Runoff or airflow over these soils however may be increased, due to impermeability and thus reduced infiltration. The relationships between soils type and structure and potential water erosion are well known, yet complex. (Similar principles apply to water erosion of waste/materials management units.)

- **Vegetative Cover.** Vegetative cover influences erosion by:

  - Reducing the rainfall or wind energy striking the soil's surface
  - Lowering the velocity of overland and channel flow which:

    – Reduces peak runoff rates and resultant impacts of channel erosion, and
    – Decreases the velocity of overland flow, enabling sediment deposition to occur closer to the original site
    – Providing roots to hold the soil in place.

  Because vegetation acts in multiple facets, the relationship between vegetation and erosion is dramatic. This is perhaps best illustrated through curve numbers. Curve numbers are used in the U.S. Geological Survey soil-cover complex method for estimating rainfall runoff and are an estimate of the percentage of rainfall runoff that will occur. The curve numbers for forested land of varying soil conditions range from 25 to 83, meaning that forested lands will produce from 25 to 83 percent runoff. In comparison, the curve numbers for a denuded construction site of varying soil conditions, range from 77 to 94.

- **Slope length.** The term "slope length" is defined as the distance from the point of origin of overland flow to the defined point of interest, which may be a channel, or the point where deposition begins. Longer sloped surfaces result in higher runoff velocities for the particular segment.

- **Erosion Control Practices in Place.** Various practices and structures can be employed to reduce the effects of land disturbances and developments. Erosion control practices work by one or more of the following mechanisms:

  - Reducing the impact of raindrops
  - Reducing the runoff volume and velocity
  - Increasing the soils resistance to erosion.

  Specific erosion control BMPs applicable to mining sites are described in Section 4.5.5 below.

4.5.2 Impacts Associated with Erosion/Runoff from Disturbed Areas

Particulate matter is toxic to fish. Decreased densities of macroinvertebrate and benthic invertebrate populations have been associated with increased suspended solids. Enhanced sedimentation within aquatic environments also has the effect of inhibiting spawning and the development of fish eggs and larvae, as well as smothering benthic fauna. In addition, high turbidity may impair the passage of light, which is necessary for photosynthetic activity of aquatic plants.

Further, exposed materials from mining operations (mine workings, wastes, contaminated soils, etc.) may contribute sediments with chemical pollutants, including heavy metals. Contaminated sediments in surface water may pose risks to human health and the environment as a persistent source of chemicals to human and aquatic life. Human exposure occurs through direct contact, eating fish/ shellfish that have bioaccumulated toxic chemicals, or drinking water exposed to contaminated sediments. Continued bioaccumulation of toxic pollutants in aquatic species may limit their use for human consumption. Accumulation in aquatic organisms, particularly benthic specifies, can also cause acute and chronic toxicity to aquatic life. Finally, organic-laden solids have the effect of reducing dissolved oxygen concentration, thus creating toxic conditions. There are no National sediment criteria for the toxic pollutants likely to be released from mining sites, although criteria for metals are currently under development and some States have established sediment standards.

Beyond the potential for pollutant impacts on human and aquatic life, there are physical impacts associated with the increased runoff velocities and volumes from new land disturbance activities. Increased velocities and volumes lead to downstream flooding, scouring of stream channels, and structural damage to bridge footings and culvert entries.

4.5.3 Establishing Background Conditions

A characterization of background conditions within a stream is necessary to assess the potential impacts of new erosion/sedimentation sources. An important element in assessing baseline stream habitat quality is an evaluation of the physical parameters of the stream. EPA (1989b) has suggested that the following physical stream parameters be characterized at each stream sampling station in the assessment of a stream habitat.

- **Predominant surrounding land use.** A description of the predominant types of land use is needed. In addition, secondary land uses may also potentially affect water quality.
- **Local watershed erosion.** A visual estimate of erosion can be made by observing the watershed land surface and the stream characteristics (both channel characteristics and sediment loads).
- **Estimated stream width.** A representative transect should be measured from shore to shore to provide an estimate of stream width.

- **Estimated stream depth.** Stream depth should be determined for three habitat types: riffle, run and pool. Measure the vertical distance from the water surface to stream bottom.

- **High water mark.** Measure the vertical distance from the bank to the peak overflow level. The peak overflow level may be indicated by debris hanging in bank or floodplain vegetation or deposition of silt or clay.

- **Velocity.** Stream velocity should be estimated in a representative stretch of the stream.

- **Dam/obstacles to flow present.** The presence of a dam upstream or downstream of the stream segment under study should be noted. Also, any other impediments to flow or sediment transport should be noted. How the dam or obstacles affect flow should be noted.

- **Channelization.** Describe whether the stream is channelized at any point along the stretch of stream under study.

- **Canopy cover.** A description of the percentage of shaded area at each sampling station along the stream should be provided.

- **Sediment odors.** Any odors emanating from the disturbed sediment should be noted.

- **Sediment oils.** A visual estimate of the proportion of any oils in the sediment should be noted.

- **Sediment deposits.** A description of the type of deposits present in the stream (sand, sludge, organic material, etc) and any blackened undersides of rocks (indicates low dissolved oxygen or anaerobic conditions).

- **Inorganic substrate components.** A visual estimation should be made of the percentage of inorganic substrate components present.

- **Organic substrate components.** A visual estimation should be made of the percentage of organic substrate components present.

This method for evaluating the physical condition of a stream can be made more rigorous by including quantitative evaluations of sediment transport. A quantitative evaluation of sediment transport may be more suited for areas where significant disturbances already exist and more rigorous documentation and understanding of the baseline conditions is necessary. Quantitative measurements may be made of suspended and bedload sediment in the stream, as well as measurements of sediment deposits (sediment bars, substrate, etc.) and turbidity (turbidity measures the ability of a fluid to transmit light). These data provide a rough estimate of the concentration of suspended sediments in water. A quantitative baseline measurement may also be made of the stream channel throughout the area of impact.

The sampling of suspended sediment can provide information on the physical and chemical characteristics of the sediment in suspension. Depth-integrated sampling, as opposed to point

sampling, is preferred to characterize both the concentration of suspended sediment carried by the stream, as well as providing a representative sediment sample for chemical characterization of the sediment and adsorbed constituents (USGS, 1977). Depth-integrated sampling involves the use of a depth-integrated sampler that is lowered/raised throughout the depth of the stream at a constant speed. If the depth-integrated sampler is also used to sample across a stream transect, the concentration of suspended sediment obtained can be multiplied by the water discharge through the sample zone and a total suspended sediment discharge can be obtained (USGS, 1977). Consequently, to provide an accurate measurement of suspended sediment loads in a stream, samples should be collected near stream gauging stations.

Sample site selection should take into account the following preferences: located near a stream gauging station, located away from any flow distorting obstacles, and far enough either upstream or downstream of confluences to prevent the hydraulic variances that exist in those zones (USGS, 1977). Frequency of sampling should be determined by the known historical streamflow or precipitation records, at a minimum, the stream should be sampled at periods of annual low and high flow.

Sampling of the deposited sediment in the streambed can provide a wide range of information including the type of sediment available for transport, mineralogy of the sediments, stratigraphy, and amounts and distribution of contaminants (USGS, 1977). Sampling methods are available for collecting disturbed or undisturbed samples. For the purposes of baseline sampling for a mining project, an undisturbed sample may not be necessary.

In addition to a physical characterization of the stream, a habitat assessment should be conducted to determine the baseline conditions of the stream's ability to support aquatic life. The parameters to be assessed represent measurements/observations of substrate and instream cover, channel morphology and riparian and bank structure. EPA (1989b) has identified the following parameters for evaluating the baseline conditions of stream habitat.

- **Bottom substrate/available cover.** A visual observation of the ability of the bottom substrate to provide niches for aquatic life should be made.
- **Embeddedness.** Embeddedness refers to the percentage of fines surrounding large size (boulders, rubble or gravel) particles.
- **Stream flow/stream velocity.** The volume and velocity of stream flow should be evaluated with respect to optimal conditions for aquatic life.
- **Channel alteration.** An observation of growth or establishment of sediment bars or other deposition can indicate changes in upstream erosion. The development of channelization should also be noted.

- **Bottom scouring and deposition.** An observation should be made of the degree to which the substrate is scoured and the amount of siltation in riffles and pools. This observation is typically reported as a percentage of the observed stretch that is scoured or silted. Bottom scouring and deposition result from sediment transport and may provide an indication of watershed erosion.

- **Pool/riffle or run/bend ratio.** This ratio is calculated by dividing the average distance between riffles or bends by the average stream width. This parameter assumes that the higher proportion of riffles and bends provides more diverse habitat than a straight or uniform depth stream.

- **Bank stability.** Bank stability is typically determined by the steepness of the bank and any observed erosion into the stream. Steeper banks generally indicate poor quality instream habitat due to there susceptibility to erosion, however, stream banks of clay may not be as susceptible to erosion as stream banks composed of other sediment.

- **Bank vegetative/rock stability.** Bank stability may also be estimated by the type and amount of vegetation and rock cover present. Proportions of shrub, trees, grasses and rocks providing bank cover should be estimated.

- **Streamside cover.** An estimate of the primary type of vegetation that is providing streamside cover should be made. It should also be noted if no cover is provided.

The above information on the sediment and habitat quality should be considered in conjunction with baseline studies of aquatic organisms within the watershed (including fish count, macroinvertebrates, etc.). The combined data will allow the reviewer to correlate background aquatic life conditions to sediment quality.

4.5.4 Predicting Sediment Loadings from New Sources

There are currently several approaches/models available to assist in the prediction of sediment losses and flow responses of basins both before and after landscape alterations due to mining and other human activities. As with any models, they are highly sensitive to the input data supplied and caution must be used in identifying and quantifying the important factors for a specific project.

The primary factors affecting basin sediment yields are:

- **Precipitation.** Volume, intensity, and duration are all important

- **Vegetation.** Vegetation increases the ability of hillslopes to retain overland flow, increase infiltration, and reduce the velocity of overland flow

- **Basin size.** Basin size controls the lagtime between the beginning of the storm event and the time of peak flow

- **Elevation and relief.** Basins with steeper overall slopes will have higher overland flow velocities and quicker response times to storm events
- **Soil/rock type.** Different soil types have varying degrees of erodability, infiltration capacities
- **Human activity.**

4.5.4.1 Available Techniques/Models

Modeling basin hydrology can take forms varying in complexity from "back of the envelope" calculations to computer-based, multivariate modeling based on data from comprehensive field investigations. Most modeling, of any level of complexity, is based on several basic equations developed specifically to predict soil losses from known basin characteristics. These equations include: the Universal Soil Loss Equation (USLE), the Modified USLE (MUSLE), and the Revised USLE (RUSLE). These equations are described below.

The Universal Soil Loss Equation (USLE)

The USLE has been developed utilizing data gathered at a large number of experimental sites. The equation utilizes six hydrologic variables to generate predictions of annual total soil loss in tons per acre for a given drainage basin. Values of the equation variables are determined by comparing site specific observations of basin characteristics to published graphs and tables to determine the appropriate value. The U.S. Soil Conservation Service publishes many of the appropriate standard tables which have been developed from numerous studies of basin characteristics in a number of climates.

The USLE is written:

$$A = RK(LS)CP$$

Where A is the total soil loss in tons per acre per year, R is the rainfall erosivity index, K is the soil erodability index, LS is the length-slope steepness factor, C is the cropping management factor, and P is the erosion control practice factor. An increase of any of these factors will result in increases in the total predicted soil losses for an area.

The Modified Universal Soil Loss Equation (MUSLE)

The MUSLE equation is written in final form identically to the USLE. It varies from its predecessor in the introduction of an exponential function for the determination of the length-slope factor (LS). The modified LS-factor has been shown to work well on slopes up to 15 to 20 percent but on steeper slopes predictions of erosion become much greater than those actually observed. The R-factor is also

changed and is now a product of the total per-acre runoff volume and the maximum rainfall intensity for a given storm.

MUSLE also improved its predecessor by allowing predictions of soil losses for single storm events. This is important because allows for the examination of losses during peak conditions which may account for a large percentage of total annual losses.

The Revised Universal Soil Loss Equation (RUSLE)

RUSLE takes the same basic form as both the USLE and MUSLE. However, the RUSLE improves upon both previous incarnations by using several LS functions to model slopes of different steepness. Of the three approaches, RUSLE works best for steep basins (slopes greater than 20 percent).

Other Soil Loss Equations

Several other soil loss prediction models have been developed that are based less on standardized tables of factors and equations but are instead theoretically based. These models are important in that they allow for the testing of hypotheses on the physics of hillslope hydrology. However, to date, they have not yet been shown to be accurate predictors of total sediment losses and so remain more theoretical than practical.

Computer Models

A number of computer models are available which utilize variations of the USLE and other soil loss equations to perform automated analysis of soil losses from basins. These models are available from commercial, governmental, and academic sources. The most sophisticated of these allow for the subdividing of larger basins into smaller sub-basins and utilize routing functions to predict the response to the same storm of sub-basin areas which may have very different soil, vegetative and land-use conditions.

4.5.4.2 Modeling Considerations

In the use of any of the above modeling schemes, the accurate determination of current and potential site conditions is vital to generating accurate results. In some cases, what seem to be fairly small variations in site conditions can make great differences in predicted soil losses. For example, the cropping management factor, C, can vary by a factor of 3 with a change in vegetative cover of 20 percent (U.S. Soil Conservation Service, 1975). Under- or over-estimating canopy cover by 20 percent will produce a 300 percent variation in the predicted soil loss.

Great importance should be placed on the accurate determination of the conditions within the basin. It is possible, and not too uncommon, to approximate values for some factors without actually visiting

a site. The Soil Conservation Service has made available tables and maps which provide probable ranges of values for various site conditions. However, since the strength of a model depends on the strength of input data, final determination of the factors to be used in a model should be based upon observations made on site. Some important factors affecting soil erodability, such as the presence of thick leaf litter on a forest floor, are not determinable from aerial photos or maps. Any modeling performed without actual site observation should be considered a first approximation.

The final step in any modeling is verification. A model should not be considered to have predictive power for hypothetical conditions until its ability to accurately model known conditions has been shown. This means comparing actual measurements of soil losses with those predicted by the model. A great disparity between these two values indicates the need to examine either assumptions of the model or the field measurement techniques.

The selection of storm events for use in modeling predictions should also be carefully considered. Since both intensity and duration affect the generation of overland flow, both short duration/high intensity storms and long duration/moderate intensity storms should be considered. Also, antecedent conditions at a site may be important. High intensity storms will produce higher peak flows and greater erosion rates if they fall on already saturated, frozen, and/or snow covered soils.

Overall, modeling results should allow the operator to quantify the impacts of the proposed land disturbance on the affected watershed (in terms of losses of soil per unit area and total solids loadings). However, available methodologies do not address deposition of generated sediments in downstream reaches. There are no specific criteria to determine what level of increase in TSS concentrations, turbidity, or total sediment loadings constitutes a significant impact. To a large extent, this is subject to best professional judgment (in consideration of the baseline watershed conditions as discussed above). Similarly, BPJ is necessary to assess how any toxic pollutants associated with solids loadings could affect sediment quality, and this should always be considered. Factors to consider include: potential sources of toxic pollutants, existing sediment quality, any available data on the affects of similar operations/land disturbance within the watershed (where applicable), and the nature/designated uses of the receiving water.

4.5.5 Sediment and Erosion Mitigation Measures

Sediment and erosion mitigation measures are used to reduce the amount of materials carried off site and deposited in a receiving stream. To meet this objective, mine operators should consider methods to limit runon, minimize the areas of disturbed soil (exposed to precipitation), reduce runoff velocity, and remove sediment from on-site runoff before it leaves the site. In many cases, a range of different BMPs/sediment and erosion controls are used concurrently at mine sites. The three main categories of sediment and erosion controls are: diversion techniques, stabilization practices, and structural controls. The following subsections briefly describe each of these categories.

4.5.5.1 Diversion Techniques

Diversion techniques are measures that prevent run-on, precipitation, and other flows from crossing areas where there is a risk of significant erosion. Diversion practices often use on-site materials, and take advantage of on-site topographic, vegetative, and hydrologic factors to divert flows away from disturbed areas/soils. Typical diversion practices used at mine sites include: interceptor dikes and swales; diversion dikes, curbs and berms; pipe slope drains; subsurface drains; and drainage/storm water conveyance systems (channels or gutters; open top box culverts, and waterbars; rolling dips and road sloping; roadway surface water deflectors; culverts).

4.5.5.2 Stabilization Practices.

Stabilization, as discussed here, refers to covering or maintaining an existing cover over soils. The cover may be vegetation, such as grass, trees, vines, or shrubs. Stabilization measures can also include nonvegetative controls such as geotextiles (matting, netting or blankets), mulches, riprap, gabions (wire mesh boxes filled with rock), and retaining walls. These stabilization practices act to prevent or minimize erosion by holding soil in place, shielding it from the impact of precipitation/snowmelt, and increase surface contours to slow runoff velocity.

The establishment and maintenance of vegetation is one of the most important factors in preventing erosion. Vegetative controls are often the most important measures taken to prevent off-site sediment movement, and can provide a six-fold reduction in the discharge of suspended sediment levels. In addition, these practices can enhance habitat values and the appearance of a site. Examples of vegetative practices include temporary or permanent seeding, vegetative buffer strips and protection of trees. Nonvegetative stabilization practices can be used as a temporary or permanent erosion prevention measure. These controls can be used in order to aid in establishing vegetation or as stand alone practices.

Vegetative controls are low cost and require low or no maintenance once a ground cover has been established. However, prior to the establishment of a vegetative cover, considerable site preparation may be necessary such as contouring of disturbed areas, placement of topsoil on barren areas, soil conditioning (e.g., with municipal sewage sludge), or spraying areas with fertilizers.

Contouring refers to a number of practices including recontouring, regrading, reshaping, and surface roughening. Contouring of waste piles will provide a number of benefits, including aiding in the reduction of storm water and run-on velocities, assisting in the establishment of a permanent vegetative cover, and improving site aesthetics. Specifically, reducing the height and steepness of a slope can greatly reduce erosion and sedimentation at a site.

Where recontouring wastes is not practical due to geographic or resource considerations, reshaping of wastes may be a viable option. Reshaping BMPs refer to the rearranging of waste piles and exposed areas in such a way as to reduce the steepness of slopes (terracing/benching), moving waste piles out of streambeds or other highly erodible areas, and other methods to reduce run-on and storm water velocities over and around areas susceptible to erosion.

After an area has been recontoured or reshaped, surface roughening may be employed to further reduce runoff velocity and promote infiltration, as well as supporting revegetation. A rough soil surface is amenable to revegetation, through creation of horizontal grooves, depressions, and/or terraces that parallel the contour of the land.

4.5.5.3 Structural Practices

Structural controls involve the installation of devices to store flow or limit runoff velocity. Structural practices can be used to remove sediment from runoff before the runoff leaves the site. Approaches to removing sediment from site runoff include diverting flows to a trapping or storage device or filtering diffuse flow through silt fences before it reaches the receiving water. These methods are designed to slow the flow of water discharged from a site; resulting in the settling of solids and the limiting of downstream erosion. Structural controls also promote infiltration.

Structural sediment and erosion control practices are typically low in cost. However, structural practices require periodic maintenance (including sediment removal) to remain functional. As such, they serve as more active-type practices which may not be appropriate for permanent use at inactive mines. However, these practices may be effectively used as temporary measures during active operation and/or prior to the implementation of permanent measures.

Some examples of structural practices include: settling ponds/detention basins, check dams, rock outlet protection, level spreaders, gradient terraces, straw bale barriers, silt fences, gravel or stone filter berms, brush barriers, sediment traps, grass swales, pipe slope drains, earth dikes, and other controls such as entrance stabilization, waterway crossings or wind breaks.

In some cases, the elimination of a pollution source through capping sources of erosion may be the most cost effective control measure for sediment discharges and other pollutants. Depending on the type of management practices chosen, the cost to eliminate the pollutant source may be very high. Once completed, however, maintenance costs will range from low to nonexistent.

4.5.5.4 Contact Prevention Measures/Reclamation Practices

Permanent reclamation, as discussed here, refers to covering or maintaining an existing cover over disturbed areas. The cover may consist of grass, trees, vines, shrubs, bark, mulch and/or straw.

Ultimately, revegetation involves establishing a sustainable ground cover at a site through permanent seeding, mulching, sodding, and other such practices.

The establishment and maintenance of vegetation is one of the most important factors in minimizing erosion. A vegetative cover reduces the potential for erosion of a site by: absorbing the kinetic energy of raindrops which would otherwise impact soil; intercepting water so it can infiltrate into the ground instead of running off; and by slowing the velocity of runoff to promote onsite deposition of sediment. Vegetative controls are often the most important measures taken to prevent offsite sediment movement, and can provide a six-fold reduction in the discharge of suspended sediment levels. In addition, these practices can enhance the habitat and aesthetic values of a site.

Typically, the costs of vegetative controls are low relative to other discharge mitigation practices. Given the limited capacity to accept large volumes of runoff, and potential erosion problems associated with large concentrated flows, vegetative controls should typically be used in combination with other management practices. These measures are universally considered to be nearly always appropriate for mining sites, as evidenced by their being required by all States that require reclamation of closing coal and non-coal sites.

As noted above, vegetative controls are low cost and require low or no maintenance once a ground cover has been established. However, prior to the establishment of a vegetative cover, considerable site preparation may be necessary such as contouring of disturbed areas, placement of topsoil on barren areas, and the spraying of areas with fertilizers. Further, predicting the likely success of reclamation practices at mine sites has often proven difficult. Where reclamation/revegetation is a key element of long-term erosion control, the operator should consider establishing representative test plots to increase the likelihood of success.

Contouring

Prior to the establishment of vegetation, surface contouring is often required. Contouring refers to a number of practices including recontouring, reshaping, and surface roughening.

Recontouring waste piles/disturbed areas at a site will provide a number of benefits. Recontouring wastes or disturbed areas to match the original land contours of a site will aid in the reduction of storm water and run-on velocities, assist in the establishment of a permanent vegetative cover, and improve site aesthetics. Reducing the height and steepness of a slope, combined with other diversion BMPs discussed above, can greatly reduce erosion and sedimentation at a site. This practice is also often times necessary to establish a vegetative cover over exposed materials.

Where recontouring wastes is not practical due to geographic or resource considerations, reshaping of wastes may be a viable option. Reshaping refers to the rearranging of waste piles and exposed areas

in such a way as to reduce the steepness of slopes (terracing/benching) and other methods to reduce run-on and storm water velocities over and around areas susceptible to erosion.

After an area has been recontoured or reshaped, surface roughening may be employed to aid in the establishment of vegetation. A rough soil surface is amenable to revegetation, through creating horizontal grooves, depressions, or steps that run with the contour of the land. Slopes may also be left in a roughened condition to reduce discharge flow and promote infiltration.

Surface roughening aids in the establishment of vegetative cover by reducing runoff velocity and giving seed an opportunity to take hold and grow. Increased vegetative cover, in turn, provides increased filtration and sediment trapping, further decreasing runoff velocity and erosion.

These techniques are appropriate for all slopes steeper than 3:1 in order to facilitate stabilization of the slope and promote the growth of a vegetative cover. Once areas have been contoured, they should be seeded as quickly as possible.

Topsoiling

Topsoiling may be necessary to improve, provide, or preserve the area on which a permanent vegetative cover will be established. These practices are not used alone to provide erosion control, but are an integral part of establishing vegetative controls. Conditioning may be required where soil is of poor quality. More resource intensive topsoiling measures may be needed where soils are without nutrient properties, where the need to quickly establish vegetation is paramount, where the existing soils contain materials toxic to plant growth (i.e., acidic soil such as that found at some mines), or where the soil rooting zone is not deep enough to support plants.

Soil conditioning may include the use of fertilizers, or less expensive measures such as the land application of municipal sewage sludge. Using topsoil may require the importing of soils from an alternate location or the use of soil from a nearby site.

When applying soil conditioners or topsoil, measures must be put in place to prevent washouts prior to the establishment of vegetation. The timing of this practice should be coordinated with seeding and planting practices so that they can be performed immediately after soil conditioning or topsoiling is completed. Additionally, it is necessary to provide measures such as mulching or diversion which prevent erosion of the topsoil or conditioned soil. These practices should be coordinated with seeding and planting practices so that they can be performed immediately after conditioning or topsoiling.

Seeding

The establishment of plant life stabilizes soils and helps to reduce sediment in runoff from a site. In addition, vegetation filters sediments, maintains the soil's capacity to absorb water, improves wildlife habitats, and enhances site aesthetics.

Seeding and planting are appropriate for any disturbed area that is subject to erosion. This practice is particularly effective in areas where soils are unstable due to texture, structure, high water table, and/or high slope such as those commonly found at inactive mining, landfill, and oil and gas sites.

Selection of appropriate vegetation, good seed bed preparation, timing, and maintenance are needed to ensure the success of this practice. Selection of native species will increase the chances for success and may lessen future maintenance requirements.

Capping of Wastes/Materials

Capping/sealing of wastes/materials (including surface mine workings, tailings and waste rock) is designed to limit or eliminate contact between runoff and potential sources of sediment/toxic pollutant loadings. The use of this practice depends on the level of control desired, the materials available, and cost considerations. Many common types of caps may be effective including soil, clay, and/or synthetic materials. Generally, soil caps will provide appreciable control for the lowest cost. Any type of cap may be covered with up to several feet of rock and soil and revegetated.

4.5.5.5 Treatment Techniques

Discharge detention structures can achieve a high removal rate of sediment and metals, such as those which may be expected to be discharged from inactive mining operations. Complemented by ease in construction and simple operations and maintenance, the use of detention structures desirable as a treatment mechanism for discharges from inactive mines and landfills. Site characteristics must be such that discharges can practically be channeled to a centralized area for treatment.

Detention basins are most cost-effective at larger sites. In addition to their pollutant treatment capacity, detention ponds can also create wildlife habitat, recreational, and landscaping benefits. Even at larger sites, however, hydrologic and topographic factors, as well as inaccessibility and cost, may limit their utility.

4.6 METALS AND DISSOLVED POLLUTANTS

Dissolved pollutants (primarily metals, sulfates, and nitrates) can migrate from mining operations to local ground and surface water. While ARD can enhance contaminant mobility by promoting leaching from exposed wastes and mine structures (see Section 4.1), releases can also occur under

neutral pH conditions. Primary sources of dissolved pollutants from coal and metal mining operations include: underground and surface mine workings; overburden and waste rock piles; tailings piles and impoundments; direct discharges from conventional milling/beneficiation operations; leach piles and processing facilities; coal processing units; chemical storage areas (runoff and spills); and reclamation activities. Discharges of process water, mine water, runoff, and seepage are the primary transport mechanisms to surface water and groundwater.

One potential source of dissolved pollutants is chemicals used in mining and beneficiation. Common types of reagents include copper, zinc, chromium, cyanide, nitrate and phenolic compounds, along with sulfuric acid at copper leaching operations. With the exception of leaching operations and possibly the extensive use of nitrate compounds in blasting and reclamation, the quantities of reagents used are very small compared to the volumes of water generated. As a result, the risks from releases of toxic pollutant from non-leaching-related reagents are generally limited (see Sections 4.1 and 4.2 for discussions of the potential impacts associated with acid and cyanide releases).

A major source of pollutants is naturally occurring substances in the ore. Mined ore not only contains the mineral being extracted but varying concentrations of a wide range of other minerals (frequently other minerals may be present at much higher concentrations and can be significantly more mobile than the target mineral). Depending on the local geology, the ore (and the surrounding waste rock and overburden) can include trace levels of aluminum, arsenic, asbestos, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, silver, selenium, and zinc.

The occurrence of specific pollutants, their release potential, and the associated risks are highly dependent on facility-specific conditions, including: design and operation of extraction and beneficiation operations, waste and materials management practices, extent of treatment/mitigation measures, the environmental setting (including climate, geology, hydrogeology, waste and ore mineralogy and geochemistry, etc.) and nature of and proximity to human and environmental receptors. In the development of the National effluent guidelines for the Ore Mining and Dressing and Coal Mining Point Source categories (40 CFR Parts 434 and Part 440), EPA conducted sampling and analysis at mine sites to identify pollutants of concern at mining operations (focusing primarily on mine water and process water, not runoff). Exhibit 4-4 provides a summary of the metal pollutants commonly associated with discharges from specific types of hardrock/non-coal mining operations (along with typical treatment practices). Exhibit 4-5 describes dissolved pollutants often found in discharges from coal mining operations.

As stated above, the data presented in the tables were primarily obtained from sampling of mine drainage and beneficiation process wastewater. With the exception of coal and refuse pile runoff at coal mining operations, runoff (as well as infiltration/seepage) have not been well characterized.

Exhibit 4-4. Typical Pollutants Associated With Hardrock Mining Operations

Type of Mining	Potential Pollutants of Concern in Discharges to Surface and Groundwater	Typical Treatment
Iron	Asbestos, arsenic, and copper, iron	Settling ponds and flocculation.
Copper, Lead, Zinc, Gold, Silver, and Molybdenum (excluding cyanide leaching operations)	Aluminum, antimony, arsenic, cadmium, chromium, copper, lead, manganese, nickel, thallium, and zinc	Recycling/reuse and settling/precipitation ponds
Aluminum	None found at high concentrations	Not Applicable
Tungsten	Copper, lead, and zinc.	Recycle (mines have generally been located in arid regions)
Mercury	Most toxic metals	Evaporation ponds and/or recycle/reuse
Uranium	Radium 226	Evaporation; ion exchange; flocculation; settling; and recycle/reuse
Antimony	Antimony, arsenic, and asbestos	Recycle/reuse
Titanium	Most toxic metals	Settling and precipitation (lime/caustic addition)
Vanadium	Mercury, arsenic, cadmium, chromium, copper, mercury, lead and zinc	Neutralization, settling and precipitation

Source: EPA, 1982; ore mining and dressing development document.

Further, they have historically not been subject to the same level of control/treatment as mine and process wastewater.

In assessing the nature and extent of potential dissolved pollutant releases from new source mining operation, reviewers can often supplement general information (such as the above tables) with site-specific data. This will include information on local geology (focussing on the chemistry of each geological unit and the likely composition of wastes/exposed materials). In addition, mining operations are often located in historic mining districts. Where this is the case, significant existing data may be available (or collected under baseline monitoring) to describe past releases to surface water and groundwater, how they have affected the environment, and the effectiveness of current treatment/control measures. It is not uncommon to find naturally occurring levels of metals and sulfates (particularly iron and manganese) in highly mineralized ground and surface water. However, mining and land disturbance activities have the potential to increase the loadings and mobility of specific pollutants.

Exhibit 4-5. Typical Pollutants Associated With Coal Mining Operations

Wastewater Type	Potential Pollutants of Concern in Discharges to Surface and Groundwater	Typical Treatment
Coal preparation plant wastewater	Arsenic, cadmium, copper, lead, silver, and zinc.	Settling and precipitation, recycle/reuse
Coal pile runoff	Manganese, iron, arsenic, chromium, copper, lead, mercury, nickel, selenium, and zinc	Neutralization and precipitation
Refuse pile runoff	Copper, cadmium, silver, and zinc	Neutralization and precipitation
Alkaline mine drainage (see Section 4.1 for discussion of acid mine drainage)	Iron and manganese	Neutralization and precipitation

EPA's *Quality Criteria for Water* provides information on the acute and chronic impacts of dissolved pollutants in surface water (including suggested water quality standards). Each State has promulgated water quality criteria for surface waters based on the designated uses of the waters as well as establishing guidelines on how to apply the standards. Reviewers should be cognizant that, unlike many other types of industrial operations and discharges, there can be extreme variability in toxic constituent loadings from mining operations, both from day to day and over months and years. Further, the receiving water may be particularly sensitive to loadings of toxic pollutants during specific periods (e.g., under certain flow conditions). In conducting baseline analysis, the operator should ensure that such conditions are identified. A long-term sampling plan should then be developed to include sampling and analyses during these critical periods. As discussed in Sections 4.1 and 4.5, traditional quarterly or biannual monitoring programs may not provide for sampling when dissolved pollutant loadings could have the most adverse impacts on surface water quality.

Dissolved pollutants discharged to surface waters can partition to sediments. Specifically, some toxic constituents (e.g., lead and mercury) associated with discharges from mining operations are often found at elevated levels in sediments, while not being detected in the water column. Sediment contamination may impact human health through consumption of fish that bioaccumulate toxic pollutants. Further, elevated levels of toxic pollutants in sediments can have direct acute and chronic impacts on macroinvertebrates and other aquatic life. Finally, sediment contamination provides a long-term source of pollutants through potential redissolution in the water column. As noted in Section 4.5, there are currently no national sediment standards/criteria for toxic pollutants associated with mining operation (although EPA is in the process of establishing criteria and partitioning techniques for toxic metals). Reviewers must typically rely on BPJ to determine the sediment impacts from new sources.

Finally, the ability of pollutants to dissolve and migrate from exposed materials/waste management units to groundwater varies significantly depending on the constituent of concern, the nature of the material/waste, the design of the management unit, soil characteristics, and local hydrogeology (including depth, flows, and geochemistry of the underlying aquifers). Potential risks to human health and the environment from contaminated groundwater usage are a function of the types of and distance to local users. In addition, impacts on groundwater can also indirectly affect surface water quality (through recharge and/or seepage). At some sites, the potential for groundwater contamination may be limited to alluvial aquifers which have limited beneficial uses but are significant source of recharge. Section 4.5.1 describes elements to consider in performing baseline and long-term groundwater monitoring.

4.7 AIR QUALITY

The primary air pollutant of concern at mining sites is particulate matter. As noted in Chapter 5, particulates with a diameter of less than 10 microns is one of the air pollutants for which EPA established National Ambient Air Quality Standards. State Implementation plans must ensure that particulate emissions from whatever source are controlled sufficiently to allow attainment of the ambient air standard and to meet opacity requirements.

Particulates are emitted from a variety of mining operations, usually as fugitive dust (as opposed to emissions from stacks), and relatively simple controls are typically sufficient:

- Ore crushing and conveyors can be a substantial source of fugitive dust, and control generally involves water sprays or mists in the immediate area of the crusher and along conveyor routes.
- Loading bins for ore, limestone, and other materials also generate dust. Again, water sprays are typically used.
- Blasting generates dust that can be, and sometimes is, controlled with water sprays.
- Equipment and vehicle travel on access (and haul roads is a major source of fine and coarse dust. Most mines use water trucks to dampen the surface periodically.
- Waste rock dumping can generate dust, but this generally consists of coarse particles that settle out rapidly with no other controls.
- Wind also entrains dust from dumps and spoil piles, roads, tailings (either dry as disposed or the dry portions of impoundments), and other disturbed areas. Spray from water trucks are often used when the mine is operating. During temporary closures and particularly after the active life, stabilization and reclamation are aimed in part at reducing fugitive dust emissions. Tailings in particular can be a potent source of fine particulates. Rock and/or topsoil covers, possibly with vegetative covers, can be effective controls.

As discussed in various sections above, tailings and waste rock at metal mines usually contain trace concentrations of heavy metals. Fugitive dust would also contain such metals, and areas immediately downwind could accumulate troubling amounts of dust as coarse particles settle out of suspension in the air.

In addition, on a few occasions, wind has caused cyanide sprays on heap leach piles to blow short distances and caused very localized damage. For this reason, more operators are turning to drip application of cyanide solutions.

4.8 SUBSIDENCE

Mining subsidence can be defined as the surface results that occur as a result of the collapse of overlying strata into mine voids. The potential for subsidence exists for all forms of underground mining. Subsidence may manifest itself in the form of sinkholes or troughs. Sinkholes are usually associated with the collapse of a portion of a mine void (such as a room in room and pillar mining); the extent of the surface disturbance is usually limited in size. Troughs are formed from the subsidence of large portions of the underground void and would be typical over areas where most of the resource had been removed (Singh and Bieniawski, 1992).

The threat and extent of subsidence is related to the method of mining employed. In many instances, traditional room and pillar methods leave enough material in place to avoid subsidence effects. However, high volume extraction techniques including pillar retreat and longwall mining result in a strong likelihood that subsidence will occur (McElfish and Beier, 1990; Britton, 1992).

Modern mining operations typically consider subsidence in the planning process. Two approaches may be taken to addressing the problem: planned subsidence or planned subsidence prevention (Britton, 1992). The approach can be governed by the type of mining activity planned or by the degree of severity of subsidence impacts.

Planned subsidence involves predicting the maximum areal extent and depth of ground lowering induced by the proposed mining activities. This prediction can be used to develop surface mitigation measures or appropriate modification of surface land uses in response to the subsidence. Typically, subsidence will occur within a few weeks after the mining face passes under an area although it may take up to ten years for the area to completely settle.

Subsidence prevention involves leaving supports (pillars) in place following mining activities to prevent subsidence from occurring. In this approach, factors governing subsidence are also analyzed so that a maximum amount of the resource may be removed while leaving enough material (either the resource or backfill) in place to prevent subsidence. A combination of the planned subsidence and

planned subsidence prevention approaches could be used in cases where some surface features require protection while most of the overlying area do not.

The subsidence that occurs in areas overlying abandoned mines is referred to as unplanned subsidence. These mines, in many cases, lacked any overlying development and were operated without concern for subsidence. Unplanned subsidence can also occur in association with more modern mining operations, arising when subsidence is not considered in the development of the mine plan, or in the event of an unpredicted occurrence (i.e., roof or pillar failures, groundwater inflow). In these cases, the depth and extent of surface disturbance cannot be (or is not) determined. Likewise the time frame for the occurrence of subsidence cannot be predicted.

The extent of subsidence depends on the thickness of the seam (or deposit) mined, the amount of coal (or ore) left in place or the amount of backfill placed in the void, the nature and thickness of the overlying strata, the depth to the void, the permeability of the overburden to water, and the presence or absence of groundwater. The area potentially affected by subsidence extends beyond the area directly above the mining void; these effects to the adjacent lands extend into what is termed the angle of draw. The angle of draw extends 15° to 30° from the edge of the mining void outward (McElfish and Beier, 1990, Singh, 1992).

Effects of subsidence may or may not be visible from the ground surface. Sinkholes or depressions in the landscape interrupt surface water drainage patterns; ponds and streams may be drained or channels may be redirected. Farmland can be impacted to the point that equipment cannot conduct surface preparation activities, irrigation systems and drainage tiles may be disrupted. In developed areas, subsidence has the potential to affect building foundations and walls, highways, and pipelines. Groundwater flow may be interrupted as impermeable strata break down, and could result in flooding of the mine voids. Impacts to groundwater include changes in water quality and flow patterns (including surface water recharge).

The Bureau of Mines has estimated that of the seven million acres of land underlain by underground mining, two million have been affected by subsidence (McElfish and Beier, 1990). SMCRA requires that underground coal mining operations prevent subsidence from causing material damage to the extent technologically and economically feasible or, to employ a mining method which provides for "planned subsidence in a predictable and controlled manner." Regulations governing subsidence from non-coal mines is dependant on the individual regulatory authority responsible for those operations.

4.9 METHANE EMISSIONS FROM COAL MINING AND PREPARATION

The biogeochemical processes known as coalification give rise to the formation of methane (natural gas) and other gases which remain closely associated with coal in virtually all coal-bearing formations. Adsorbed to surface sites within the highly fractured coal matrix, methane typically

constitutes only a small fraction of the total energy content of the in-place coal. Within the formation, methane remains bound to surface sites in a monomolecular layer under the influence formation pressure. However, under reduced pressure conditions resulting from mining, water draw down, or erosion, methane desorbs from coal and becomes free to migrate within and beyond the coal matrix.

Miners have long known of the release of methane from mined coal; methane is responsible for some of the worst mine explosions to have occurred in this country and elsewhere. Accordingly, coal mining operations always include substantial ventilation equipment to maintain airborne methane concentrations below one or two percent. Typically the vented air is released directly to the atmosphere, though in some instances an effort has been made to collect and compress the methane for onsite energy use or pipeline sales.

The necessity of venting methane from coal mines in advance of and during extraction operations raises a number of environmental issues, both local and global. In particular, current political and scientific concern over the prospect of global warming associated with the release of greenhouse gases to the atmosphere has focused an increasing amount of attention on the role of methane in radiative forcing. Methane is a potent greenhouse gas with a radiative forcing potential of 30 to 55 times that of carbon dioxide. Because methane's estimated contribution to the total atmospheric radiative forcing associated with industrial emissions is significant, and because at least some of those emissions may be relatively easily and profitably reduced, such emissions from coal mine degassification may warrant consideration as incremental or cumulative impacts associated with coal mining.

One recent study by EPA (EPA, September 1990) estimated the total methane emissions associated with U.S. coal mining activity in 1987 to be roughly 7 million metric tons of methane, amounting to approximately 7-12 percent of annual methane emissions from all U.S. sources. Methane is released during degassification of operating mines (78 percent of releases), during pre-mining coal seam degassification (18 percent), and during coal preparation (4 percent). Further, due to increasing methane concentrations in coal with depth (due to temperature and pressure), an estimated 88 percent of all methane releases from coal mining and use results from underground coal, with the remaining 12 percent attributable to surface-mined coal.

As a practical matter, few or no individual mines could be expected to release sufficient methane to constitute a significant impact on the global atmospheric methane budget. However, the importance of the overall potential impacts of greenhouse gas emissions make it appropriate to examine methane emissions from coal mines in the context of cumulative and incremental impacts.

More locally, some of the technologies associated with pre-mining degassification may have direct surface impacts similar to those associated with oil and gas exploration and production activities. Specifically, wells closely resembling conventional gas production wells may be completed into the area directly above long wall mining panels several years in advance of mining for the purpose of removing (and recovering) methane from the coal seam. The wells are designed to draw down formation water pressure allowing methane to enter the gas phase and flow to the well. Under favorable conditions, methane may be recovered in sufficient quantities and under sufficient pressure to allow onsite use or pipeline sale. In fact, coalbed methane development projects have grown dramatically in number since the early 1980s, particularly in areas where coal is too deep to mine economically.

Coalbed gas development wells typically produce substantial quantities of formation water along with the gas. Such water may be high in chlorides and other dissolved solids, and presents a surface management challenge. Additionally, drilling muds, workover and completion wastes, and other oil and gas associated wastes may be generated at the degassification site. Any impacts caused by coalbed degassification prior to or during mining could be considered as indirect effects of issuance of a new source permit. Accordingly, the effects should be assessed along with other cumulative impacts.

5. IMPACT ANALYSIS

This chapter describes specific NEPA documentation requirements and needs. Where appropriate, the following sections distinguish among requirements that apply to EIDs, EAs, and EISs.

In many ways, this chapter builds on information presented in previous sections. Chapter 2 provided an overview of requirements for NEPA reviews of new source NPDES permitting actions. Chapter 4 identified the key environmental issues and impacts associated with mining industry operations.

5.1 DETERMINE THE SCOPE OF ANALYSIS

"Scoping" refers to the process of determining the nature and extent of significant issues associated with a proposed action. Scoping is a key preliminary step for all types of assessments, allowing the analyst to focus on what is most important.

In the case of EIDs, scoping is an informal process. As part of an initial consultation between EPA and the permit applicant, the applicant should be prepared to explain why a permit for a new source discharge is being requested. The applicant should be prepared to discuss the context for the permit application and to address such questions as:

- How is the action related to your firm's business or other objectives?
- How would the proposed new activities relate to any existing operations?
- What issues are thought to be important with regard to the new source permit (e.g., any additional employment opportunities or effects on the local economy, pollution, nearby historic or cultural sites)?
- What existing environmental or other studies or data would be helpful in this review?
- Is the proposed new source discharge anticipated to raise any concerns within your community?
- Are any groups or individuals likely to be particularly interested in or concerned about the new wastewater discharge?

In preparing an EA on the proposed issuance of a new source permit, EPA will review information provided by the applicant to help identify any potentially significant issues. EPA also will contact representatives of any Federal, State, or local government agencies that may have a particular interest in the proposed action. Among those agencies likely to offer information that may be helpful in the early identification of key issues are State mine land regulatory agencies and Federal land managers, local land use planning agencies, the State environmental protection and natural resource management

agencies, and the State Historic Preservation Officer (SHPO). Contact with Regional representatives of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service can be helpful in early identification of any potential issues relating to federally listed threatened and endangered species.

Where an EIS is required, scoping becomes a formal process that involves public participation and interagency coordination.

Generally, a Notice of Intent for EIS preparation will contain an initial identification of potentially important issues associated with a proposed action. The NOI also will describe the proposed method for conducting the scoping process and will identify the office or person responsible for matters related to scoping.

EIS preparation also involves holding one or more scoping meetings, where affected Federal, State, and local agencies, affected Tribes, and other interested persons are invited to participate in the identification of key issues. Participants help draw attention to any other actions or previous assessments that may bear on the proposed action. In addition, the scoping process may involve addressing procedural issues. For example, the review and consultation procedures for the process may be identified, a planning schedule may be developed, and page and time limits for the assessment may be set.

5.2 IDENTIFY ALTERNATIVES

In accordance with NEPA, impact analysis requires a description of the proposed action as well as a description of all reasonable alternatives. The identification of alternatives is an essential step in the preparation of EIDs, EAs, and EISs. For EISs, alternatives should be described in great detail.

The description of alternatives should include an identification of any alternatives that were considered and rejected during the planning process. Any reasonable alternative should be considered by the Applicant in order to provide EPA with more latitude in considering whether to issue the permit or not. The rationale for the elimination of any alternatives from further consideration should be provided. Alternatives generally are rejected based on technical, economic, environmental, or institutional considerations. In the case of an EIS, the decision to dismiss an alternative must be supported by data sufficient to respond to a challenging question or comment.

EPA's NEPA procedures recognize three general categories of alternatives: alternatives available to EPA; alternatives considered by the applicant; and alternatives available to other agencies with jurisdiction.

5.2.1 ALTERNATIVES AVAILABLE TO EPA

Three types of alternatives are available to EPA in assessing the potential impacts of a proposed new source NPDES permitting action:

- Issue the NPDES permit
- Issue the NPDES permit with modifications to the proposal (including modifications that may not have been considered by the Applicant)
- Deny the NPDES permit.

The third option is generally referred to as the "no action alternative." This alternative provides a baseline for comparing the impacts of other options.

5.2.2 ALTERNATIVES CONSIDERED BY THE APPLICANT

When new industrial facilities are planned, operators typically undertake feasibility and planning studies. Companies typically investigate processing options, markets, siting alternatives, and a host of other technical, financial, and legal issues. These planning studies can be helpful in the early identification of critical issues, including potential land use conflicts, proximity to protected natural resources or historic sites, or any indication of hazard potential (e.g., location of facilities in floodplains).

The Applicant should explain the planning process to provide insight into the breadth and depth of alternatives considered and rejected or pursued for further study. **A well-documented explanation of the Applicant's analysis of alternatives is critically important to the impact assessment process.** In particular, it is important for the Applicant to explore and document a broad scope of alternatives that look at pollution prevention opportunities.

As part of an EID, the Applicant should provide a detailed description of the proposed action(s) as well as a description of any alternatives that were considered, but rejected. The Applicant should also consider the "no action alternative," which would be not to apply for the NPDES permit.

EPA's NEPA procedures require that the Applicant provide: (1) "balanced" descriptions of each alternative and (2) a discussion covering size and location of facilities, land requirements, operations and management requirements, auxiliary structures such as pipelines or transmission lines, and construction schedules.

The Applicant should explain the implications of each option with regard to the firm's goals and objectives. The Applicant should consider the full range of options for meeting these goals and objectives, including options that do not involve a discharge subject to permit requirements.

5.2.3 ALTERNATIVES AVAILABLE TO OTHER AGENCIES

A third category of alternatives are those available when EPA is preparing an EIS or other environmental document in conjunction with another Federal or State agency. These additional alternatives would be based on other relevant regulatory authorities. For example, in addition to a new source NPDES discharge, a proposed project might involve dredging or filling of a wetland. In this case, the U.S. Army Corps of Engineers would be responsible for issuing a permit under Section 404 of the CWA. Accordingly, the environmental analysis should account for the various alternatives available to the Corps of Engineers, which would include: granting the permit; granting the permit with modifications or conditions; or denying the permit. The information to support issuance of a permit under Section 404 should be included in the EIS, including how impacts to aquatic resources were avoided, minimized, or compensated for.

5.3 DESCRIBE THE AFFECTED ENVIRONMENT

The affected environment section of any NEPA document should be no longer or more detailed than needed to understand potential environmental impacts. Background information on topics not directly related to expected effects should be summarized, consolidated, or referenced to focus attention on important issues.

The scope and content of this section of an EID will be determined during an initial consultation between EPA and the Applicant. Generally, the Applicant will be required to provide any relevant information that is readily available. In establishing the scope of this section of an EID, EPA will consider the size of the new source and the extent to which the Applicant is capable of providing information. Requests for data should be kept to a minimum consistent with requirements under NEPA.

For an EA, the description of the affected environment should focus on key issue areas, including the following:

- Current and projected land use within the project area and within the region
- Current and projected population and population density
- Relevant land use regulations
- Local and regional patterns of energy demand and supply

- Local ambient air quality conditions
- Local ambient noise levels
- Location of designated floodplains within the vicinity of the project
- Surface water and groundwater quality and quantity
- Local biological communities and fish and wildlife habitats
- Critical habitats of any Federal- or State-listed threatened or endangered species
- Location of any properties listed in or eligible for listing in the National Register of Historic Places
- Location of specially protected areas, including parklands, wetlands, wild and scenic rivers, navigational areas, or prime agricultural lands.

In the case of an EIS, the description of the affected environment is more extensive and detailed. The breadth of topics typically addressed within an EIS is discussed below.

5.3.1 THE PHYSICAL-CHEMICAL ENVIRONMENT

The physical-chemical environment comprises the air, water, and geological characteristics of sites where the environmental impacts of alternatives will be evaluated. This section of an EIS should provide sufficient information to determine whether impacts are likely to be significant.

5.3.1.1 Air Resources

Air resources are described by the physical dynamic behavior of the lower atmosphere and by variations in the concentrations of various gases and suspended matter. Physical dynamic behavior is described by parameters such as the seasonal distribution of wind velocity and the frequency and height of inversions. Wind velocity and the frequency of occurrence of inversions are often determined by specific local topographic features, particularly surrounding hills or mountains. Air quality is described by the variations in the concentrations of pollutant gases in the lower atmosphere. Both are needed to determine the environmental impacts of facility stack emissions, the effects of mobile sources on local air quality, and the likelihood that dust will be of importance during construction, operation, and after abandonment.

The description of meteorological regime(s) should include a generalized discussion of regional and site-specific climate including:

- Diurnal and seasonal ground-level temperature

- Wind characteristics at different heights and times (wind roses are particularly helpful and provide wind speed, direction, frequency, and stability characteristics of the atmosphere)
- Total monthly, seasonal, and annual precipitation, frequency of storms and their intensity, including both average and extreme events
- Height, frequency, and persistence of inversions and atmospheric mixing characteristics
- Description of pattern(s) evident for days of significant pollution episodes; evaporation.

Information on ambient air quality is often required to predict the impacts during construction and the operation of a facility. Using existing air quality as the background, incremental increases in air pollution concentrations can be predicted for comparison with various Federal, State, and local standards. Depending on the scale of the analysis, data should be presented for the relevant airshed, for the site itself, or both. Also, the site's location relative to any Class I areas (e.g., National Parks) and any areas that are in nonattainment with any National Ambient Air Quality Standard should be provided.

Emission inventories and ambient air quality as reported by State and local air pollution control districts are the data sources for an air basin or regional airshed level analysis. At a minimum, major stationary sources and their emissions should be characterized, with diurnal variations in emissions by month, year, and peak season for pollutants of concern. Projections of increases in emissions and long-term pollutant concentrations are also important at this level. The comparison of expected trends with existing Federal, State, and local standards (including identification of Class I areas and the attainment status of the area) becomes a major design parameter for gaseous emission controls.

Site-level analyses are more detailed in their geographic scope, but require similar information. One of the major concerns at the site level is the transport of odors, dust, and emissions towards potentially sensitive environments. Thus local variations in wind velocities, frequency of inversions, and ambient pollutant concentrations may become important in determining local impacts. Air quality models are often used to determine the directions and ground level concentrations of pollutants of concern, and these models require most of the information described in the previous paragraph along with specific stack characteristics such as stack height, emission temperature, emission velocity, and the chemical composition of the stack gases.

5.3.1.2 Water Resources

Information on water resources to be included in the affected environment chapter should cover: whether these waterbodies are jurisdictional waters of the United States, any special aquatic sites, descriptions of waterbody types (i.e., local streams, lakes, rivers, and estuaries), and descriptions of groundwater aquifers. Descriptions of water body types, flows and dilutions, pollutant

concentrations, special aquatic sites, and habitat types near potential discharges are necessary to determine the changes in the water environment that will occur with facility construction and operation. Descriptions of alluvial and bedrock aquifers are necessary to determine the potential for contamination of groundwaters from site activities. Of key importance here is the depth to the water table, and the nature of overlying soils and geologic features. Descriptions of groundwaters should include the location of recharge areas, and, in areas of water shortage, their present uses.

Descriptions of surface waters should include seasonal and historical maximum, minimum, and mean flows for rivers and streams, and water levels or stages and seasonal patterns of thermal stratification for lakes and impoundments. The use of surface waters (diversions, returns, and reclamation) may also be important in certain locations where water resources are scarce. Information on ambient concentrations of pollutants, and other local sources, are also necessary to determine resulting concentrations of pollutants with new discharges.

If imported water is to be used at the site for process water or other purposes, the source, quantity, and quality of the water should be described. Any existing NPDES permits should be identified along with a description of wastewater flows and quality.

If the site might be subject to flooding (is within the 100-year floodplain), the dates, levels, and peak discharges of previous floods should be reported along with the meteorological conditions that created them. Projections of future flood levels should also be included for typical planning levels of 50- and 100-year floods. These projections should include anticipated flood control projects such as levees and dams that will be built.

5.3.1.3 Soils and Geology

The physical structure of soils and their underlying geologic elements determine the extent to which soils will be affected by facility construction and operation. Useful parameters include permeability, erodability, water table depth, and depths to impervious layers. The engineering properties and a detailed description of surface and subsurface soil materials and their distribution over a site provide most of the information necessary.

Local and regional topographic features such as ridges, hills, mountains, and valleys provide information on watershed boundaries, and site topography (slope and elevation characteristics) provides information that is needed in determining the potential for erosion.

Geological features are important when paleontological sites and other areas of scientific or educational value may be disturbed or overlain by facility structures.

In regions of the country that are seismically active, the description of the affected environment should information necessary to assess potential risks. Relevant information can include proximity to faults, the history of earthquakes in the area, locations of epicenters, magnitudes, and frequency of occurrence.

5.3.2 BIOLOGICAL CONDITIONS

Key elements of a description of biological conditions include the distribution of dominant species, identification and description of rare, threatened, or endangered species, and a characterization of ecological interrelationships.

5.3.2.1 Vegetation

To understand the significance of vegetation changes associated with construction and operation of a facility, it is necessary to know the types of plant communities in the general area and the specific distribution of vegetation types within the project area. The presence in the area of rare, threatened, or endangered species and unique plant assemblages are particularly important, especially if any are likely to occur at the site. There are a variety of ways to describe vegetation, but the most useful is to divide the site flora into four or five "typical" assemblages and map their distribution and that of recognized scientific and educational areas. For threatened, endangered, or rare species, however, it is necessary to map their occurrence separate from the assemblages.

In areas subject to forest fires, fire hazard should be described by describing the history of fires in the area, projecting the severity of fire hazard in the future, and describing existing fire control and management actions.

Aquatic and marine vegetation, particularly in the vicinity and downstream of proposed discharges, also should be characterized. General community characteristics, including dominant species and diversity, should be identified.

5.3.2.2 Wildlife

The presence of wildlife at a site is largely dependent on the nature and distribution of vegetation. Particular emphasis should be placed on the presence of rare, threatened, or endangered species in the general vicinity of the site, and site-specific discussions are mandatory when the site provides habitat that is used by rare, threatened, or endangered species. Under these circumstances, the relative abundance of all rare, threatened or endangered species and the dominant wildlife fauna should be surveyed on site and presented in the EIS. Otherwise, a general description of the wildlife species within the area is sufficient.

5.3.2.3 Ecological Interrelationships

A characterization of the key interrelations and dynamics within an ecosystem provides a foundation for impact assessment.

Although it is difficult to determine the extent to which plants and animals are interdependent at a given site, specific attention should be given to identifying the food sources of dominant or rare animal species, the factors that limit these food sources (including factors such as soil structure and moisture content, soil surface temperature ranges, and specific soil micronutrients), and the ability of animal species to substitute food sources should current food sources be reduced in abundance. Ecological interdependencies in aquatic systems are also important, and aquatic communities change dramatically with large increases in nutrient or sediment discharges. While prediction of changes in plant and animal populations is difficult under the best of circumstances, significant changes (either positive or negative) cause concomitant changes in both terrestrial and aquatic fauna.

5.3.3 SOCIOECONOMIC ENVIRONMENT

The socioeconomic environment encompasses the interrelated areas of community services, transportation, employment, health and safety, and economic activity. The activities associated with the construction and operation of new source facilities must impact human resources (employment, population, and housing), institutional resources (services or facilities), and economic activity. The information required to assess impacts are described below.

5.3.3.1 Community Services

Community services such as water supply, sewerage and storm drainage, power supply, and education, medical, and fire and police services are almost always affected by major new projects. It is important in an EA or EIS to describe the nature of existing public facilities and services within the general vicinity, the quality of the service provided, and the ability of the existing public facilities and services to accommodate additional users. The most critical consideration is the level of services that would be provided in the anticipated peak year assuming no project were to be undertaken.

Permanent and temporary household relocations create demands on the housing market. The number of nearby housing units, their cost, vacancy rates, and owner-occupancy rate are all significant factors in determining the suitability of the existing housing stock for occupancy by a temporary or permanent workforce. In addition, the present rate of growth within the housing sector can be compared with the anticipated growth in housing supply and demand and the amount of land available for new housing to determine whether existing policies and attitudes toward growth are adequate to accommodate the additional residents.

5.3.3.2 Transportation

Transportation systems provide access to a facility for the import of raw materials, export of final products, and the movement of staff and service personnel. All relevant forms of transport for the facility should be described. For all facilities, road-based transport is of potential significance, but railways, airways, pipelines, and navigable waterways may also be important for some facilities. Current traffic volumes, current traffic capacity, and an assessment of the adequacy of the systems for meeting peak demands during construction and operation should be presented.

5.3.3.3 Population

Total population, rate of growth, general socioeconomic composition, transient population, and the urban or rural nature of the local population are parameters needed to assess the importance of the impacts of project-induced changes on the local community. Information on average household size, average age, age/sex distributions, ethnic composition, average household income, percent of households below poverty level, and median educational level allow a more refined analysis of project-induced changes. Projections of demographic trends for the region and project area without the project are also necessary to determine the relative impacts of the project in future years.

5.3.3.4 Employment

Employment is generated by the construction and operation of any new facility. Construction is normally carried out by a temporary workforce of construction workers, not by the permanent workforce in the area near the site. On the other hand, facility operation usually relies on a permanent workforce, and the source of personnel for this workforce may be local or from other parts of the country. In any case, increases in the number of personnel required to build or operate a facility, direct employment, is accompanied by increases in employment in enterprises required to support the facility, indirect (secondary, non-basic) employment, as demands for goods and services are increased. The direct and indirect employment generated by a project, in turn, generates movements of households, resulting in population shifts and changes in the demographic characteristics of communities.

To determine impacts of additional employment on the local environment, it is necessary to present information about the local labor base—where people work, what they do, their skills and education level, their rates of pay, and the unemployment rate. The characteristics of the unemployed population are especially important if there is an expectation that a new facility will generate employment for them. Projections should also be included on anticipated trends in employment and unemployment without the project so that project-induced changes in these parameters can be compared against a baseline.

5.3.3.5 Health and Safety

Description of the present health and safety environment should include statistics on industrial accidents in the local area; a discussion of air, water, and radioactive emissions from existing and prior facilities and their effects on human health and the environment; and an analysis of present levels of noise and their impacts on people and wildlife. The identification of applicable regulatory standards provides a benchmark against which the present and future health and safety environment, with and without the project, can be judged.

5.3.3.6 Economic Activity

Economic activity will always be affected by new facilities. Current economic activity should be described by characteristics of local businesses (number and types of businesses, annual revenues, and ownership patterns) and the availability of capital for future growth. To predict changes in the kinds of economic activity that would occur with the project, it is necessary to describe the kinds of goods and services that would be required by the project or associated workforce and determine whether they are provided locally or imported. Unique features of the business community such as high seasonality, high outflow of profit, declining trade, or downtown revitalization should also be included.

5.3.4 Land Use

A description of land use should identify the current use of land needed specifically for the facility, its system components, its safe area, and its residuals, and land use patterns in the nearby area that will be indirectly affected by the project. Particular emphasis should be placed on land uses that pose potential conflicts for large-scale industrial activity—residential areas, agricultural lands, woodlands, wetlands—and on the local or regional zoning laws that may limit the development of industry or commercial activities on which it relies. Also of crucial importance is the anticipated (and/or required) use of the land once mining operations end.

5.3.5 Aesthetics

Aesthetics involve the general visual, audio, and tactile environment (imagine the sensory differences among urban, industrial, agricultural, and forest environments). A description of the aesthetic characteristics of the existing environment should include things that are seen, heard, and smelled in and around the site and their emotional or psychological effect on people. Descriptions (or pictures) of views of the site, of unique features or features deemed of special value, and public use and appreciation of the site provide information that must be available for the assessment of impacts.

5.3.6 CULTURAL RESOURCES

Cultural resources is a broad category that encompass resources of current, prehistoric and historic significance. The location of a facility near significant historical and cultural sites can degrade their resource value or emotional impact. The location of the following kinds of sites should be described in relation to the project site:

- Archeological sites (where man-made artifacts or other remains dating from prehistoric times are found)
- Paleontological sites (where bones, shells, and fossils of ancient plants or animals are found in soil or imbedded in rock formations)
- Historic sites (where significant events happened or where well-known people lived or worked)
- Sites of particular educational, religious, scientific, or cultural value.

Of particular concern would be complying with §106 of the National Historic Preservation Act for sites listed on, or eligible for listing on, the National Register.

5.4 ANALYZE POTENTIAL IMPACTS

The major environmental issues associated with the mining industries were discussed in the previous chapter. Although Chapter 4 presents guidance for the analysis of impacts that tend to be common to these industrial categories, it is important to recognize that other types of impacts are bound to be associated with specific proposed actions. Thus, reviewers must ensure that all key issues identified during the scoping process are fully analyzed. The section below provides more specific guidance on the preparation of the "Environmental Consequences" section of an EIS. It also serves as the focus of any administrative appeal or legal challenge of the permit.

The "Environmental Consequences" section of an EIS forms the scientific and analytical basis for the comparison of alternatives. Accordingly, it should contain discussions of beneficial and adverse impacts of each reasonable alternative and mitigation measure (40 CFR 1502.16 and 1508.8) including clear, technical demonstrations of:

- Direct effects and their significance—direct effects are caused by the proposed action and occur at the same time and place.
- Indirect effects and their significance—indirect effects are those caused by the action but are later in time or farther removed in distance, but are reasonably foreseeable. This also includes growth effects related to induced changes in the pattern of land use, population density, or growth rate and related effects on air, water, and ecosystems.

- Possible conflicts between proposed actions and the objectives of Federal, regional, State, local and tribal land use plans, policies, and controls for the area concerned.
- Energy requirements and conservation potential.
- Natural or depletable resource requirements and conservation potential.
- Urban quality, historical and cultural resources, including reuse and conservation potential.
- Means to mitigate adverse environmental impacts not fully covered by the alternatives.
- Project compliance with water quality standards and the significance of the anticipated impact of the discharge (this is particularly important for new source permits).
- Project compliance with National Ambient Air Quality Standards and, if applicable, Prevention of Significant Deterioration increments.

The potential impacts of each alternative are identified by a systematic disciplinary and interdisciplinary examination of the consequences of implementing each alternative.

5.4.1 Methods of Analysis

While information may be gathered from new source NPDES applications, EIDs, and other sources, EPA is responsible for the scientific and professional integrity of any information used in EISs for which it is responsible. The applicant's EID and other sources of data, therefore, must clearly explain all sources, references, methodologies, and models used to analyze or predict results. Applicants should consider the uses and audiences for their data and EPA's affirmative responsibility in using them. EPA has the same responsibility in the use of data submitted by other agencies, private individuals, or groups.

Each impact has its own means of identification, qualification, and quantification. For example, air quality impacts are modeled using standard State or Federally approved programs. These numerical models depend on standardized parameters and site-specific data. Stationary source emissions from plant operation as well as mobile emissions related to traffic circulation from induced employment or growth all contribute to air quality impact quantification. The goal is to quantify impacts on air quality, water quality, employment, land use, and community services—categories that lend themselves to numerical calculations, modeling, and projections. Some environmental elements like aesthetics lend themselves to more qualitative or graphic analyses.

Biological impacts frequently are not readily quantifiable because absolute abundance of individual species are difficult to determine. Impacts may be described as acres of habitat lost or modified or to qualitative impact descriptions of population changes in major species or species groups. The key in the Environmental Consequences section is to clearly and succinctly lead a reader through each impact

identification, qualification and/or quantification. Detailed methodologies or extensive data can be incorporated by reference if the source is readily obtainable. Wildlife agencies can be sources of data for this section. Materials from applicants must carefully follow this pattern to facilitate validation and incorporation in the EIS.

5.4.2 Determination of Significance

As discussed in Chapter 2 of these guidelines, The term "significant effect" is pivotal under NEPA, for an EIS must be prepared when a new source facility is likely to cause a significant impact. What is significant can be set by law, regulation, policy, or practice of an agency; the collective wisdom of a recognized group (e.g., industry or trade association standards); or the professional judgment of an expert or group of experts. CEQ (40 CFR 1508.27) explains significance in terms of context and intensity of an action. Context relates to scale—local, regional, State, national, or global; intensity refers to the severity of the impact. Primary impact areas include affects on public health and safety, and unique characteristics of the area (e.g., historical or cultural resources, parks, prime farm lands, wetlands, wild and scenic rivers, or ecologically critical areas). Other important factors include:

- Degree of controversy
- Degree of uncertain or unknown risks
- Likelihood a precedent will be set
- Occurrence of cumulative impacts (especially if individually not significant)
- Degree to which sites listed, or eligible for listing, in the National Register of Historic Places may be affected
- Degree to which significant scientific, cultural, or historical resources are lost
- Degree to which threatened or endangered species or their critical habitat is affected
- The likelihood of violations of Federal, State, regional or local environmental law or requirements or alternatively, likelihood that applicable standards applicable to the operation and various environmental media can be achieved.

EPA's NEPA procedures require that the Agency consider short-term and long-term effects, direct and indirect effects, and beneficial and adverse effects. Of particular concern are the following types of impacts:

- 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 environmental effects. Factors that should be considered in determining whether these changes are environmentally significant include but are not limited to:

- The nature and extent of the vacant land subject to increased development pressure as a result of the new source
- The increases in population or population density which may be induced and the ramifications of such changes
- The nature of the land use regulation in the affected areas and their potential effects on development and the environment
- The changes in the availability or demand for energy and the resulting environmental consequences.

- The new source will directly, or through induced development, have significant adverse effects upon local ambient noise levels, floodplain, surface or groundwater quality or quantity, fish, wildlife, and their natural habitats.
- Any major part of the new source will have significant adverse effect on the habitat of threatened or endangered species on the Department of the Interior's or a State's list of threatened and endangered species.
- The environmental impacts of the issue of a new source NPDES permit will have significant direct and adverse effect on property listed in the National Register of Historic Places.
- Any major part of the source will have significant adverse effects on park lands, wetlands, wild and scenic rivers, reservoirs, or other important bodies of water, navigation projects, or agricultural lands.

With the regulations in mind, it is ultimately up to the EA and/or EIS preparer(s) to make judgments on what constitutes a significant impact. **The threshold of significance is different for each impact, and those making the judgments need to explain the rationale for the thresholds chosen.** Clear descriptions of the choice of the threshold of significance provides a reviewer with a basis for agreeing or disagreeing with the determination of significance on based on specific assumptions, criteria, or data. Sometimes the thresholds are numerical standards set by regulation. In other cases, the thresholds may be set by agency practice (e.g., the U.S. Fish and Wildlife Service may consider the potential loss of a single individual of an endangered species as a significant impact), or the EPA preparer's professional judgment that determines the rationale for the threshold. The NPDES permit applicant may suggest a threshold for each impact identified in the EID, but it is critical to carefully define how and why each particular threshold was chosen and applied.

5.4.3 Comparisons of Impacts under Differing Alternatives

Alternatives can be compared in several different ways. All of the impacts associated with a single alternative may be examined together and summarized in a final list of significant unavoidable impacts, or the like impacts of all the alternatives can be determined and compared within a final summarized list of significant unavoidable impacts. The choice of approach should be determined by the EIS preparers based on the approach that would provide the most clear, concise evaluation for decision makers and reviewers. The summary information on possible impacts and mitigation measures is usually prepared in tabular form and included in the executive summary. Examples of formats that can be used are found in standard environmental assessment technology texts, agency manuals, EAs, EISs, and similar documents.

5.4.4 Summary Discussions

CEQ and EPA NEPA guidelines describe the expected general contents of the section called "Environmental Consequences." In addition to identifying, quantifying, and comparing the impacts of each alternative, 40 CFR 1502.16 specifies that discussions will include "...any adverse environmental impacts which cannot be avoided should the proposal be implemented, the relationship between short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible or irretrievable commitments of resources which would be involved in the proposal should it be implemented."

Over the last 20 years, these three topics have been included as a separate chapter(s) in draft EISs along with chapters called cumulative impacts, adverse effects which cannot be avoided, or residual impacts and mitigation. No matter what format is used with these topics, they often receive only cursory treatment. Such a practice is unfortunate because these long-term, larger scale issues are those that affect overall environmental quality and amenities. The important point is not the location of these topics in the document, but the need to present data and analytical procedures used to qualify and quantify these concerns.

A section called cumulative impacts can be addressed in several ways. Some EISs consider cumulative impact sections to be summaries of all residual impacts for each alternative. They may also include any synergistic effects among impacts. A second, and more helpful, approach to cumulative impacts reflects a broad view of environmental quality and suggests how impacts of the proposed project or alternatives contribute to the overall environmental quality of the locale, in the immediate future and over a longer time. In this approach, the impacts of the new source project are considered in relation to the impacts associated with projects approved, but not constructed; projects being considered for approval; or planned projects. This "accumulating" impacts approach to cumulative impacts is particularly instructive when no single project is a major cause of a problem, but contributes incrementally to a growing problem.

All of these summary topics focus on broad views and long time lines in a attempt to put project impacts in perspective. The data requests from EPA to applicants must specify the environmental setting and consequences data needed to qualify and quantify the potential impacts and put each potential impact in perspective in terms of local, regional and perhaps State or national environmental quality.

5.5 DETERMINE MITIGATING MEASURES

Initial efforts to meet requirements under NEPA emphasized the identification of mitigation measures for all potential impacts conceivably associated with a project or its alternatives. Current practices emphasize avoiding and minimizing potential impacts before a NEPA document is prepared. This is accomplished by refining the proposed project and alternatives during siting, feasibility, and design processes. The goal is to propose project alternatives with as few significant impacts as possible.

CEQ NEPA regulations define mitigation (40 CFR 1508.20) to include:

- Avoiding the impact altogether by not taking a certain action or parts of an action
- Minimizing impacts by limiting the degree or magnitude of the action and its implementation
- Rectifying the impact by repairing, rehabilitating, or restoring the affected environment
- Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action
- Compensating for the impact by replacing or providing substitute resources or environments.

This listing of mitigation measures has been interpreted as a hierarchy with "avoiding impacts" as the best mitigation and "compensating" for a loss as the least desirable (but preferable to loss without compensation). This hierarchy reinforces the present approach of trying to avoid or minimize potential impacts during project siting and design. The goal is to have the most environmentally sound project and alternatives to carry into the impact assessment process of NEPA.

Even with the best project siting and design, there will be environmental impacts associated with each of the alternatives. For the impacts, especially for the impacts judged to be significant impacts, mitigation measures need to be suggested.

The first source of possible mitigation measures should be those offered in an applicant's EID. Each mitigation measure should be described in enough detail so that its environmental consequences can be evaluated and any residual impacts clearly identified.

The preferred alternative typically reflects choices among tradeoffs. The tradeoffs can include different processes, pollution control technologies, costs, or other features. Typically the tradeoffs are complex for new source facilities with dissimilar beneficial and detrimental impacts among the alternatives. The EIS always should describe the process that led to, and the rationale for, the selection of the preferred alternative. The analysis should be deemed complete if:

- The alternatives brought forward for analysis are all reasonable
- All possible refinements and modifications for environmental protection have been incorporated in the alternatives
- Any residual impacts and consequences of mitigating those impacts have been evaluated.

5.6 CONSULTATION AND COORDINATION

Each of the many laws, regulations, executive orders, and policies identified in Chapter 6 should be addressed in the Consultation and Coordination section of an EIS. The applicant should provide a record of their activities and actions under each of the initiatives. The applicant-provided environmental setting and environmental consequences materials should include sufficient data on the environment issues raised by these laws, regulations, and orders to identify and analyze the potential impacts.

6. STATUTORY FRAMEWORK

Mining operations are subject to a complex web of Federal, State, and local requirements. Many of these require permits before the mining operations commence, while many simply require consultations, mandate the submission of various reports, and/or establish specific prohibitions or performance-based standards. Among the Federal statutes that are potentially applicable are those shown in Exhibit 6-1. Also shown are the agency with primary responsibility for implementing or administering the statute and the types of requirements that are imposed on those subject to various statutory provisions.

The following sections describe the purposes and broad goals of these statutes. The discussion for each statute also provides an overview of the requirements and programs that are implemented by the respective implementing agencies.

6.1 CLEAN WATER ACT

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 §303, States are responsible for establishing water quality standards and criteria for waters under their jurisdictions: these are the beneficial uses that various waters are to support and the numeric (and narrative) criteria that must be achieved to allow these uses to be met. Water quality standards and criteria serve as a basis both for identifying waters that do not meet their designated uses and for developing effluent limits in permitted discharges. EPA also establishes nonbinding numeric water quality criteria as guidance; when States fail to adopt sufficient water quality standards, EPA may do so.

Under §402 of the Act, all point source discharges (see below) of pollutants to navigable waters of the United States must be permitted under the National Pollutant Discharge Elimination System (NPDES). Effluent limits in NPDES permits may be technology- or water quality-based. For various categories of industries, EPA establishes National technology-based effluent limitation guidelines pursuant to §§301, 306, and 307.

The term "navigable waters" or "waters of the U.S." includes all waters within the territorial seas (i.e., within the three-mile contiguous zone around the United States). Waters of the United States need not be navigable in fact (see *U.S. v. Ashland Oil*, 504 F2d 1317 (6th Cir. 1974)), and may be

Exhibit 6-1. Major Federal Statutes Generally Applicable to Mining Operations

Statute/Section	Implementing/Responsible Agency	Procedural Requirements*	Overview
Federal Water Pollution Control Act (Clean Water Act) (33 U.S.C. §§1251-1387)	EPA, Authorized States and Tribes; Army Corps of Engineers, Authorized States (§404)	Permit; Standards; Reporting; Prohibitions	Permit required for all point source discharges to waters of the U.S. Technology-based effluent limits established for ore mining and dressing, coal mining and preparation. Water quality-based in lieu of technology-based limits must be developed on site-specific basis for discharges that contribute to non-attainment of State-established beneficial uses and water quality standards. Permit required for dredging/filling in waters of U.S., including wetlands. EPA-issued NPDES permits issued to new sources trigger NEPA reviews.
Clean Air Act (42 U.S.C., §§7401-7626)	EPA, States	Standards; Approvals; Permits	Establishes ambient air concentrations for criteria pollutants, including particulates from dust. 1990 amendments call for studies and, if necessary, regulation of hazardous air pollutants from specified industries, including mining.
Resource Conservation and Recovery Act (42 U.S.C. §§6901-6992k)	EPA, Authorized States	Permits (hazardous waste); Standards (hazardous and nonhazardous)	Under Subtitle C, EPA regulates hazardous waste management from generation to disposal. Wastes that are uniquely associated with mining (including tailings, waste rock) are exempt from hazardous waste regulation. Under Subtitle D, EPA establishes non-mandatory criteria for State programs regulating nonhazardous solid wastes. Existing criteria are generally not suitable for mining wastes.
National Environmental Policy Act (42 U.S.C., §§4321-4370a)	EPA, Federal land managers	Studies; Approvals; Consultations	Triggers examination of all of applicable statutes.

Exhibit 6-1. Major Federal Statutes Generally Applicable to Mining Operations (Continued)

Statute/Section	Implementing/Responsible Agency	Procedural Requirements*	Overview
Endangered Species Act (16 U.S.C. §§1531-1544)	Fish and Wildlife Service	Prohibitions; Consultations	Requires federal agencies to ensure that all federally associated activities within the U.S. do not have adverse impacts on the continued existence of threatened or endangered species or on critical habitat. Agencies undertaking a federal action must consult with the U.S. Fish and Wildlife Service (USFWS) or the National Marine Fisheries Service (NMFS) to determine the potential impacts a project may have on protected species.
National Historic Preservation Act (16 U.S.C. §§470 et seq.)	Advisory Council on Historic Preservation	Consultation	Federally licensed mining activities that affect any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register, must afford the Advisory Council on Historic Preservation a reasonable opportunity to comment.
Coastal Zone Management Act (16 U.S.C. §§1451-1464)	EPA, States	Notification	Applicants for federal licenses or permits must submit consistency certifications indicating that their activities comply with CMP requirements. In addition, activities of federal agencies that directly affect the coastal zone must be consistent with approved state CMPs to the maximum extent practicable.
Farmland Protection Policy Act (FPPA) (P.L. 97-98)	U.S. Soil Conservation Service	Consultation	U.S. Soil Conservation Service (SCS) must be asked to identify whether a proposed facility will affect any lands classified as prime and unique farmlands.
Rivers and Harbors Act (33 U.S.C. §§401-413)	U.S. Corps of Engineers	Permits	The RHA regulates obstructions to navigation and prohibits the unpermitted dumping or discharging of refuse into a navigable water of the U.S. The Act also provides authority to regulate the disposal of dredgings in navigable waters. Also see §402 and §404 of the CWA.

Exhibit 6-1. Major Federal Statutes Generally Applicable to Mining Operations (Continued)

Statute/Section	Implementing/Responsible Agency	Procedural Requirements*	Overview
Surface Mining Control and Reclamation Act (30 U.S.C. §§1201-1328)	Office of Surface Mining, Authorized States	Permits; Standards; Reporting; Royalties	Regulates surface effects of surface and underground coal mining that occurred after 1977. Permit required for all mines over two acres. Provides for reclamation of coal mines abandoned before 1977.
Mining Law of 1872 (30 U.S.C. §§22-54)	Bureau of Land Management, Federal land managers	Notification	Provides rights of free access to unrestricted public lands for purposes of claiming and recovering most metallic minerals. Provides mechanism for claimants to obtain full title to claimed public lands.
Federal Land Policy Management Act (43 U.S.C. §§1701-1782)	Bureau of Land Management	Notification; Studies; Approvals	Requires BLM to prevent unnecessary and undue degradation of public lands. Implementing regulations specify noncompliance with Clean Water Act and other statutes as "unnecessary and undue" degradation. Establishes land planning process, including compliance with NEPA. Regulations impose procedural requirements on mining operations on BLM lands (e.g., approval of plans of operations), with most technical requirements determined by managers of BLM units or BLM State offices.
National Park System Mining Regulation Act (Mining in the Parks Act, or MPA) (16 U.S.C. §§1901-1912)	National Park Service	Standards; Notification; Approvals	Regulates mining activities within the National Park System. All mining claims in NPS system made prior to September, 1977 has to be recorded by that time. No claims are allowed after that time. Protects natural or historic landmarks within the park system by requiring that persons conducting mining operations that threaten such landmarks notify NPS and the Council on Historic Preservation.

Exhibit 6-1. Major Federal Statutes Generally Applicable to Mining Operations (Continued)

Statute/Section	Implementing/Responsible Agency	Procedural Requirements*	Overview
Multiple Use and Sustained Yield Act (16 U.S.C. §§528-531), National Forest Management Act	Forest Service	Notification; Studies; Approvals	Establishes that the National Forest System is to be managed for outdoor recreation, range, timber, watershed, and fish and wildlife purposes. Provides that the renewable surface resources of the national forests are to be administered for multiple use and sustained yield of products and services. Establishes land planning process, including compliance with NEPA. Regulations impose procedural requirements on mining operations on FS lands (e.g., approval of plans of operations), with most technical requirements determined by managers of FS units or FS State offices.
Mineral Leasing Act (30 U.S.C. §§181-287)	Bureau of Land Management	Lease (permit); Reporting; Studies	Requires leases and royalty payments for mining fuel minerals (including coal and uranium) on Federal lands, and for mining hardrock minerals on acquired lands.
Comprehensive Environmental Response, Compensation, and Liability Act (42 U.S.C. §§9601-9675)	EPA	Reporting (releases); Studies	Requires reporting of spills of reportable quantities of specified hazardous substances. Requires remediation of contaminated sites that meet specified criteria.
Emergency Planning and Community Right-to-Know Act (42 U.S.C. §§11001-11050)	States, local agencies, EPA	Reporting	Requires submission to State and local emergency response agencies of data on specified toxic chemicals that are produced/used/stored. Mining operations not subject to National Toxic Release Inventory reporting requirements, which are currently applicable only to SIC codes 20-39.

Exhibit 6-1. Major Federal Statutes Generally Applicable to Mining Operations (Continued)

*NOTE:

Permits: "License" to undertake an action subject to enforceable standards, reporting requirements, prohibitions, etc.

Approvals: Formal approvals by responsible official/agency of specified actions.

Standards: Numeric performance- or technology-based standards to limit emissions/discharges/releases, or numeric standards for protection of environmental medium.

Prohibitions: General restrictions or prohibitions on specified actions or on causing a particular effect by any action.

Studies: Requires studies of site-specific environmental conditions, proposed or existing operation, and/or potential environmental effects of operation.

Consultation: Requires consultations with specified officials/agencies prior to undertaking an action.

Reporting: Periodic reporting to regulatory agency on compliance.

Point Sources Under the Clean Water Act

The term "point source" means any discernible, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft from which pollutants are or may be discharged" [CWA §502(14)]. For purposes of the [CWA], the term "point source" includes a landfill leachate collection system. 1987 Water Quality Act, PL 100-4, §507. The definition has been codified at 40 CFR 122.2.

In the preamble for a storm water rulemaking (55 *FR* 47997; November 19, 1990), EPA cited court decisions that bear on the definition (*Sierra Club v. Abston Construction Company*, 620 F.2d (5th Cir. 1980)): ". . . Nothing in the [Clean Water] Act relieves [dischargers] from liability simply because operators did not construct those conveyances, so long as they are reasonably likely to be the means by which pollutants are ultimately deposited into a navigable body of water. Conveyance of pollution formed either as a result of natural erosion or by material means, and which constitute a component of a . . . drainage system, may fit the statutory definition and thereby subject the operators to liability under the Act." Overall, EPA concluded that it intended to ". . . embrace the broadest possible definition of point source consistent with the legislative intent of the CWA and court interpretations to include any identifiable conveyance from which pollutants might enter the waters of the United States." Further, EPA noted that facilities themselves had the burden of determining whether an application should be submitted for a point source (and, by implication, of determining whether a discharge was from a point source) and advised facilities to submit an application or consult with permitting authorities in cases of uncertainty. It should be noted that Federal courts have spoken to the issue of point sources at mine sites: for example, in *Kennecott Copper Corp. v. EPA*, 612 F.2d 1232 (10 Cir. 1979), the court was asked to rule on whether certain discharges were subject to 40 CFR Part 440. One of the court's conclusions was that whether certain of Kennecott's facilities were point sources was a determination "to be made in the first instance in the context of a permit proceeding."

intermittent or seasonal. In at least one case, a discharge which was traced into and through groundwater was considered a discharge to waters of the United States (see *Quivera Mining Co. v. U.S. EPA*, 15 ELR 20530 (10th Cir. 1985)).

EPA's NPDES regulations [40 CFR 122.21(l)] require prospective dischargers (in States without an approved NPDES program) to submit information to the EPA Region, prior to beginning on-site construction, that will allow a determination by EPA of whether the facility is a new source. The criteria for this determination are in 40 CFR 122.29. The Region must then issue a public notice of the determination. If the facility is determined to be a new source, the applicant must comply with the environmental review requirements of 40 CFR Part 6 Subpart F. In preparing a draft new source NPDES permit, the administrative record on which the draft permit is based must include the environmental information document prepared by the applicant, the environmental assessment (and, if applicable, the FNSI) prepared by EPA, and the environmental impact statement (EIS) or supplement;

if applicable [40 CFR Part 124.9(b)(6)]. 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)].

EPA has established National technology-based effluent limitation guidelines for coal mining and preparation plants (40 CFR Part 434) and ore mining and dressing (40 CFR Part 440). National effluent limits are based on three levels of technologies. First, Best Practicable Control Technology Currently Available (BPT) limits are based on the best existing performance (in the mid-1970s) at plants of various sizes, ages, and unit processes in the industry. Limits based on the Best Available Technology Economically Achievable (BAT) control toxic pollutants (i.e., 126 chemical substances identified by Congress) and nonconventional pollutants (any pollutant other than toxic and conventional [BOD, TSS, oil and grease, fecal coliforms, and pH] pollutants). BAT limits generally represent the best existing performance in the industry. Finally, new source performance standards are based on the Best Available Demonstrated Technology (BADT), since new plants can install the best and most efficient production processes and wastewater treatment technologies. Exhibits 6-2 through 6-4 present the new source performance standards for coal mining and preparation plants and ore mining and dressing facilities.

In general, standards have been established for "mine drainage" and mill/preparation plant discharges. For coal mining, there also are standards for post-mining areas (i.e., reclamation areas prior to bond release). For coal mining, mine drainage generally includes all point source discharges other than those from haul and access roads, rail lines, conveyor areas, equipment storage and maintenance yards, and coal handling buildings and structures (discharges/runoff from these areas are subject to storm water permitting, as described below). For metal mining, the discharges to which mine drainage limitations apply have proven somewhat more difficult to delineate; Exhibit 6-5 provides examples of point source discharges that are subject to mine drainage limits (and examples of those that are subject to storm water permitting).

The National effluent limitations consist of maximum concentrations of individual pollutants that may be present in specific discharges as well as various conditions and exemptions; in some cases, the effluent limitation allows no discharge. Typically, only a limited number of the pollutants that are likely or known to be present are limited in the National standards, since the technologies on which the limits are based prove effective in treating/removing other pollutants as well. Permit writers must use Best Professional Judgment to develop technology-based limits for any other pollutants of concern, and discharges, for which there are no National effluent limitations. In addition, when technology-based effluent limits will not ensure compliance with applicable water quality standards for the receiving waters, permit writers must develop water quality-based limits that are more stringent than the technology-based limits.

Exhibit 6-2. New Source Performance Standards for Coal Mining Category (40 CFR Part 434)

Effluent Characteristic	Preparation plants and associated areas (Subpart B)		Acid or ferruginous mine drainage [3] (Subpart C)		Alkaline mine drainage [3] (Subpart D)		Post-mining areas (Subpart E)		
							Reclamation areas prior to bond release	Underground mine drainage	
	1-day maximum	30-day average	1-day maximum	30-day average	1-day maximum	30-day average		1-day maximum	30-day average
pH (s.u.) [1]	6.0 - 9.0		6.0 - 9.0		6.0 - 9.0		6.0 - 9.0	6.0 - 9.0	
TSS (mg/l) [2]	70	35	70.0	35.0	70.0	35.0	N/A	70.0	35.0
Fe (total) (mg/l) [2]	6.0	3.0	6.0	3.0	6.0	3.0	N/A	6.0	3.0
Manganese (total) (mg/l) [2]	4.0[4]	2.0[4]	4.0	2.0	N/A		N/A	4.0[5]	2.0[5]
Settleable solids (ml/l) [2]	N/A		N/A		N/A		0.5	N/A	

NOTES:

N/A Not applicable (standard not promulgated)

1 pH limit may be slightly > 9.0 s.u. if neutralization and sedimentation technology does not result in compliance with applicable manganese limits (Subpart F, §434.62).

2 Alternative standards may be applied to discharges during precipitation (Subpart F, §434.63):
Some discharges may be subject to pH limit and to limit of 0.5 ml/l for settleable solids rather than otherwise applicable TSS, iron, and manganese limits if caused by 24-hour precipitation ≤ 10-year/24-hour event [Subpart F, §434.63(a), (b), and (c)]:
- Discharges of alkaline mine drainage (with exceptions), discharges from steep slope areas and mountaintop removal (as defined in SMCRA), and discharges from preparation plants (except from acid coal refuse piles) caused by 24-hour precipitation ≤ 10-year/24-hour event.
- Discharge from acid coal refuse piles caused by 24-hour precipitation > 1-year/24-hour event and ≤ 10-year/24-hour event.
- Discharges of acid mine drainage (except from steep slope areas and mountaintop removal, underground mines, and controlled surface mine. discharges) caused by 24-hour precipitation > 2-year/24-hour event and ≤ 10-year/24-hour event. Discharges from 24-hour precipitation ≤ 2-year/24-hour event also subject to daily maximum limits of 7.0 mg/l of total iron.

Some discharges may be subject only to pH limit if caused by 24-hour precipitation > 10-year/24-hour event [Subpart F, §434.63(d)]:
- All discharges subject to alternative limits above.
- Discharges of acid mine drainage from underground mine workings which are commingled with other discharges eligible for this alternative limit.
- Controlled acid surface mine drainage and discharges from reclamation areas.

3 Acid or ferruginous mine drainage is drainage which, before any treatment, either has pH < 6.0 or total iron concentration ≥ 10.0 mg/l. Alkaline mine drainage is drainage which, before any treatment, either has pH ≥ 6.0 or total iron < 10.0 mg/l.

4 These manganese standards are applicable only to preparation plants where the pH is normally < 6.0 prior to treatment.

5 These manganese standards are applicable only to acid mine drainage from underground mines.

Commingled wastestreams: discharge concentrations of pollutants in combined wastestreams may not exceed the most stringent limitation applicable to any component wastestream.

Exhibit 6-3. New Source Performance Standards for Mine Drainage, Ore Mining and Dressing Category (40 CFR Part 440, Subparts A-K and M)

(units in milligrams per liter except as noted)

Effluent Characteristic	Iron ore (Subpart A)		Aluminum ore (Subpart B)		Uranium, Radium, Vanadium ores (Subpart C)		Mercury ore (Subpart D)		Titanium ore (Subpart E)	
	1-day maximum	30-day average	1-day maximum	30-day average	1-day maximum	30-day average	1-day maximum	30-day average	1-day maximum	30-day average
pH (s.u.)	6.0 - 9.0		6.0 - 9.0		6.0 - 9.0		6.0 - 9.0		6.0 - 9.0	
TSS	30.0	20.0	30.0	20.0	30.0	20.0	30.0	20.0	30.0	20.0
COD	N/A		N/A		200	100	N/A		N/A	
Al	N/A		2.0	1.0	N/A		N/A		N/A	
Cd	N/A		N/A		N/A		N/A		N/A	
Cu	N/A		N/A		N/A		N/A		N/A	
Fe	2.0[1]	1.0[1]	1.0[2]	0.5[2]	N/A		N/A		2.0	1.0
Hg	N/A		N/A		N/A		0.002	0.001	N/A	
Pb	N/A		N/A		N/A		N/A		N/A	
U	N/A		N/A		4.0	2.0	N/A		N/A	
Zn	N/A		N/A		1.0	0.5	N/A		N/A	
Ra_{226} (pCi/l)[1]	N/A		N/A		10.0	3.0	N/A		N/A	
Ra_{226} (pCi/l)[2]	N/A		N/A		30.0	10.0	N/A		N/A	

Exhibit 6-3. New Source Performance Standards for Mine Drainage, Ore Mining and Dressing Category (40 CFR Part 440, Subparts A-K and M) (Continued)

(units in milligrams per liter except as noted)

Effluent Characteristic	Tungsten ore (Subpart F)		Copper, Lead, Zinc, Gold, Silver, Molybdenum ores (Subpart J)	
	1-day maximum	30-day average	1-day maximum	30-day average
pH (s.u.)	6.0 - 9.0		6.0 - 9.0	
TSS	30.0	20.0	30.0	20.0
Al	N/A		N/A	
Cd	0.10	0.05	0.1	0.05
Cu	0.3	0.15	0.3	0.15
Fe	N/A		N/A	
Hg	N/A		0.002	0.001
Pb	N/A		0.6	0.3
U	N/A		N/A	
Zn	1.0	0.5	1.5	0.75

NOTES:

N/A Not applicable (standard not promulgated)

New Source Performance Standards for mine drainage from facilities mining Nickel (Subpart G), Vanadium (H), Antimony (I), and Platinum (K) ores are reserved. Discharges are thus subject to limits based on Best Professional Judgment.

1 Dissolved

2 Total

Storm exemption (Subpart L, §440.131(b): overflow resulting from rainfall/snowmelt may be exempt from standards at facilities designed/constructed/maintained to contain or treat the normal 24-hour wastewater flow and the maximum volume from the 10-year/24-hour precipitation event, including runon/runoff. The exemption is available only if provided for in the facility's permit and if the permittee takes all reasonable steps to treat the flow and minimize overflow and meets notification requirements.

Exhibit 6-4. New Source Performance Standards for Mills and Beneficiation Processes, Ore Mining and Dressing Category (40 CFR Part 440, Subparts A-K and M)

(units in milligrams per liter except as noted)

Effluent Characteristic	Iron ore[1] (Subpart A)		Uranium, Radium, Vanadium ores (Subpart C)	Mercury ore (Subpart D)	Titanium ore (Subpart E)		Tungsten ore (Subpart F)		Copper, Lead, Zinc, Gold, Silver, Molybdenum ores (Subpart J)	Gold placer (Subpart M)[2]
	1-day maximum	30-day average			1-day maximum	30-day average	1-day maximum	30-day average		
pH (s.u.)	6.0 - 9.0		Zero discharge	Zero discharge	6.0 - 9.0		6.0 - 9.0		Zero discharge	N/A
TSS	30.0	20.0			30.0	20.0	30.0	20.0		N/A
Settleable solids (ml/l)	N/A				N/A		N/A			0.2
Cd	N/A				N/A		0.1	0.05		N/A
Cu	N/A				N/A		0.3	0.15		N/A
Fe (dissolved)	2.0	1.0			N/A		N/A			N/A
Zn	N/A				1.0	0.5	1.0	0.5		N/A

NOTES:

N/A Not applicable (standard not promulgated)

NSPS for Nickel (Subpart G), Vanadium (H), Antimony (I), and Platinum (K) subcategories are reserved. Discharges are thus subject to limits based on BPJ.

1 These standards are applicable to iron ore mills other than in the Mesabi Range. NSPS for iron ore mills in Mesabi Range is zero discharge

2 Standards for gold placer mines (Subpart M) are for "process wastewater" (beneficiation water).

3 Mills subject to Subpart J NSPS where contaminants build up in recycle water and interfere with ore recovery may be allowed to discharge the necessary amount to correct the interference problem following treatment, subject to mine drainage standards.

Net precipitation areas: Facilities subject to zero discharge standards that are located in net precipitation zones (i.e., precipitation exceeds evaporation) may be allowed to discharge an amount equal to the excess precipitation, subject to the mine drainage standards for the applicable subcategory.

Storm exemption [Subpart L, §§440.131(b) and 440.131(c)]: overflow resulting from rainfall/snowmelt may be exempted from standards, including zero discharge standards, at facilities designed/constructed/maintained to contain or treat the normal 24-hour wastewater flow (or normal operating volumes, for zero discharge facilities) and the maximum volume from the 10-year/24-hour precipitation event (5-year/6-hour event for gold placer mines). The exemption is available only if provided for in the facility's permit and if the permittee takes all reasonable steps to treat the flow and minimize overflow, and meets notification requirements (and, for gold placer, if BMPs are implemented).

Groundwater infiltration: If facilities subject to zero discharge standards demonstrate that groundwater infiltrates the tailings impoundment or wastewater holding facility, they may be allowed to discharge an equivalent volume subject to mine drainage standards.

Exhibit 6-5. Examples of Discharges From Ore Mining and Dressing Facilities That Are Subject to 40 CFR Part 440 or to Storm Water Permitting

Runoff/drainage discharges subject to 40 CFR Part 440 effluent limitation guidelines	Subject to storm water permitting (not subject to 40 CFR Part 440)
Mine drainage limits	Topsoil piles Haul roads not on active mining area Onsite haul roads not constructed of waste rock or spent ore (unless wastewater subject to mine drainage limits is used for dust control) Tailings dams/dikes when not constructed of waste rock/tailings [1] Concentration/mill building/site (if discharge is storm water only, with no contact with piles) Reclaimed areas released from reclamation bonds prior to 12/17/90 Partially/inadequately reclaimed areas or areas not released from reclamation bond Most ancillary areas (e.g., chemical and explosives storage, power plant, equipment/truck maintenance and wash areas, etc.)
Land application area [1] Crusher area [1] Spent ore piles [1], surge piles, ore stockpiles, waste rock/overburden piles Pumped and unpumped drainage and mine water from pits/underground mines Seeps/French drains [1] Onsite haul roads, if constructed of waste rock or spent ore or if wastewater subject to mine drainage limits is used for dust control Tailings dams/dikes when constructed of waste rock/tailings [1] Unreclaimed disturbed areas	
Mill discharges limits (including zero discharge limits)	
Land application area [1] Crusher area [1] Spent ore piles [1], surge piles, waste rock/overburden piles Seeps/French drains [1] Tailings impoundment/pile Heap leach runoff/seepage Pregnant, barren, overflow, and polishing ponds Product storage areas (e.g., concentrate pile)	

NOTE:
1 Point source discharges from these areas are subject to 40 CFR Part 440 effluent limitation guidelines for (a) mills if process fluids are present or (b) mine drainage if process fluids are not.

Section §402(p)(2)(B) (added by the Water Quality Act of 1987) required that point source discharges of storm water associated with industrial activity be permitted by October 1, 1992. Pursuant to this requirement, EPA's storm water program requires that all point source discharges of storm water associated with industrial activity, including storm water discharges from mining activity, be permitted under the NPDES program. *Storm water* is defined at 40 CFR 122.26(b)(13) as "storm water runoff, snow melt runoff, and surface runoff and drainage." *Storm water associated with industrial activity* is defined at §122.26(b)(14) as "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 . . . ." It also includes discharges from "areas

where industrial activity has taken place in the past and significant materials remain and are exposed to storm water."

Certain storm water discharges from mine sites, whether active or inactive, are not subject to NPDES permitting: storm water that is not contaminated by contact with or that has not come into contact with any overburden, raw material, intermediate products, finished products, byproducts, or waste products located on the site of the operation is not subject to permitting by virtue of §402(l)(2) of the Act. Also, inactive sites where there is no identifiable owner/operator are not subject to permitting under the storm water rule (however, it is not clear that any sites are actually excluded by virtue of this, since there is presumably an owner of all lands on which sites may be located). Finally, sites on Federal lands where claims have been established under the Mining Law of 1872 and where only nominal claim-holding activities are being undertaken are not subject to permitting. However, it is not clear how the program will address claims where this is the case but where there is a discharge of contaminated storm water from mines abandoned by a previous claimant. Finally, NPDES permits are not required for discharges of contaminated storm water from coal mines that have been released from SMCRA reclamation bonds or from noncoal mines that have been released from applicable State/Federal reclamation requirements on or after December 17, 1990.

There are no New Source Performance Standards for storm water discharges, so the issuance of an NPDES permit for storm water discharges (or the coverage by an existing permit of a new or previously unpermitted discharge) would not trigger NEPA.

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. "Jurisdictional wetlands" are those subject to regulation under Section 404. Jurisdictional wetlands are those that meet the criteria defined in the 1987 Corps of Wetlands Delineation Manual (USACE, 1987). Regulatory authority for Section 404 is divided between the Army Corps of Engineers (Corps) and EPA. Section 404(a) establishes the requirement for the Corps to issue permits for discharges of dredged or fill materials into waters of the United States at specific disposal sites. Disposal sites are to be specified for each permit using the §404(b)(1) guidelines; the guidelines were established by EPA in conjunction with the Corps. Further, §404(c) gives EPA the authority to veto any of the permits issued by the Corps under §404. In practice, EPA rarely exercises its veto power as it typically reviews and provides comments on §404 permits prior to their issuance, and any disputes are resolved then.

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 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.

The process of issuing a §404 permit begins with a permit application. The application typically contains information describing the project and the project area; wetlands to be disturbed and the extent; and, mitigation plans. Upon receipt of the application, the Corps issues a public notice describing the proposed activity and establishing a deadline for public comment. Although a public hearing is not normally held, one may be scheduled at the request of concerned citizens. Following the comment period (typically 30 days), the Corps evaluates the application based on requirements of the Clean Water Act. In the final stages, the Corps prepares an environmental assessment and issues a statement of finding. A permit is then issued or denied based on the finding. It is at this time that EPA may exercise its veto authority.

Enforcement authority is divided between the two agencies; the Corps provides enforcement action for operations discharging in violation of an approved permit while EPA has authority over any operation discharging dredged or fill materials without a permit. Within EPA, the Office of Wetlands Protection addresses wetland issues through two divisions. The Regulatory Activities Division develops policy and regulations, and administers the statutory requirements including appeals and determinations. The Wetlands Strategies and State Programs Division works to expand protection and further scientific knowledge of these ecosystem types through coordination efforts with other Federal and State agencies (Want 1990).

6.2 CLEAN AIR ACT

The Clean Air Act (CAA) (42 U.S.C. §§7401-7626) requires EPA to develop ambient air quality standards as well as standards for hazardous air pollutants. The Act also imposes strict performance standards applicable to new or modified sources of air pollution, a stringent approval process for new sources of pollution in both attainment and non-attainment areas, and emission controls on motor vehicles.

Under §109, EPA has established national primary and secondary ambient air quality standards for six "criteria" pollutants. These are known as the National Ambient Air Quality Standards (NAAQSs). The NAAQSs set maximum concentrations in ambient air for lead, nitrogen oxides, sulfur dioxide, carbon monoxide, suspended particulate matter of less than 10 microns in diameter, and ozone. States and local authorities have the responsibility for bringing their regions into compliance with NAAQSs or more strict standards they may adopt. This is accomplished through the development and implementation of State Implementation Plans (SIPs), which are EPA-approved plans that set forth the pollution control requirements applicable to the various sources addressed by each SIP.

Under §111, EPA has promulgated New Source Performance Standards (NSPSs) applicable to metallic mineral-processing plants (40 CFR Part 60, Subpart LL). A processing plant is defined as "any combination of equipment that produces metallic mineral concentrates from ore; metallic mineral processing commences with the mining of the ore." However, all underground processing facilities are exempt from the NSPSs. Also, NSPS particulate emission concentration standards only apply to stack emissions. NSPSs require operations to contain stack-emitted particulate matter in excess of 0.05 grams per dry standard cubic meter (dscm). In addition, stack emissions must not exhibit greater than 7 percent opacity, unless the stack emissions are discharged from an affected facility using a wet scrubbing emission control device. However, on or after 60 days following the achievement of the maximum production rate (but no later than 180 days after initial startup), operations must limit all process fugitive emissions (meaning fugitive dust created during operation though not released through a stack) to 10 percent opacity.

In addition to the NSPSs, Prevention of Significant Deterioration (PSD) provisions are intended to ensure that NAAQS are not exceeded in those areas that are in attainment for NAAQSs. Under this program, new sources are subject to extensive study requirements if they will emit (after controls are applied) specified quantities of certain pollutants.

State programs to meet or exceed Federal NAAQSs are generally maintained through permit programs that limit the release of airborne pollutants from industrial and land-disturbing activities. Fugitive dust emissions from mining activities may be regulated through these permit programs (usually by requiring dust suppression management activities).

As indicated above, only six criteria pollutants are currently regulated by NAAQSs. Several other pollutants are regulated under National Emission Standards for Hazardous Air Pollutants (NESHAPs). NESHAPs address health concerns that are considered too localized to be included under the scope of NAAQSs. Prior to the passage of the Clean Air Amendments of 1990, the EPA had promulgated NESHAPs for seven pollutants: arsenic, asbestos, benzene, beryllium, mercury, vinyl chloride, and radionuclides (40 CFR Part 61).

The Clear Air Act Amendments of 1990 substantially revised the existing statutory provisions of the CAA. The Amendments require that States develop air emission permit programs for major sources (these will supplement SIPs) and dramatically expand the air toxics (i.e., NESHAPs) program to address 189 specific compounds. Under the Amendments, Congress required EPA to establish stringent, technology-based standards for a variety of hazardous air pollutants, including cyanide compounds. In November of 1993, EPA published a list of source categories and a schedule for setting standards for the selected sources. Among the mining-related industry groups that have been identified as sources of hazardous air pollutants are the ferrous and non-ferrous metals processing industries, and the minerals products processing industry (58 FR 63952; 12/3/93). Under the

amended air toxics program, if a source emits more than 10 tons per year of a single hazardous air pollutant or more than 25 tons per year of a combination of hazardous air pollutants, the source is considered a "major source." Major sources are required to use the Maximum Available Control Technology (MACT) to control the release of the pollutants (CAA §112). The CAA Amendments also intensify the requirements applicable to nonattainment areas.

6.3 RESOURCE CONSERVATION AND RECOVERY ACT

The Solid Waste Disposal Act was amended in 1976 with the passage of the Resource Conservation and Recovery Act (RCRA)(42 U.S.C. §§6901-6992k). Under Subtitle C of RCRA, EPA has established requirements for managing hazardous wastes from their generation through their storage, transportation, treatment, and ultimate disposal. Hazardous wastes include specific wastes that are listed as such under 40 CFR §261 Subpart D as well as other wastes that exhibit one or more EPA-defined "characteristics," including reactivity, corrosivity, and toxicity. Other solid wastes (which can be solid, liquid, or gaseous) that are not hazardous wastes are subject to Subtitle D, under which EPA establishes criteria for State management programs, approves State programs, and can provide funding for State implementation. EPA has promulgated specific criteria for municipal solid wastes and more general criteria for all nonhazardous solid wastes.

The scope of RCRA as it applies to mining waste was amended in 1980 when Congress passed the Bevill Amendment, RCRA §3001(b)(3)(A). The Bevill Amendment states that "solid waste from the extraction, beneficiation, and processing of ores and minerals" is excluded from the definition of hazardous waste under Subtitle C of RCRA (40 CFR §261.4(b)(7)). The exemption was conditional upon EPA's completion of studies required by RCRA Section 8002(f) and (p) on the environmental and health consequences of the disposal and use of these wastes. EPA then conducted separate studies of extraction and beneficiation wastes (roughly, mining and milling wastes) and processing wastes (smelting and refining wastes). EPA submitted the results of the first study in the 1985 *Report to Congress: Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden From Uranium Mining, and Oil Shale* (EPA, 1985). In July 1986, EPA made a regulatory determination that regulation of extraction and beneficiation wastes as hazardous wastes under Subtitle C was not warranted (51 *FR* 24496; July 3, 1986). EPA found that a wide variety of existing Federal and State programs already addressed many of the risks posed by extraction and beneficiation wastes. To address gaps in existing programs, EPA indicated that these wastes should be controlled under a Subtitle D program specific to mining wastes.

EPA reported its findings on mineral processing wastes from the studies required by the Bevill Amendment in the 1990 *Report to Congress: Special Wastes From Mineral Processing* (EPA, 1990). This report covered 20 specific mineral processing wastes. In June 1991, EPA issued a regulatory determination (56 *FR* 27300; June 13, 1990) stating that regulation of these 20 mineral processing wastes as hazardous wastes under RCRA Subtitle C is inappropriate or infeasible. Eighteen of the

wastes are subject to applicable State requirements. The remaining two wastes (phosphogypsum and phosphoric acid process waste water) are currently being evaluated under the authority of the Toxic Substances Control Act (TSCA) to investigate pollution prevention alternatives. Five specific wastes are listed as hazardous wastes and must be managed as such; other than these and the 20 wastes exempted in 1991, mineral processing wastes are subject to regulation as hazardous waste if they exhibit one or more hazardous waste characteristics.

EPA interprets the exclusion from hazardous waste regulation to encompass only those wastes that are uniquely related to the extraction and beneficiation of ores and minerals. Thus, the exclusion does not apply to wastes that may be generated at a mine site but that are not uniquely associated with mining. For example, waste solvents are listed as a hazardous waste under 40 CFR §261.31 (Hazardous Wastes from Nonspecific Sources). They are generated at mining sites as a result of cleaning metals parts. Because this activity (and this waste) is not uniquely associated with extraction and beneficiation operations, such solvents must be managed as are any other hazardous wastes, subject to the Federal requirements in 40 CFR Parts 260 through 271, or State requirements if the State is authorized to implement the RCRA Subtitle C program. In practice, most mine sites generate relatively small quantities of hazardous wastes. There are a few large coal and noncoal mines, however, that generate large quantities and thus may be regulated as hazardous waste treatment, storage, or disposal facilities. In these cases, the units in which exempt wastes are managed may be subject to the requirements of 40 CFR §264.101, which require corrective action at certain solid waste management units at regulated facilities.

Since the 1986 Regulatory Determination, EPA's Office of Solid Waste (OSW) has undertaken a number of activities to bolster State programs and to enhance EPA's understanding of the mining industry and its associated environmental impacts. To identify and focus discussion on the key technical and programmatic issues of concern, EPA developed staff-level approaches to regulating mining wastes under RCRA Subtitle D that were widely reviewed and discussed. EPA also established a Policy Dialogue Committee under the Federal Advisory Committees Act to facilitate discussions with other Federal agencies, States, industry, and public interest groups. Grant funding was provided to the Western Governors' Association to support a Mine Waste Task Force, which has fostered the refinement of State programs that regulate mining operations, allowed coordinated discussions among States of mining-related issues, and commissioned a number of technical studies. Grant funding also has been provided to several States for developing and enhancing mining-related programs and to educational institutions for technical investigations.

OSW also has continued its investigation of the mining industry. EPA is currently preparing detailed profiles of a number of mining industry sectors. These profiles are intended to represent current extraction and beneficiation operations and environmental management practices, and applicable Federal and State regulatory programs.

In addition, OSW visited a number of mine sites and prepared comprehensive reports on the operational, environmental, and regulatory characteristics of the sites. Together with the profiles, reports on visits to mines in specific industry sectors are being compiled into Technical Resource Documents. OSW also has compiled data from State regulatory agencies on waste characteristics, releases, and environmental effects; prepared detailed summaries of over 50 mining-related sites on the Superfund National Priorities List (NPL); and examined a number of specific waste management practices and technologies, including several currently available pollution prevention practices technologies. EPA has also conducted studies of State mining-related regulatory programs and their implementation. Finally, EPA has undertaken a number of technical studies, including investigations of prediction techniques for acid generation potential, tailings dam design, closure and reclamation of cyanide heap leach facilities, and other topics. (Profiles and technical studies, currently in draft form, were used extensively in preparing these guidelines).

6.4 ENDANGERED SPECIES ACT

The Endangered Species Act (ESA) (16 U.S.C. §§1531-1544) provides a means whereby ecosystems supporting threatened or endangered species may be conserved and provides a program for the conservation of such species. Under the ESA, the Secretary of the Interior or the Secretary of Commerce, depending on their program responsibilities pursuant to the provisions of Reorganization Plan No. 4 of 1970, must determine whether any species is endangered or threatened due to habitat destruction, overutilization, disease or predation, the inadequacy of existing regulatory mechanisms, or other natural or manmade factors. When the Secretary determines that a species is endangered or threatened, the Secretary must issue regulations deemed necessary and advisable for the conservation of the species. In addition, to the extent prudent and determinable, she or he must designate the critical habitat of the species.

Section 7 of the ESA requires Federal agencies to ensure that all federally associated activities within the United States do not have adverse impacts on the continued existence of threatened or endangered species or on critical habitat that are important in conserving those species. Agencies undertaking a Federal action must consult with the U.S. Fish and Wildlife Service (USFWS), which maintains current lists of species that have been designated as threatened or endangered, to determine the potential impacts a project may have on protected species. The National Marine Fisheries Service undertakes the consultation function for marine and anadromous fish species while the USFWS is responsible for terrestrial (and avian), wetland and fresh-water species.

The USFWS has established a system of informal and formal consultation procedures, and these must be undertaken as appropriate in preparing an EA or EIS. Many States also have programs to identify and protect threatened or endangered species other than Federally listed species. As noted in Chapter 2, 40 CFR 6.605(3) requires that an EIS be prepared if "any major part of a new source will have significant adverse effect on the habitat" of a Federally or State-listed threatened or endangered

species. If a Federally listed threatened or endangered species may be located within the project area and/or may be affected by the project, a detailed endangered species assessment (Biological Assessment) may be prepared independently or concurrently with the EIS and included as an appendix. States may have similar requirements for detailed biological assessments as well.

6.5 NATIONAL HISTORIC PRESERVATION ACT

The National Historic Preservation Act (NHPA) (16 U.S.C. §§470 et seq.) establishes Federal programs to further the efforts of private agencies and individuals in preserving the historical and cultural foundations of the Nation. The NHPA authorizes the establishment of the National Register of Historic Places. It establishes an Advisory Council on Historic Preservation authorized to review and comment upon activities licensed by the Federal government that have an effect upon sites listed on the National Register of Historic Places or that are eligible to be listed. The NHPA establishes a National Trust Fund to administer grants for historic preservation. It authorizes the development of regulations to require Federal agencies to consider the effects of Federal-assisted activities on properties included in, or eligible for, the National Register of Historic Places. It also authorizes regulations addressing State historical preservation programs. State preservation programs can be approved where they meet minimum specified criteria. Additionally, Native American tribes may assume the functions of State Historical Preservation Officers over tribal lands where the tribes meet minimum requirements. Under the Act, Federal agencies assume the responsibility for preserving historical properties owned or controlled by the agencies.

A series of amendments to the NHPA in 1980 codify portions of Executive Order 11593 (Protection and Enhancement of the Cultural Environment—16 U.S.C. §470). These amendments require an inventory of Federal resources and Federal agency programs that protect historic resources, and authorize Federal agencies to charge Federal permittees and licensees reasonable costs for protection activities.

Where mining activities involve a proposed Federal action or federally assisted undertaking, or require a license from a Federal or independent agency, and such activities affect any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register, the agency or licensee must afford the Advisory Council on Historic Preservation a reasonable opportunity to comment with regard to the undertaking. Such agencies or licensees are also obligated to consult with State and Native American Historic Preservation Officers responsible for implementing approved State programs.

As noted in Chapter 2, 40 CFR 6.605(b)(4) provides that issuance of a new source NPDES permit that will have "significant direct and adverse effect on a property listed in or eligible for listing in the National Register of Historic Places" triggers the preparation of an EIS. Many proposed mining operations are located in areas where mining has occurred in the past. Particularly in the west and

Alaska, States and localities are viewing the artifacts of past mining (e.g., headframes, mill buildings, even waste rock piles) as valuable evidence of their heritage. Since modern mining operations can obliterate any remnants of historic operations, care must be taken to identify any valuable cultural resources and mitigate any unavoidable impacts. Innovative approaches are often called for and implemented. In Cripple Creek, Colorado, for example, a mining operation wished to recover gold from turn-of-the-century waste rock piles. As mitigation for removing this evidence of the area's past mining, the operator replaced the piles with waste rock from their modern pit. In addition, they will provide interpretative signs in the area for the public.

6.6 COASTAL ZONE MANAGEMENT ACT

The Coastal Zone Management Act's (CZMA) (16 U.S.C. §§1451-1464) seeks to "preserve, protect, develop, and where possible, restore or enhance the resources of the Nation's coastal zone for this and future generations." To achieve these goals, the Act provides for financial and technical assistance and Federal guidance to States and territories for the conservation and management of coastal resources.

Under the CZMA, Federal grants are used to encourage coastal States to develop a coastal zone management program (CMP). The CMPs specify permissible land and water uses and require participating States to specify how they will implement their management programs. In developing CMPs, States must consider such criteria as ecological, cultural, historic and aesthetic values as well as economic development needs. Applicants for Federal licenses or permits must submit consistency certifications indicating that their activities comply with CMP requirements. In addition, activities of Federal agencies that directly affect the coastal zone must be consistent with approved State CMPs to the maximum extent practicable. The CZMA also establishes the National Estuarine Reserve System, which fosters the proper management and continued research of areas designated as national estuarine reserves.

To the extent that mining activities are federally licensed or permitted, applicants must certify that such activities are consistent with applicable CMPs.

6.7 EXECUTIVE ORDERS 11988 AND 11990

Executive Orders 11988 (Floodplain Management) and 11990 (Protection of Wetlands) apply to executive agencies that acquire, manage or dispose of Federal lands or facilities; construct or finance construction on such lands; or conduct Federal activities or programs affecting land use. Under E.O. 11988, such agencies are required to ". . . avoid to the extent possible the long- and short-term adverse impacts associated with the occupancy and modification of floodplain and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative. . ." within the 100-year flood elevation. This requires that alternatives to avoid development in a floodplain be

considered and that environmental impacts be assessed. If development requires siting in a floodplain, action must be taken to modify or design the facility in a way to avoid damage by floods.

E.O. 11990 is similar to E.O. 11988 in that it requires such agencies to ". . . avoid to the extent possible the long-and short-term adverse impacts associated with the destruction or modification of wetlands and to avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative . . ." When constructing a new facility, actions that minimize the destruction, loss, or degradation of wetlands, and actions to preserve and enhance the natural and beneficial value of wetlands are required. If there is no practicable alternative to wetland construction projects, proposed actions must include measures to minimize harm. Construction in wetlands also falls under §404 of the Clean Water Act, administered by the U.S. Corps of Engineers.

6.8 FARMLAND PROTECTION POLICY ACT

The Farmland Protection Policy Act (FPPA) (P.L. 97-98) seeks to minimize the conversion of farmland to non-agricultural uses. It requires that, to the extent practicable, Federal programs be compatible with agricultural land uses. The Act requires that in conducting agency actions Federal agencies follow established criteria for considering and taking into account any adverse effects such actions may have on farmland. Where adverse effects are anticipated, Federal agencies must consider alternatives that will mitigate any harmful impacts. Under the Act, the U.S. Soil Conservation Service (SCS) is required to be contacted and asked to identify whether a proposed facility will affect any lands classified as prime and unique farmlands. However, beyond considering potential adverse effects and alternatives to agency action, the Act does not provide the basis for actions challenging Federal programs affecting farmlands.

6.9 RIVERS AND HARBORS ACT OF 1899

The Rivers and Harbors Act (RHA) (33 U.S.C. §§401-413) was originally enacted to regulate obstructions to navigation and to prohibit the unpermitted dumping or discharging of any refuse into a navigable water of the United States. The Act also provides authority to regulate the disposal of dredgings in navigable waters. The provisions of §407 forbid any discharge of any refuse matter of any kind or description whatever other than that flowing from streets and sewers in a liquid state. Under §403, a permit is required from the U.S. Army Corps of Engineers for the construction of any structure in or over navigable waters of the United States. Section 403 is usually combined with §404 of the Clean Water Act, which addresses the discharges of fill to all waters of the United States.

Since the passage of the Clean Water Act, the waste discharge-permitting function of the RHA has been superseded by NPDES program under §402 of the CWA. Nevertheless, some provisions of the RHA, primarily Sections 403, 404, and 407, could still be used to enforce single-instance waste discharges that affect navigation and anchorage.

6.10 SURFACE MINING CONTROL AND RECLAMATION ACT

The Surface Mining Control and Reclamation Act (SMCRA) addresses all elements of surface coal operations and the surface effects of underground coal mining. The major component of SMCRA relevant to new mining operations is Title V, which establishes a regulatory and permit program for coal mines operating after 1977. SMCRA Title IV primarily addresses the Abandoned Mined Lands (AML) Program, under which coal mine sites that were abandoned prior to 1977 are reclaimed.

SMCRA provides for delegation of program implementation authority to States, with State programs overseen by the Office of Surface Mining Reclamation and Enforcement (OSM) and direct OSM implementation in nondelegated States. To date, OSM has delegated primacy to 23 States. In addition, three Native American tribes administer their own AML programs. OSM administers SMCRA requirements in 13 States (most of which have no current coal production) and on all other Native American lands.

6.10.1 PERMITTING PROGRAM FOR ACTIVE COAL MINING OPERATIONS

SMCRA requires permits to be issued for all active mining operations. In 30 CFR Parts 816 and 817, OSM has promulgated specific design, operating, and performance standards to ensure that statutory performance standards are met. Special performance standards were established for: auger mining; anthracite mines in Pennsylvania; operations in alluvial valley floors; operations in prime farmlands; mountaintop removal;, special bituminous mines in Wyoming; coal preparation plants not located within the permit area of a mine; and *in situ* processing. Some of the significant standards covering surface and underground operations include:

- Surface Resources
  - Disturbed areas must be returned in a timely manner to conditions that support the land use(s) of the site prior to mining or to a "higher and better use." Land uses include industrial, agricultural, fish and wildlife habitat, or combinations of land uses.
  - Backfilling and grading to achieve approximate original contour (AOC); AOC includes elimination of highwalls, spoil piles, and depressions. Exceptions to AOC requirements are permitted for mountaintop removal operations and mines that are considered to operate in thick or thin overburden conditions.
  - Exposed coal seams and combustible, toxic, or acid-forming materials must be covered with a minimum of four feet of suitable material.
  - Reclamation/revegetation requirements include that a permanent, diverse and effective vegetation cover of native plants be established that will support the postmining land uses.

- Water Resources

  - Mining should be conducted to minimize disturbance to the prevailing hydrologic balance to prevent long-term adverse impacts. Changes in quality and quantity of ground and surface water must be minimized. Protection of the hydrologic system requires that runoff from all disturbed areas (including those that have been regraded and seeded) pass through a sedimentation pond prior to discharge. Sediment ponds must be designed to retain at least the 10-year 24-hour precipitation event. Effluent limitations have been established under the Clean Water Act, as discussed in Section 6.1 above.

  - The groundwater recharge capacity of reclaimed lands must be restored and backfilled materials must be placed to minimize impacts to flow and quality of the aquifer.

  - Alluvial valley floors west of the 100th meridian must be restored to their full hydrologic function, including gradient, shape, capillary and perched water zones, and moisture-holding capacity.

Permits can be issued only if a mine can be successfully reclaimed. Along with permit applications, applicants must submit reclamation plans that include approaches to addressing all environment risks identified in the application. Permit applications must be denied if the operator (or corporate affiliates) has, at any other site in the country, unabated violations of SMCRA or other environmental laws. In addition, permits can be denied or revoked if applicants or permittees have shown a consistent pattern of violations, again at any site. The Comprehensive National Energy Policy Act of 1992 provided for an exemption from the permit prohibition process at SMCRA §510(c). This exemption specifically applies to authorized remining sites where violations of permit conditions occur due to "unanticipated events." The exemption does not preclude the permitting authority from taking other enforcement actions, however.

SMCRA specifically requires that discharges to surface waters be in compliance with applicable State and Federal water quality regulations and the coal mining effluent guidelines at 40 CFR Part 434. Several of the design requirements under 30 CFR Part 816 also pertain to controlling discharges from active mining areas. Permittees are specifically required to design and install sediment/siltation control measures that represent the "Best Technology Currently Available (BTCA)." For sediment control, BTCA originally consisted of controlling discharges from disturbed areas through sedimentation ponds. This uniform approach was challenged and BTCA determinations are now made on a case-by-case basis.

SMCRA requires reclamation bonds for all sites. The basic requirement is a bond for the full cost of site reclamation, although OSM can approve alternative bonding approaches if they are deemed adequate. Alternative approaches such as fixed amounts per acre disturbed have been adopted by some States.

In practice, reclamation plans and bonding requirements have emphasized land restoration (i.e., recontouring and revegetation) rather than water quality issues (except for impacts from erosion). Following reclamation and full bond release, any point source discharges of pollutants remain subject to NPDES permitting. However, NPDES permits have not generally been required following reclamation and bond release (i.e., after discharges are not subject to effluent guidelines). The NPDES storm water program has followed this lead: sites that have been reclaimed after SMCRA's enactment are not subject to the program. In some cases, operators have forfeited bonds that were inadequate to reclaim sites (and to address water quality). The responsible party for any remaining discharges is a matter of some contention at the present time; under the storm water program, the owner of the site would be responsible for obtaining a permit for point source discharges of contaminated storm water.

A limited exception to EPA's 40 CFR Part 434 effluent guidelines was provided in the Water Quality Act of 1987, which allows modifications to the National technology-based limits in cases where remining abandoned sites will result in the potential for improvement of water quality. Where such exemptions are granted, technology-based limits are based on the permit writer's best professional judgment. Limits on pH, iron, and manganese cannot exceed the levels discharged prior to remining; discharges also cannot violate applicable water quality standards and criteria under §303 of the Clean Water Act. Pennsylvania is notable for having used this provision to encourage remining of problem sites, and other States are increasingly using or considering the provision.

It should be noted that certain provisions of SMCRA and the Clean Water Act may provide disincentives to remining abandoned coal sites. For example, neither SMCRA standards nor the effluent limitation guidelines established under the Clean Water Act distinguish between remining previously abandoned sites and mining undisturbed land (except as noted above). To the extent that there is a greater potential for noncompliance at remining sites (e.g., because of greater complexity or unpredictability of the hydrogeologic regime), the "permit block" provisions of SMCRA (§510(c)) could be a disincentive to remining: failure to comply with an NPDES permit can prevent the operator from obtaining future SMCRA permits. The relative stringency of water quality standards, particularly for pH, also may prevent operators from remining sites, since permits must provide for attainment of water quality standards and criteria, notwithstanding any prior nonattainment. (To the extent that water quality standards and criteria act as a disincentive to remining, this may increase as numeric criteria are established for an increased number of toxic pollutants in response to the 1987 amendments to §303.)

6.10.2 Abandoned Mine Lands Program

Title IV of SMCRA established the Abandoned Mine Lands (AML) Program to provide for reclamation of mine sites abandoned prior to 1977 (the date of enactment). The program was subsequently amended to allow the expenditure of funding to reclaim post-1977 operations where an

abandonment occurred between 1977 and the date of State program approval and the reclamation/abatement bond was not sufficient; or where a surety provider became insolvent and available funds were not sufficient to reclaim the site. The AML program is supported by the Abandoned Mine Reclamation Fund. The fund receives reclamation fees paid by active mining operations: for lignite coal, the contribution to the fund is 10¢ per ton; for other coal, the fee is 15¢ per ton of coal from underground mines and 35¢ per ton of surface-mine coal. The fund is currently authorized to collect fees through the year 2004.

6.11 MINING LAW OF 1872

The Mining Law of 1872 (30 U.S.C. §§22-54) establishes the conditions under which citizens of the United States can explore and purchase mineral deposits and occupy and purchase the lands on which such claims are located. The basic provision of the law provides that:

> Except as otherwise provided, all valuable mineral deposits in lands belonging to the U.S. . . . shall be free and open to exploration and purchase, and the lands in which they are found to occupation and purchase, by citizens of the U.S. . . . under regulations prescribed by law, and according to the local customs or rules of miners in the several mining districts, so far as the same are applicable and not inconsistent with the laws of the U.S.

The Mining Law establishes the basic standards for the location, recordation, and patenting of mining claims. In general, persons are authorized to enter Federal lands and establish or locate a claim to a valuable mineral deposit (originally, nearly all minerals but now a much more restricted number, as described below). Once a claim has been properly located (and, since 1976, recorded with BLM), the claimant gains a possessory right to the land for purposes of mineral development and thereafter retains the claim if small amounts of development work is done or small fees are paid. Upon proving that a valuable mineral deposit has been discovered (this proof must meet regulatory standards), claim holders may patent the claim and purchase the land for nominal sums. Except as specifically authorized by law (e.g., certain inholdings), land management agencies have no further jurisdiction over patented lands. Mining claims, whether patented or not, are fully recognized private interests that may be traded or sold. The possessory interest is considered private property subject to Fifth Amendment protection against takings by the United States without just compensation. The standards set in the Mining law may be supplemented by local law not in conflict with the Mining Law or State law.

Over time, various laws have restricted the minerals that are subject to location under the Mining Law; restrictions were generally not retroactive but were subject to valid existing rights. "Locatable" minerals subject to location of claims under the Mining Law now include most metallic minerals (except uranium) and some nonmetallic minerals. In addition, certain Federal lands have been or may be closed to mineral development, subject to valid existing rights (these include the National Parks

and National Monuments, among other lands). In addition, only "public domain" lands are generally open to mineral location under the Mining Law.

Only since 1976 have claimants been required to record claims with BLM. Through the end of fiscal year 1991, more than 2,700,000 claims had been accepted for recording by BLM. Of these, more than 1,500,000 had been abandoned, relinquished, or rejected, leaving more than 1,100,000 unpatented claims on Federal lands. The number of claims on which significant prospecting or mining occurred prior to 1976 is simply unknown, since there were no reporting (and few other) requirements at the time.

6.12 FEDERAL LAND POLICY MANAGEMENT ACT

The Federal Land Policy Management Act (FLPMA) (43 U.S.C. §§1701-1782) provides the Bureau of Land Management with authority for public land planning and management, and governs such disparate land use activities as range management, rights-of-way and other easements, withdrawals, exchanges, acquisitions, trespass, and many others. FLPMA declares it to be the policy of the United States to retain lands in public ownership (i.e., rather than "disposing" of the lands by transferring ownership to private parties) and to manage them for purposes of multiple use and sustained yield. Under §202, BLM must develop and maintain plans for the use of tracts or areas of the public lands. To the extent feasible, BLM must coordinate its land use planning with other Federal, State, and local agencies. BLM also must provide for compliance with "applicable" pollution control laws (including Federal and State air, water, and noise standards and implementation plans) in the development and revision of land use plans. The overall protective standard is provided in §302(b), under which BLM is to take any necessary action, including regulation, to prevent "unnecessary or undue degradation" of public lands. Subject to this and several more limited exceptions, nothing in FLPMA "shall in any way amend the Mining Law of 1872 or impair the rights of any locators of claims under that Act, including, but not limited to, rights of ingress and egress" (§302(b)).

BLM regulations (43 CFR Group 3800) impose a number of broad requirements upon operations on mining claims on BLM-managed lands, but contain few specific technical standards. The basic compliance standard is that operations must be conducted so as to prevent unnecessary or undue degradation of the lands or their resources, including environmental resources and the mineral resources themselves. According to 43 CFR §3809.0-5(k), "unnecessary or undue degradation" means surface disturbance greater than what would normally result when an activity is being accomplished by a prudent operator in usual, customary, and proficient operations of similar character and taking into consideration the effects of operations on other resources and land uses, including those resources and uses outside the area of operations. Failure to initiate and complete reasonable mitigation measures, including reclamation of disturbed areas, may constitute unnecessary or undue degradation. Finally, failure to comply with applicable environmental protection statutes and regulations constitutes unnecessary and undue degradation.

BLM's implementing regulations pertaining to development of mining claims include three levels of review:

- **Casual use**—for which no notification or approval is necessary
- **Notice-level**—for cumulative annual disturbances total less than five acres. Operators must notify BLM officials (and commit to reclamation), but no approval is required. Consultation may be required if access routes are to be constructed.
- **Approval-level**—for disturbances exceeding 5 acres in a calendar year or in certain specified areas (wilderness areas, wild and scenic rivers, critical habitat, areas of the California Desert Conservation Area). Operators must obtain BLM approval (within specified timeframes) of a Plan of Operations for such operations.

A plan of operations must describe in detail the site and the proposed operation, including measures that will be taken to prevent undue and unnecessary degradation and to reclaim the site to regulatory standards. Reclamation must include salvaging topsoil for later use, erosion and runoff control, toxic materials isolation and control, reshaping the area, reapplication of topsoil, and revegetation (where reasonably practical). BLM may require operators to furnish bonds (site-specific or blanket) or cash deposits, with the amount left to the responsible official (policy now calls for full reclamation bonding for cyanide and other chemical leaching operations, and a similar policy is anticipated to be issued in 1994 for potentially acid-generating mines). Following approval of a plan of operation, BLM may monitor the operation to ensure that the approved plan is being followed. Failure to follow approved plans of operations, or to reclaim lands, may result in a notice of noncompliance, which in turn can lead to injunctive relief.

Plans of operations may be modified at BLM's request or at the operator's behest. Significant modifications follow the same review and approval procedures as original plans. Proposed plans of operations (and modifications) are reviewed by BLM "in the context of the requirement to prevent unnecessary and undue degradation and provide for reasonable reclamation" (§3809.1-6(a)). Within 30 days, BLM must notify the operator that: the plan is approved; changes or additions to the plan are necessary; that up to 60 more days are required for review; that the plan cannot be approved until after an EIS is prepared and filed with EPA; or that the plan cannot be approved until BLM complies with the Endangered Species Act or National Historic Preservation Act or consults with other surface managing agencies. (Should cultural resources be discovered during an inventory, BLM is responsible for any costs of salvage that may be necessary.)

Upon receipt of a proposed plan of operations (or modification), BLM must conduct an environmental assessment (or supplement). This EA is used to assess the adequacy of proposed mitigation measures and reclamation procedures to prevent unnecessary and undue degradation. The EA then leads to a Finding of No Significant Impact (with or without stipulations) or to the preparation of an EIS and

Record of Decision. If the proposed operation is to be issued a new source NPDES permit and is in a State where EPA is the permitting authority, or if in other cases where EPA has significant environmental concerns, EPA typically becomes a cooperating agency in the NEPA process.

There are a number of issues related to plans of operations and BLM regulatory oversight that bear noting. For example, plans of operations themselves become the "permit" to which operators must adhere. These are often enormous multi-volume documents that reflect the uncertainties of mining: they often note multiple contingencies in the event that specific conditions are found or develop. Detailed descriptions of planned operations under each contingency are not generally feasible (and are certainly not economic). As a result, plans provide appropriate caveats that additional plans, consultations, studies, or modifications will be made if necessary. It is not practical to modify plans of operations with every such change, and even when plans are formally modified, they often address only the modification, not the entire operation. Thus, a mine that evolves over time, as most do, comes to resemble the original plan less and less, and determining exactly which modification addresses a particular mine component can be extremely difficult. In addition, BLM administration of its regulations is very decentralized, with State offices and local resource area offices generally responsible. This recognizes the site- and region-specific nature of the mining industry, and its environmental impacts, but has led to inconsistency in several areas, including the level of "significance" that triggers preparation of an environmental impact statement. Environmental impact assessments (whether in EAs or EISs) follow the same pattern as plans of operations: they often address the plan or modification at hand, not necessarily the entire mining operation as it has grown and evolved over time. Finally, BLM considers itself extremely constrained by the Mining Law; there is no provision for BLM disapproval of proposed plans of operations, only the prevention of unnecessary and undue degradation of public lands.

6.13 NATIONAL PARK SYSTEM MINING REGULATION ACT

The National Park System Mining Regulation Act (also known as the Mining in the Parks Act, or MPA) (16 U.S.C. §§1901-1912) reconciles the recreational purpose of the National Park System with mining activities affecting park lands. The Act subjects mining activities within the National Park System to such regulations as deemed necessary by the Secretary of the Interior. It also required that all mining claims within the park system be recorded by September, 1977, or become void.

The National Park Service has extensive regulations governing exercise of valid existing mineral rights (36 CFR Part 9 Subpart A). The regulations restrict water use, limit access, and require complete reclamation. They also require that operators obtain an access permit and approval of a plan of operations prior to beginning any activity. A plan of operations requires specific site and operations information, and may require the operator to submit a detailed environmental report. Operators must comply with any applicable Federal, State, and local laws or regulations.

6.14 ORGANIC ACT; MULTIPLE USE AND SUSTAINED YIELD ACT; NATIONAL FOREST MANAGEMENT ACT

The Organic Act of 1897 (16 U.S.C. §§473-482, 551) has governed the Forest Service's activities since the earliest days of National Forest management. The Act delegated broad authority over virtually all forms of use in the National Forest System. It also provides for continued State jurisdiction over National Forest lands. Finally, it declares that forests shall remain open to prospecting, location, and development under applicable laws, and that waters within the boundaries of the National Forests may be used for domestic mining and milling, among other uses.

The Multiple Use and Sustained Yield Act of 1960 (MUSYA) (16 U.S.C. §§528-531) establishes that the National Forest System is to be managed for outdoor recreation, range, timber, watershed, and fish and wildlife purposes, and that these purposes are supplemental to the purposes for which the national forests were established as set forth in the Forest Service Organic Legislation (16 U.S.C. §§475, 477, 478, 481, 551). MUSYA provides that the renewable surface resources of the national forests are to be administered for multiple use and sustained yield of products and services. Nothing in MUSYA is intended to affect the use or administration of the mineral resources of the national forest lands. (16 U.S.C. §528). Section 530 of the MUSYA authorizes the Forest Service to cooperate with State and local governments in managing the National Forests. MUSYA is implemented by the Secretary of Agriculture. The National Forest Management Act of 1976 provides the Forest Service with authorities and responsibilities similar to those provided to BLM by FLPMA. It establishes a planning process for National Forests that in many ways parallels the process established under FLPMA for BLM lands.

Forest Service regulations (36 CFR Part 228) are broad and similar to BLM's in that they impose few specific technical standards. In all cases where the land's surface is to be disturbed, operators must file a notice of intent. For significant disturbances (i.e., where mechanized equipment or explosives are to be used), operators must submit a proposed plan of operations. Forest Service regulations concerning plans of operations and their review and approval, reclamation standards, and environmental review are similar to those described for BLM above. Like BLM's regulations, they require compliance with the Clean Water Act and other environmental statutes and regulations.

6.15 MINERAL LEASING ACT; MINERAL LEASING ACT FOR ACQUIRED LANDS

The Mineral Leasing Act of 1920 (MLA) (30 U.S.C. §§181-287) and the Mineral Leasing Act for Acquired Lands (1947) (30 U.S.C. §§351-359) created a leasing system for coal, oil, gas, phosphate, and certain other fuel and chemical minerals ("leasable" minerals) on Federal lands. In addition, Section 402 of Reorganization Plan No. 3 of 1946 (and other authorities) authorizes leases for locatable minerals on certain lands (e.g., some acquired lands, as opposed to public domain lands). Under the leasing system, the government determines which acquired lands will be available for

mineral development. The Department of the Interior has promulgated extensive regulations governing various aspects of leases. BLM may issue competitive, noncompetitive, and preference right leases that set the terms, including environmental terms, under which mineral development can take place. Prior to lease issuance, BLM must consult with the appropriate surface managing agency (e.g., the Forest Service), and for acquired lands must have the written consent of the other agency. Regulations require compliance with Federal and State water and air quality standards, and failure to comply with lease terms can result in lease suspension or forfeiture. At the end of fiscal year 1991, a total of 69 nonenergy mineral leases (more than 49,000 acres) were in effect; in addition, there were 475 coal leases in effect, covering nearly 700,000 acres of public domain and acquired land.

6.16 COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 U.S.C. §§9601-9675) established the Superfund program to deal with releases and threatened releases of hazardous substances to the environment. CERCLA provides funding and enforcement authority for Federal and State clean-up programs at thousands of sites throughout the United States that are contaminated due to the release of specified hazardous substances. The statute establishes notification requirements for releases of hazardous substances in reportable quantities (RQs), provides abatement and response authorities for situations where a substance or pollutant may present an imminent and substantial danger to the public health or welfare, requires the development of a National Contingency Plan (NCP) designed to provide for consistent and coordinated responses (both removal and remedial) to hazardous substance discharges, and creates a Hazardous Substance Response Trust Fund (Superfund) to pay for emergency removal actions and long-term remediations at abandoned sites where liable parties cannot be identified. CERCLA establishes that owners and operators of contaminated sites, as well as waste generators and others who were responsible for waste disposal and waste transportation are subject to strict, joint, and several liability for response costs and natural resources damages. The statute also establishes site cleanup standards.

Over 52 mining- and mineral processing-related sites are currently on the NPL, including some of the largest and most complex of all NPL sites. The cleanup standards applied to specific NPL sites are determined on a site-specific basis, following detailed studies of the site, the potential and actual risks, and possible remedial actions. Because the United States is the land owner at several of the mining-related NPL sites, Federal agencies are responsible persons in some cases.

It should also be noted that several Federal courts have addressed the issue of whether mining wastes are "hazardous substances" under CERCLA, and thus whether mining sites where releases of mining wastes occur are subject to CERCLA removal or remedial actions. The basic question is whether the exemption of mining wastes from regulation as hazardous wastes under RCRA excludes them from the definition of "hazardous substance" in §104(14). In *Eagle Picher Industries v. EPA* (245 U.S.

App. D.C. 196, 759 F.2d 922 (D.C. Cir. 1985), it was determined that mining wastes exempt from hazardous waste regulation were within the CERCLA definition of hazardous substances. There has been additional judicial consideration of this issue, with the decisions generally consistent with the *Eagle Picher* decision.

Issuance of an NPDES permit for a discharge(s) from a new source mining operation can exclude the operator from potential CERCLA liability. New operations are often located in historic mining districts, where CERCLA action may be ongoing or could occur in the future. In such cases, the reviewer should be especially cautious that the project will not further degrade water quality (including sediment) and that water quality-based limits/requirements are included in the NPDES permit. Further, prior to operation of the new source, adequate baseline data should be available to characterize existing water column and sediments conditions. This will minimize any uncertainty related to the sources of pollutant levels (PRPs versus the non-liable new operator).

6.17 EMERGENCY PLANNING AND COMMUNITY RIGHT-TO-KNOW ACT

The Emergency Planning and Community Right-to-Know Act (EPCRA) (42 U.S.C. §§11001-11050) requires States to establish emergency response commissions and emergency planning districts as well as local emergency planning committees. These planning groups must prepare and review emergency plans. The Act also requires that owners and operators of facilities who must submit materials safety data sheets under the Occupational Safety and Health Act (OSHA) must report information about these hazardous substances to the local emergency planning committee, the State emergency response commission, and the local fire department. Mining operations must report on chemical storage and use, and on spills or releases, to these entities.

EPCRA also requires facilities that use, manufacture, or process certain listed toxic chemicals to report the amount of each chemical released to the environment on an annual basis. These data comprise the Toxics Release Inventory, or TRI. TRI reporting requirements apply to manufacturing facilities in Standard Industrial Classifications (SIC) Codes 20 through 39. Mining operations are not within these SIC codes and thus are not subject to TRI reporting. However, it should be noted that the TRI list of chemicals and the types of facilities required to report releases are currently being expanded or considered for expansion by EPA.

6.18 WILD AND SCENIC RIVERS ACT

The Wild and Scenic Rivers Act of 1968 (16 U.S.C. 1273 *et seq.*) provides that "[c]ertain selected rivers . . . shall be preserved in a free flowing condition, and that they and their immediate environments shall be protected for the benefit and enjoyment of present and future generations." Section 7 of the Act prohibits the issuance of a license for construction of any water resources project that would have a direct adverse effect on rivers (or reaches of rivers) that have been selected on the

basis of their remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values for the National Wild and Scenic Rivers System.

The System includes rivers and streams placed in the System by acts of Congress and rivers that have been studied and deemed to be suitable for inclusion. Any potential impacts on rivers and streams in the System must be considered, and direct adverse effects on the values for which the river was selected for the System must be prevented.

States also have their own systems for protecting rivers and streams or portions thereof. While EPA has no legal requirement to consider State-protected wild and scenic rivers and streams, any potential impacts to such areas should nevertheless be considered and addressed.

6.19 FISH AND WILDLIFE COORDINATION ACT

The Fish and Wildlife Coordination Act of 1934 (16 U.S.C. 661 *et seq.*, P.L. 85-624) authorizes the Secretary of the Interior to provide assistance to, and cooperate with, Federal, State, and public or private agencies and organizations in the development, protection, rearing, and stocking of all species of wildlife, resources thereof, and their habitat. The majority of the Act is associated with the coordination of wildlife conservation and other features of water-resource development programs.

6.20 FISH AND WILDLIFE CONSERVATION ACT

The Fish and Wildlife Coordination Act of 1980 (16 U.S.C. 2901 *et seq.*) encourages Federal agencies to conserve and promote conservation of nongame fish and wildlife and their habitats to the maximum extent possible within each agency's statutory responsibilities. The Act places no affirmative requirements on Federal agencies.

6.21 MIGRATORY BIRD PROTECTION TREATY ACT

The Migratory Bird Protection Treaty Act (16 U.S.C. 703-711) prohibits the killing, capturing, or transporting of protected migratory birds, their nests, and eggs. Consultations with the Fish and Wildlife Service are encouraged if project activities could directly or indirectly harm migratory birds.

7. REFERENCES

Adamus, P.R., E.J. Clairain, Jr., R.D. Smith, and R.E. Young. 1987. *Wetlands Evaluation Technique (WET); Volume II: Methodology*. Operational Draft Technical Report Y-87-_, U.S. Army Corps of Engineer Waterways Experiment Station, Vicksburg, MS.

Ahsan, M.Q., et al. 1989. "Detoxification of Cyanide in Heap Leach Piles Using Hydrogen Peroxide." In *World Gold*, proceedings of the First Joint SME/Australian Institute of Mining and Metallurgy Meeting. R. Bhappu and R. Ibardin (editors).

Alaska Department of Environmental Conservation. 1986. *A Water Use Assessment of Selected Alaska Stream Basins Affected by Gold Placer Mining*. Prepared by Dames & Moore, Arctic Hydrologic Consultants, Stephen R. Braund and Associates, L.A. Peterson and Associates, and Hellenthal and Associates.

Alaska Department of Environmental Conservation. 1987 (March). *Placer Mining Demonstration Grant Project Design Handbook* (prepared by L.A. Peterson & Associates, Inc.). Fairbanks, AK.

Alaska Miners Association. 1986. *Placer Mining -- A Systems Approach*. Short Course, Alaska Miners Association Eleventh Annual Convention, October 29-30, 1986. Anchorage, Alaska.

Altringer, P. B., R.H. Lien, and K.R. Gardner. 1991. *Biological and Chemical Selenium Removal From Precious Metals Solutions*. Proceedings of the Symposium on Environmental Management for the 1990s, Denver, Colorado, February 25-28.

Argall, G.O., Jr. 1987 (December). "The New California Gold Rush." *Engineering & Mining Journal*: 30-37.

Arizona BADCT Guidance Document for the Mining Category, Draft Guidance Document. 1990. Arizona Revised Statute 49-243 B.1., For Permitted Facilities Utilizing BADCT.

ASARCO. 1991 (February 4). *Ray Unit Tailing Impoundment Alternative Analysis*. Appendix 11.19. Submitted to EPA Water Management Division Region IX Wetlands Program.

Beard, R.R. 1987 (March). "Treating Ores by Amalgamation." Circular No. 27. Phoenix, AZ: Department of Mines and Mineral Resources.

Beard, R.R. 1990 (October). *The Primary Copper Industry of Arizona in 1989*. State of Arizona Department of Mines and Mineral Resources, Special Report No. 16.

Biswas, A.K., and W.G. Davenport. 1976. *Extractive Metallurgy of Copper*. Pergamon International Library, International Series on Materials Science and Technology, Vol. 20, Chapter 2.

Boyle, R.W. 1979. *The Geochemistry of Gold and Its Deposits*. Canada Geological Survey Bulletin 280. Canadian Publishing Centre. Hull, Quebec, Canada. 584 pp.

Bradham, W. S., and F. T. Caruccio. 1990. *A Comparative Study of Tailings Analysis using Acid/ Base Accounting, Cells, Columns and Soxhelets.* Proceeding of the 1990 Mining and Reclamation Conference and Exhibition, Charleston, WV.

Brady et al. 1994. *Evaluation of Acid-base Accounting to Predict the Quality of Drainage at Surface Coal Mines in Pennsylvania, U.S.A.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

British Columbia AMD Task Force. 1989. *Acid Rock Drainage Draft Technical Guide, Volumes I and II.* Report 66002/2. Prepared for the British Columbia AMD Task Force by SRK, Inc.

British Columbia AMD Task Force. 1990 (August). *Monitoring Acid Mine Drainage.* Prepared by E. Robertson in association with Steffen Robertson and Kirsten (B.C.) Inc. Bitech Publishing, Richmond, British Columbia.

Britton, S.G. 1992a. *Mine Exploitation, in SME Mining Engineering Handbook, 2nd Edition* (H.L. Hartman, ed.). Society for Mining, Metallurgy and Exploration, Inc. Littleton, CO.

Britton, S.G. and G.T. Lineberry. 1992b. *"Underground Mine Development," in SME Mining Engineering Handbook, 2nd Edition (H.L. Hartman, ed.).* Society for Mining, Metallurgy and Exploration, Inc. Littleton, CO.

Brodie, M. J., L. M. Broughton, and Dr. A. MacG. Robertson. 1991. *A Conceptual Rock Classification System for Waste Management and a Laboratory Method for ARD Prediction From Rock Piles.* In Second International Conference on the Abatement of Acidic Drainage. Conference Proceedings, Volumes 1 - 4, September 16, 17, and 18, 1991, Montreal, Quebec.

Broughton, L. M. and Dr. A. MacG. Robertson. 1991. *Modeling of Leachate Quality From Acid Generation Waste Dumps.* In Second International Conference on the Abatement of Acidic Drainage. Conference Proceedings, Volumes 1 - 4, September 16, 17, and 18, 1991, Montreal, Quebec.

Broughton, L. M. and Dr. A. MacG. Robertson. 1992. *Acid Rock Drainage From Mines - Where Are We Now.* Steffen, Robertson and Kirsten, Vancouver, British Columbia. Internal Draft Paper.

Bruynesteyn, A. and R. Hackl. 1982. "Evaluation of Acid Production Potential of Mining Waste Materials." *Minerals and the Environment* 4(1).

California Mining Association. 1991. *Mine Waste Management.* Edited and Authored by Ian Hutchison and Richard D. Ellison. Sponsored by the California Mining Association, Sacramento, California.

California Regional Water Control Board. 1987 (April 22). "Cyanide Requirements for Cyanidation Process Wastes." Internal Memorandum from Dr. R.S. Gill to O.R. Butterfield.

California Regional Water Quality Control Board. 1993 (January 19). *Personal communication between Richard Humphreys and Joe Rissing, Science Applications International Corporation.* Falls Church, VA.

Clark, W.B. 1970. *Gold Districts of California.* California Division of Mines and Geology, Bulletin 193. San Francisco, CA.

Coastech Research Inc. 1989. *Investigation of Prediction Techniques for Acid Mine Drainage.* MEND Project 1.16.1a. Canada Center for Mineral and Energy Technology, Energy, Mines, and Resources Canada.

Cohen, Ronald R.H. and Staub, Margaret W. 1992 (December). *Technical Manual for the Design and Operation of a Passive Mine Drainage Treatment System*, prepared for the U.S. Bureau of Reclamation. Golden, CO.

Colorado Department of Natural Resources. 1992 (March). *Guidelines for Cyanide Leaching Projects.* Mined Land Reclamation Division.

Cravotta, F. T. et al. 1990. *Effectiveness of the Addition of Alkaline Materials at Surface Mines in Preventing or Abating Acid Mine Drainage: Part 1. Theoretical Considerations.* In Proceedings of the 1990 Mioning and Reclamation Conference and Exhibition, April 23-26.

Cumming, A.B. (Chairman of Editorial Board). 1973. *SME Mining Engineering Handbook.* Society of Mining Engineers, AIME. New York, New York.

Dadgar, A. 1989. "Extraction of Gold from Refractory Concentrates: Cyanide Leach vs. Bromide Process." Presented at the Metallurgical Society Annual Meeting. Las Vegas, NV. February 27-March 2, 1989.

Day. 1994. *Evaluation of Acid Generating Rock and Acid Consuming Rock Mixing to Prevent Acid Rock Drainage.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Devuyst, E.A., et al. 1990 (September). *Inco's Cyanide Destruction Technology.* Preprint No. 90-406. Littleton, CO: Society For Mining, Metallurgy, and Exploration, Inc.

Dietz et al. 1994. *Evaluation of Acidic Mine Drainage Treatment in Constructed Wetland Systems.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Doe Run Company. 1990 (February). *Fletcher Project: Application for Metallic Minerals Waste Management Area Permit.*

Doyle, F.M. (editor). 1990. *Mining and Mineral Processing Wastes*, proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes. Berkeley, CA. May 30-June 1, 1990. Littleton, CO: Society for Mining, Metallurgy and Exploration, Inc.

Duncan, D. and C. Walden. 1975. *Prediction of Acid Generation Potential.* Report to Water Pollution Control Directorate, Environmental Protection Service, Environment Canada.

Durkin, T.V. 1990. *Neutralization of Spent Ore from Cyanide Heap Leach Gold Mine Facilities in the Black Hills of South Dakota - Current Practices and Requirements.* AIME's Proceedings of the 4th Western Regional Conference on Precious Metals and the Environment, Lead. South Dakota.

Eger, A., and K. Lapakko. 1985. *Heavy Metal Study Progress Report on the Field Leaching and Reclamation Program: 1977-1983.* MN Dept. Nat. Res., Division of Minerals, St. Paul, MI.

Eger et al. 1994. *Metal Removal in Wetland Treatment Systems.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Engineering and Mining Journal. 1990 (January). "Technology Turns Southwest Waste into Ore." Vol. 191, pp. 41-44.

Environmental Law Institute. 1992 (November). *State Regulation of Mining Waste: Current State of the Art.*

Fast, John L. 1988 (June). "Carbons-in-Pulp Pioneering at the Carlton Mill." *Engineering & Mining Journal.* 56-57.

Ferguson, K. D. and P. M. Erickson. 1988. *Pre-Mine Prediction of Acid Mine Drainage. In: Dredged Material and Mine Tailings.* Edited by Dr. Willem Salomons and Professor Dr. Ulrich Forstner. Copyright by Springer-Verlag. Berlin, Heidelberg.

Ferguson, K. D., and K. A. Morin. 1991. *The Prediction of Acid Rock Drainage - Lessons From the Database.* In Second International Conference on the Abatement of Acidic Drainage. Conference Proceedings, Volumes 1 - 4, September 16, 17, and 18, Montreal, Quebec.

Flatt, P. 1990 (March). "Fine Placer Gold Recovery Methods." *California Mining Journal*: 5-8.

Fuerstenau, M. C., (editor). 1976. *Flotation, Volume 2.* New York: Society of Mining Engineers.

Gentry, D.W. and M.K. McCarter. 1992. *"Surface Mining: Mechanical Extraction Methods," in SME Mining Engineering Handbook, 2nd Edition (H.L. Hartman, ed.).* Society for Mining, Metallurgy and Exploration, Inc. Littleton, CO.

Guilbert, John M., and Charles F. Park, Jr. 1986. *The Geology of Ore Deposits*, W.H. Freeman and Company, New York, New York.

Hackel, R.P. 1990 (December). "Operating A Commercial-Scale Bioleach Reactor at the Congress Gold Property." *Mining Engineering.*

Halbert, B., J. Scharer, R. Knapp, and D. Gorber. 1983. *Determination of Acid Generation Rates in Pyritic Mine Tailings.* Presented at the 56th Annual Conference of Water Pollution Control Federation, October 2-7.

Harrelson, C.C., C.L. Rawlins, and J.P. Potyondy. 1994. *Stream Channel Reference Sites: An Illustrated Guide to Field Technique.* U.S. Department of Agriculture, U.S. Forest Service, Fort Collins, Colorado.

Harty, D.M. and P.M. Terlecky. 1984a (February). "Existing Wastewater Recycle Practices at Alaskan Placer Gold Mines", Frontier Technical Associates, Memorandum to B.M. Jarrett, U.S. EPA, Effluent Guidelines Division.

Harty, D.M. and P.M. Terlecky. 1984b (February). "Water Use Rates at Alaskan Placer Gold Mines Using Classification Methods", Frontier Technical Associates, Memorandum to B.M. Jarrett, U.S. EPA, Effluent Guidelines Division.

Hedin, Robert S. and Watzlaf. 1994. *The Effects of Anoxic Limestone Drains on Mine Water Chemistry.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Hellier, William W. 1994. *Best Professional Judgement Analysis for Constructed Wetlands as a Best Available Technology for the Treatment of Post-Mining Ground-water Seeps.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Hittman Associates, Inc. 1976. *Underground Coal Mining: An Assessment of Technology.* Prepared for Electric Power Research Institute, Palo Alto, CA, EPRI-AF-219, variously paged.

Holmes, K.W. 1981 (January). Natural Revegetation of Dredge Tailings at Fox, Alaska. In *Agroborealis*: 26-29.

Hood, W. and A. Oertel. 1984. *A Leaching Column Method for Predicting Effluent Quality From Surface Mines.* In Proc. Symp. on Surface Mining Hydrology, Sedimentology and Reclamation. University of Kentucky.

Hurlbut, C.S., and C. Klein. 1977. *Manual of Mineralogy.* New York: John Wiley & Sons.

Hutchinson, R.W. and J.D. Blackwell. 1984. Time, crustal evolution and generation of uranium deposits. In: *Uranium Geochemistry, Mineralogy, Geology, Exploration and Resources.* The Institution of Mining and Metallurgy, London, England.

Idaho, Division of Environmental Quality, Water Quality Bureau. 1993 (May 11). *Personal communication between Jerry Yoder and Michelle Stowers, Science Applications International Corporation.* Falls Church, VA.

Jarrett, A.R. (1983). Water Management, 5th Edition.

Kim, A. G., B. Heisey, R. Kleinmann, and M. Duel. 1982. *Acid Mine Drainage: Control and Abatement Research.* U.S. DOI, Bureau of Mines IC 8905.

Kruczynski, W.L. 1990. Options to be considered in preparation and evaluation of mitigation plans. In: *Wetland Creation and Restoration: the Status of the Science*, J.A. Kusler and M.E. Kentula (eds.). Island Press, Washington, D.C. pp. 555-569.

Lapakko, K. 1988. *Prediction of Acid Mine Drainage From Duluth Complex Mining Wastes In Northeastern Minnesota*. In: Mine Drainage and Surface Mine Reclamation. Volume I: Mine Water and Mine Waste. U.S. Department of Interior, Bureau of Mines Information Circular 9183.

Lapakko, K. 1990a. *Regulatory Mine Waste Characterization: A Parallel to Economic Resource Evaluation*. In: Mining and Mineral Processing Wastes. Proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes, May 30 - June 1, 1990, Berkeley, California p.31-39. Edited by Fiona Doyle, Published by the Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

Lapakko, K. 1990b. *Solid Phase Characterization in Conjunction with Dissolution Experiments for Prediction of Drainage Quality*. In: Mining and Mineral Processing Wastes. Proceedings of the Western Regional Symposium on Mining and Mineral Processing Wastes, May 30 - June 1, 1990, Berkeley, California p.31-39. Edited by Fiona Doyle, Published by the Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO.

Lapakko, K. 1992. *Evaluation of Tests for Predicting Mine Waste Drainage pH*. Draft Report to the Western Governors' Association, May 1992.

Lapakko, K. 1993a. *Predictive Testing for Mine Waste Drainage Quality*. In Mine Operation and Closure Short Course. Sponsored by EPA and others April 27 - 29. Helena, Montana.

Lapakko, K. 1993b. *Mine Waste Drainage Quality Prediction: A Literature Review*. Draft Paper. Minnesota Department of Natural Resources, Division of Minerals, St. Paul, Minnesota.

Lapakko, K. 1994a. *Evaluation of Neutralization Potential Determinations for Metal Mine Waste and a Proposed Alternative*. In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Lapakko, K. 1994b. *Subaqueous Disposal of Mine Waste: Laboratory Investigation*. In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

LaPierriere, J.D., S.M. Wagener and D.M. Bjerklie. 1985 (April). Gold-Mining Effects on Heavy Metals in Streams, Circle Quadrangle, Alaska. *Water Resources Bulletin:* 245-252.

LeHoux, P.L., and Holden, L. T. 1990 (December). "Atmospheric Carbon Elution Without the Use of Cyanide at Barneys Canyon Mine." *Mining Engineering*: 1323.

Lopes, R.F., and R.J. Johnston. 1988 (August). "A Technical Review of Heap Leaching." In *Environmental Management for the 1990s*, proceedings of the Symposium on Environmental Management for the 1990s. Denver, CO. February 25-28, 1991. D.J. Lootens, W.M.

Greenslade, and J.M. Barker (editors). Littleton, CO: Society for Mining, Metallurgy, and Exploration, Inc.

LTV Steel Mining Company. 1991 (June). LTV Steel Hoyt Lakes, Minnesota 2-E Tailing Basin Site Investigation and Stability Analysis. Prepared by EBASCO. 19 pp.

Lu, Ning, and Yiqiang Zhang, undated. *Thermally Induced Gas Convection in Mine Wastes.* Disposal Safety Inc., Washington, D.C.

Lucht, R. 1990 (September 12). *Personal communication between Mr. Robert Lucht, Underground Injection Control Coordinator, Wyoming Department of Environmental Quality, and Ms. Laurie Lamb, Science Applications International Corporation.* Denver, CO.

Manahan, Stanley E. 1991. *Environmental Chemistry.* Fifth edition. Lewis Publishers, Inc., Chelsa, Michigan.

Mandelker, D.R. 1992. *NEPA Law and Litigation.* Second edition. Clark Boardman Callaghan, New York.

McElfish, J.M., Jr. and A.E. Beier. 1990. *Environmental Regulation of Coal Mining SMCRA's Second Decade.* Environmental Law Institute. Washington, DC.

Merritt, R.C. 1971. *The Extractive Metallurgy of Uranium.* Colorado School of Mines, Golden, CO.

Michigan State, Geological Survey Division. 1983 (December). *Assessment of Inactive Iron Mines in East Iron County, Michigan.* Lansing, Michigan.

Mine Safety and Health Administration. 1988. *Closed Metal/Nonmetal Mine Employment and Address Data Tape.* Washington, DC.

Morin, Kevin A. and Hutt, Nora M. 1994. *Observed Preferential Depletion of Neutralization Potential Over Sulfide Minerals in Kinetic Tests: Site-specific Criteria for Safe NP/AP Ratio.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Mudder T.I. and A. Smith. 1992. *Solution Management During Decommissioning of Heap Leach Operations.* Paper presented at Society for Mining, Metallurgy, and Exploration's Annual Meeting, Phoenix, Arizona, February 24-27.

National Institute of Occupational Safety and Health. 1990 (August 17). *National Occupational Health Survey of Mining: Gold Report.* Morgantown, WV.

National Institute for Occupational Safety and Health. 1990 (August 27). *National Occupational Health Survey of Mining: Lead-Zinc Report.* Unpublished. Morgantown, WV.

Nevada, Bureau of Water Quality Planning. 1993 (January 21). *Personal communication between Kathy Sertic and Joe Rissing, Science Applications International Corporation.* Falls Church, VA.

Nicholson, Ronald V. 1992. *A Review of Models to Predict Acid Generation Rates in Sulphide Waste Rock at Mine Sites*. Presented to the International Workshop on Waste Rock Modelling, sponsored by the Mine Environment Neutral Drainage Program, September 29 - October 1, 1992 in Toronto, Ontario.

Nummela, W., and I. Iwasaki. 1986. "Iron Ore Flotation." In *SME Advances in Mineral Processing*. Society of Mining Engineers of the American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. New York, New York.

Osiensky, J.L. and R.E. Williams. 1990. "Factors affecting efficient aquifer restoration at in situ uranium mine sites." *Groundwater Monitoring Review*, p. 107-112.

Park, C.F. and R.A. MacDiarmid. 1975. *Ore Deposits*, published by W.H. Freeman and Company, San Francisco.

Pillmore, D.M. 1992. "Arizona Strip Uranium Mining District Northern Arizona." *The Professional Geologist* 29(4):8.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. *Methods for Evaluating Stream, Riparian, and Biotic Conditions*. General Technical Report INT-138. U.S. Department of Agriculture, U.S. Forest Service, Ogden, Utah.

Price, William A. and Errington, John C. 1994. *ARD Policy for Mine Sites in British Columbia*. In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29, 1994.

Ramani, R.V. and E.C. Grim. 1978. "Surface mining - a review of practices and progress in land disturbance control." *In: Reclamation of Drastically Disturbed Lands, F.W. Shaller and P. Sutton (eds.)*. American Society of Agronomy, Crop Science Society of America, Soil Science of America. Madison WI.

Rawson Academy of Aquatic Science. 1992 (July 21). *A Critical Review of MEND Studies Conducted to 1991 on Subaqueous Disposal of Tailings*. Canada Centre for Mineral and Energy Technology (CANMET); Energy, Mines and Resources Canada.

Reynolds, J.B., R.C. Simmons and A.R. Burkholder. 1989 (June). Effects of Placer Mining Discharge on Health and Food of Arctic Grayling. *Water Resources Bulletin*: 625-635.

Ritcey, G.M. 1989. "Tailings Management, Problems and Solutions in the Mining Industry." *Process Metallurgy 6.*

"RIP Move in South Africa." 1991 (March). *Australia's Mining Monthly.*

Robertson, Dr. A. MacG. and L. M. Broughton. 1992 (April). *Reliability of Acid Rock Drainage Testing*. Steffen, Robertson and Kirsten, Vancouver, British Columbia.

Rowley, Michael V et al. 1994. *The Biosulfide Process: Integrated Biological/Chemical Acid Mine Drainage Treatment - Results of Laboratory Piloting*. In the Proceedings of the International

Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Ryan, G. 1991. *Personal Communication between G. Ryan, the American Iron Ore Association, and Jonathan Passe of Science Applications International Corporation.* McLean, Virginia.

Schafer, Dr. William M. 1993. *Design of Geochemical Sampling Programs.* In Mine Operation and Closure Short Course. Sponsored by EPA and others April 27 - 29. Helena, Montana.

Singleton, G. A. and L. M. Lavkulich. 1978. "Adaption of the Soxhelet Extractor for Pedologic Studies." *Soil Science Society of America Journal*, Vol. 42, p. 984-986.

Schwandt, A.J.W. 1970. "The Magmont Operation." In *AIME World Symposium on Mining and Metallurgy of Lead and Zinc, Volume 1: Mining and Concentrating of Lead and Zinc.* New York: American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc.

Silva, M. 1986. *Placer Gold Recovery Methods.* California Division of Mines and Geology. Special Publication 87. Sacramento, CA.

Silva, M.A. 1988 (July). "Cyanide Heap Leaching in California." *California Geology*: 147-56.

Singh, M.M, and Z.T. Bieniawski. 1992. Geomechanics, in SME Mining Engineering Handbook, 2nd Edition (H.L. Hartman, ed.). Society for Mining, Metallurgy and Exploration, Inc. Littleton, CO.

Smith, A. and J. B. Barton Bridges. 1991. *Some Considerations in the Prediction and Control of Acid Mine Drainage Impact on Groundwater From Mining in North America.* In: Proceeding of the EPPIC Water Symposium, Johannesburg, South Africa, May 16-17.

Smith, D.K, Jr. 1984. Uranium mineralogy. In: *Uranium geochemistry, mineralogy, geology, exploration and resources.* The Institution of Mining and Metallurgy, London, England.

Sobek, A. A., Schuller, W. A., Freeman, J.R. Smith, R.M. 1978. *Field and Laboratory Methods Applicable to Overburden and Minesoils.* EPA 600/2-78-054.

Society of Mining Engineers. 1973. *SME Mining Engineering Handbook.* Volume 1 and 2. Published by the Society of Mining Engineers, Littleton, CO.

Society of Mining Engineers, Mineral Processing Handbook 1985. Edited by N.L. Weiss, Volume 2. Published by the Society of Mining Engineers, Littleton, CO.

South Dakota, Office of Minerals and Mining. 1993 (January 19). *Personal communication between Tom Durkin and Joe Rissing, Science Applications International Corporation.* Falls Church, VA.

St. Arnaud, Luc. 1994. *Water Covers for the Decommissioning of Sulfidic Mine Tailings Impoundments.* In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29, 1994.

Stanford, W.D. 1987 (April). "Amax Sleeper Mine Exceeds Expectations On All Counts As Low-Cost Gold Producers." *Mining Engineering* (1987): 241-46.

Stillwater Mining Company. Undated. *Stillwater Mining Company* (company produced brochure).

Sullivan, P. J. and A. Sobek. 1982. "Laboratory Weathering Studies of Coal Refuse." *Minerals and the Environment* 4(1).

Tatsch, J.H. 1976. *Uranium deposits*. Tatsch Associates, Sudbury Massachusetts.

Tenut, Carl. 1994. Memorandum from Carl Tenut, State of Tennessee to Cheryl Espy, EPA Region 4.

U.S. Congress, Office of Technology Assessment. 1988 (September). *Copper: Technology and Competitiveness*. OTA-E-367. U.S. Government Printing Office. Washington DC.

U.S. Department of Agriculture, Forest Service. 1992. *A Conceptual Waste Rock Sampling Program for Mines Operating in Metallic Sulfide Ores With a Potential for Acid Rock Drainage*. Written by Gene Farmer with the Department of Agriculture, Forest Service, Ogden, Utah.

U.S. Department of Agriculture, Forest Service. 1993. *Acid Mine Drainage From Mines on the National Forests, A Management Challenge*. Program Aid 1505, p.12.

U.S. Department of the Army, Corps of Engineers. 1987. *Corps of Engineers Wetlands Delineation Manual*. Final Technical Report Y-87-1. U.S. Army Corps of Engineers, Environmental Laboratory, Waterways Experiment Station, Vicksburg, MS.

U.S. Department of Energy (USDOE). 1978b. *International Coal Technology Summary Document*. Office of Technical Programs Evaluation, Washington DC, JHCP/P-3885, 178 p.

U.S. Department of Energy, Energy Information Administration. 1992. *Uranium Industry Annual 1991*. DOE/EIA-0478(91), Distribution Category UC-98, Washington, DC.

U.S. Department of Health and Human Services. 1982 (April). *Technological Feasibility of Control of Asbestos at Mines and Mills, Task 1 Progress Report, Exposure Profiles*. Washington, DC.

U.S. Department of the Interior, Bureau of Land Management. 1992. *Solid Minerals Reclamation Handbook*. BLM Manual Handbook H-3042-1.

U.S. Department of the Interior, Bureau of Mines. 1968. *A Dictionary of Mining, Minerals, and Related Terms*. Washington, D.C.

U.S. Department of the Interior, Bureau of Mines. 1977. *Capital and Operating Cost Estimating System Handbook for Mining and Beneficiation of Metallic and Non-metallic Minerals Except Fossil Fuels in the U.S. and Canada*. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1978. *Processing Gold Ores Using Heap Leach-Carbon Adsorption Methods*. Information Circular No. 8770. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1979. *Environmental Assessment of In Situ Leach Mining, Final Report*. Prepared by PRC Toups and Mountain States Research and Development. 292 p.

U.S. Department of the Interior, Bureau of Mines. 1983a. *Development Guidelines for Closing Underground Mines: Michigan Case Histories*. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1984a. *Gold and Silver Leaching Practices in the United States*. Information Circular No. 8969. Washington, DC.

U.S. Department of the Interior, Bureau of Mines, Division of Minerals Availability. 1984b (November). *Waste Disposal Activities and Practices: Copper, Lead, Zinc, Gold, and Silver Waste Disposal Activities and Practices in the United States*. Division of Minerals Availability Open File Report. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1984c (November). *Waste Disposal Activities and Practices in the United States: Copper, Lead, Zinc, Gold, and Silver*. Division of Minerals Availability Open File Report, by L.V. Coppa. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1985. "Gold" (by J.M. Lucas). In *Mineral Facts and Problems, 1985*. Washington, DC: GPO.

U.S. Department of the Interior, Bureau of Mines. 1985. "Lead" (by W.D. Woodbury). In *Mineral Facts and Problems, 1985*. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1985. "Mineral Facts and Problems 1985 Edition" (by Jolly, J.L.). Bulletin 675. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1986. *Precious Metals Recovery for Low-Grade Resources*, proceedings of the Bureau of Mines Open Industry Briefing Session at the National Western Mining Conference. Denver, CO. February 12, 1986. Information Circular No. 9059. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1987. "Froth Flotation in the United States, 1985" (by Edelstein, D.). Information Circular. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1990a. "Gold" (by J.M. Lucas). In *1988 Minerals Yearbook, Volume 1: Metals and Minerals*. Washington, DC: GPO.

U.S. Department of the Interior, Bureau of Mines. 1990a. "Lead" (by W.D. Woodbury). In *Minerals Yearbook, Volume 1: Metals and Minerals, 1988*. Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1990b. "Mining and Quarrying Trends in the Metals and Industrial Minerals Industries" (by A.O. Tanner). In *1988 Minerals Yearbook, Volume 1: Metals and Minerals*. Washington, DC

U.S. Department of the Interior, Bureau of Mines. 1990c. "Gold" (by J.M. Lucas). In *1989 Minerals Yearbook*. Washington, DC: GPO.

U.S. Department of the Interior, Bureau of Mines. 1992a. "Gold 1991 Annual Report" (by J.M. Lucas). Published in Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1992b. "Iron Ore." In *Mineral Commodity Summaries, 1992* (by P.H. Kuck). Washington, D.C.

U.S. Department of the Interior, Bureau of Mines. 1991a (May). "Mining and Quarrying Trends in the Metals and Industrial Minerals Industries" (by A.O. Tanner). In *1989 Minerals Yearbook*. Washington, DC: GPO.

U.S. Department of the Interior, Bureau of Mines. 1992. *Submarine Disposal of Mill Tailings from On-Land Sources - An Overview and Bibliography*. An Overview and bibliographic Compilation of References on the Biological, Chemical, Environmental, and Technical Aspects. By R.L. Baer, G.E. Sherman, and P.D. Plumb. OFR 89-92.

U.S. Department of the Interior, Bureau of Mines. 1993a. *Mineral Commodities Summaries, 1993*. Published in Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1993b. *1991 Copper Annual Report* (by Janice Jolly). Washington, DC.

U.S. Department of the Interior, Bureau of Mines. 1993c. *Platinum-Group Metals 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1993d. *Tungsten 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1993e. *Molybdenum 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1993f. *Titanium 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1993g. *Vanadium 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1993h. *Aluminum, Bauxite and Alumina 1992 Annual Report*.

U.S. Department of the Interior, Bureau of Mines. 1994. *International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage*. Proceedings of a conference held in Pittsburgh, Pennsylvania, April 24-29, 1994. Bureau of Mines Special Publications SP 06A-94 through SP 06D-94. 4 volumes.

U.S. Department of the Interior, Bureau of Mines. Undated(a). *Gold Environmental Research Highlights* (by S.L. McGill and T.G. Carnahan). Reno, NV.

U.S. Department of the Interior, Bureau of Mines. Unpublished. *Copper Mine Address and Current Status All Mines Operating 1984-1987 and Status of Domestic Copper Mines, Leaching, and SX Operations*. Washington, DC.

U.S. Department of the Interior, Geological Survey. 1973. "Copper". In *United States Mineral Resources*. Geological Survey Professional Paper 820, by F.S. Simons and W.C. Prinz. Reston, VA.

U.S. Department of the Interior, Geological Survey. 1973. "Gold." *United States Mineral Resources*. Professional Paper No. 820. Reston, VA.

U.S. Department of the Interior, Geological Survey. 1973a. "Iron." In *United States Mineral Resources: Geological Survey Paper 820* (by H. Klemic, H.L. James, and G.D. Eberlein). Reston, VA.

U.S. Department of Interior, U.S. Geological Survey. 1977. *National Handbook of Recommended Methods for Water-data Acquisition/Prepared Under the Sponsorship of the Office of Water Data Coordination*. Reston, VA.

U.S. Department of Interior, U.S. Geological Survey. 1990. *Water Resources Investigations Report*. Blevins. No.90-4047. Reston VA.

U.S. Environmental Protection Agency. 1973. *Processes, Procedures, and Methods to Control Pollution from Mining Activities*. Washington DC, DOE/EPA-430/9-73-011, 390 p.

U.S. Environmental Protection Agency. 1975. *Coal Mining Point Source Category*. Washington DC. Federal Register 40 202 48830-8.

U.S. Environmental Protection Agency, Office of Water and Hazardous Material. 1976a. *Development document for interim final effluent limitations guidelines and new source performance standards for the coal mining point source category*. Washington, DC. EPA 440/1-76/057-a, 288 p.

U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory. 1976b (June). *Metals Mining and Milling Process Profiles with Environmental Aspects*. Prepared by Battelle Columbus Laboratories for U.S. Environmental Protection Agency. NTIS Publication No. 256394. Washington, DC.

U.S. Environmental Protection Agency. 1978a. *Acid Mine Drainage and Subsidence: Effects of Increased Coal Utilization*. Washington DC, EPA-600/2-78-068, 141 p.

U.S. Environmental Protection Agency. 1978b. *Site Selection and Design for Minimizing Pollution from Underground Coal Mining Operations*. Washington DC, EPA-600/7-78-006, 98 p.

U.S. Environmental Protection Agency. 1979. *Assessment of Environmental Impact of the Mineral Mining Industry*. Prepared by PEDCo Environmental, Inc. EPA-600/2-79-107. Washington DC.

U.S. Environmental Protection Agency, Office of Water, Effluent Guidelines Division. 1982 (May). *Development Document for Effluent Limitations Guidelines and Standards for the Ore Mining and Dressing Point Source Category*. EPA 440/1-82/061. Washington, DC.

U.S. Environmental Protection Agency. 1984 (December). *Overview of Solid Waste Generation, Management, and Chemical Characteristics*. Prepared for U.S. EPA under Contract Nos. 68-03-3197, PN 3617-3 by PEI Associates, Inc.

U.S. Environmental Protection Agency, Office of Solid Waste. 1985 (December). *Report to Congress -Wastes from the Extraction and Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale*. EPA 530-SW-85-033. Washington, DC.

U.S. Environmental Protection Agency. 1986. *Quality Criteria for Water*. REPA 440/5-86-001. Washington, DC.

U.S. Environmental Protection Agency, Office of Water. 1988a (May). *Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Ore Mining and Dressing Point Source Category: Gold Placer Mine Subcategory (Final Draft)*. Washington, DC.

U.S. Environmental Protection Agency. 1988b. *Economic Impact Analysis of Final Effluent Guidelines and Standards for the Gold Placer Mining Industry*. Office of Water Regulations and Standards. Washington, DC.

U.S. Environmental Protection Agency. 1989a. *Final Report: Copper Dump Leaching and Management Practices that Minimize the Potential for Environmental Releases*. Prepared by PEI Associates, Inc. (Hearn, R. and Hoye, R.) under U.S. EPA Contract No. 68-02-3995. Washington, DC.

U.S. Environmental Protection Agency. 1989b. *Rapid Bioassessment Protocols for Use in Streams and Rivers*. EPA/440/4-89/001. Washington, DC.

U.S. Environmental Protection Agency. 1989c. *Ecological Assessment of Hazardous Waste Sites: A Field and Laboratory Reference*. EPA/600/3-89/013.

U.S. Environmental Protection Agency. 1990 (January). *Performance of Current Sediment Control Measures at Maryland Construction Sites*. Metropolitan Washington Council of Governments.

U.S. Environmental Protection Agency. 1990 (April). *Draft - Sediment and Erosion Control, An Inventory of Current Practices*. Washington, DC.

U.S. Environmental Protection Agency, Office of Research and Development. 1992. Draft. *Predicting Acid Generation From Non-Coal Mining Waste*: Notes of July 1992 Workshop. Prepared for the Environmental Monitoring Systems Laboratory, Las Vegas, Nevada 89193-3478 by SAIC, Falls Church, Virginia.

U.S. Environmental Protection Agency, Office of Research and Development. 1993 (May 20). *Personal communication between Ed Heithmar, U.S. EPA Office of Research and Development, and Michelle Stowers, Science Applications International Corporation*. Falls Church, VA.

U.S. Environmental Protection Agency. 1993a. *Habitat Evaluation: Guidance for the Review of Environmental Impact Assessment Documents*.

U.S. Environmental Protection Agency. 1994. *Workshop on the Use of Sulfate Reducing Bacteria for Treating Mine Drainage from Metals Mines*. Cincinnati, OH, February 23-24, 1994.

U.S. General Accounting Office. 1991(June). *Mineral Resources: Increased Attention Being Given to Cyanide Operations*. Report to the Chairman, Subcommittee on Mining and Natural Resources, Committee on Interior and Insular Affairs, House of Representatives. GAO/RCED-91-145.

U.S. Soil Conservation Service. 1975. *Procedure for Computing Sheet and Rill Erosion on Project Area*. Technical Release No. 51.

United States Steel. 1973. *The Making, Shaping, and Treating of Steel* (H.E. McGannon, editor). Herbick and Held, Pittsburgh, PA.

University of California at Berkeley. 1988 (July). *Mining Waste Study, Final Report*. Prepared for the California State Legislature. Berkeley, CA.

University of Nevada - Reno. 1993 (January 13). *Personal communication between Glen Miller and Joseph Rissing, Science Applications International Corporation*. Falls Church, VA.

van Zyl, D.J.A., I.P.G. Hutchison, and J.E. Kiel (editors). 1988. *Introduction to Evaluation, Design and Operation of Precious Metal Heap Leaching Projects*. Society for Mining, Metallurgy, and Exploration, Inc. Littleton, CO.

Want, W.L. 1990. *Laws of Wetlands Regulations*. Clark Boardman Company, Ltd. New York, NY.

Weiss, N.L. (editor). 1985. *SME Mineral Processing Handbook, Volume 2*. New York: Society of Mining Engineers.

White, William W. et al. 1994. *Chemical Predicative Modeling of Acid Mine Drainage From Waste Rock: Model Development and Comparison of Modeled Output to Experimental Data*. In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Whiteway, P. (editor). 1990. "Mining Explained: A Guide To Prospecting and Mining." *The Northern Miner*.

The Wildlife Society, 1980. *Wildlife Management Techniques Manual. Fourth Edition: Revised*. Sanford D. Schemnitz (editor). Washington, D.C.

Williams, R. David. 1994. *The Bureau of Land Management Acid Rock Drainage Policy An Evolution in Environmental Protection*. In the Proceedings of the International Land Reclamation and Mine Drainage Conference and Third International Conference on the Abatement of Acidic Drainage, April 24-29.

Wyoming Department of Environmental Quality, Land Quality Division. 1991. In Situ Mining State Decision Document for Everest Minerals Highland Uranium, WDEQ/LQD Permit No. 603-A2.

Wyoming Department of Environmental Quality, Land Quality Division. 1990. Guideline No. 4, *In Situ* Mining.

Zaburunov, S.A. 1989 (August). "Ridgeway: Gold Deposit Producing Big Returns Through Good Design." *Engineering & Mining Journal*: 52-55.